

**CHARACTERIZATION, CLASSIFICATION AND
EVALUATION OF SOIL AND WATER RESOURCES
ACROSS THE TOPOSEQUENCES OF
SOUTHERN SAURASHTRA**

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**DOCTOR OF PHILOSOPHY
(AGRICULTURE)**

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ABSTRACT

Sixty three soil samples from sixteen representative pedons of four toposequences viz., Hiran, Shingoda, Machhundri and Rayadi in southern Saurashtra across the five land forms viz., hill slopes, upper piedmont, lower piedmont, piedmont plain and coastal plain were collected during 2002-03 to study the morphological, mineralogical, physical, hydrological and chemical characteristics, taxonomic classification of soils, underground water quality and soil-water and climatic conditions with the aim to evaluate soil-site suitability and water resources for different crops.

The results reveal that the soils of different toposequences across the land forms of southern Saurashtra have developed from basaltic and Gaj bed milliolithic lime stone parent materials from hill slope to lower piedmont and alluvium in piedmont plain and coastal plain. The soils have clay loam to clayey texture, moderate to strong sub angular blocky structure and very dark grayish (10YR 3/1M) to brown (10YR 5/3M) colour. Smectite was the dominant clay mineral, while plagioclase and quartz were dominant in silt and sand fractions. The total sand, silt and clay content varied from 20.56 to

51.87, 20.20 to 43.98 and 16.40 to 49.45 per cent with the mean of 34.12, 33.57 and 32.31 per cent, respectively. The proportion of silt content in soil separate increased with the decrease in elevation. The bulk density varied from 1.28 to 1.57 Mg m^{-3} with the mean of 1.41 Mg m^{-3} . Higher bulk density was recorded from lower piedmont and coastal plain. The soils of upper piedmont were highly expandable as compared to other land slopes. The maximum water holding capacity (MWHC), saturated hydraulic conductivity and infiltration rate of soils decreased with the decrease in elevation from hill slope to coastal plain. The total plant available water capacity (PAWC) and water storage capacity (WSC) of the soils varied from 0.063 to 0.767 and 0.179 to 1.539 m ha^{-1} with mean of 0.229 and 0.537 m ha^{-1} , respectively which were found in the order of piedmont plain > coastal plain > lower piedmont > upper piedmont > hill slope. The PAWC/ WSC ratio ranged from 0.346 to 0.498 with the mean of 0.407 indicating 41 per cent available water for plant out of total water storage capacity of the soils of 0.537 m ha^{-1} .

In general, the pH, EC, O.C. and CaCO_3 ranged from 7.70 to 8.59, 0.18 to 1.06 dSm^{-1} , 0.12 to 0.93 per cent and 1.96 to 47.05 per cent with the mean of 8.13, 0.36 dSm^{-1} , 0.49 per cent and 17.24 per cent, respectively indicating that the soils were moderately alkaline in reaction, low in EC and O.C. status and highly calcareous in nature.

The values of pH and EC increased gradually along the elevation gradient from hill slope to coastal plain. While traversing from hill slopes to coastal plain, a gradual decrease in the content of organic carbon was observed. The CaCO_3 content increased down the slope and it was maximum (22.42 per cent) in coastal plain. The CEC varied from 16.11 to 28.80 $\text{cmol (p}^+) \text{ kg}^{-1}$ with the mean of 24.39 $\text{cmol (p}^+) \text{ kg}^{-1}$. However, no definite trend in distribution of CEC from hill slope to coastal plain was observable. The proportion of exchangeable cations were observed in order of $\text{Ca}^{2+} > \text{Mg}^{2+} > \text{Na}^+ > \text{K}^+$. The BSP and ESP ranged from 90.15 to 93.50 and 6.38 to 14.90 with the mean of

92.47 and 9.67, respectively. The ESP > 10.0 in lower piedmont to coastal plain and has the potential of achieving alarming proportions, if neglected.

The pHs and ECe ranged from 7.79 to 8.16 and 0.75 to 3.66 dSm⁻¹ with mean of 7.96 and 1.32 dSm⁻¹, respectively indicating that the soils were non-sodic and non saline except some part of coastal plain. The pHs and ECe increased with decrease in elevation from hill slope to piedmont plain and hill slope to coastal plain, respectively, The proportion of water soluble Na⁺ was dominant followed by Mg²⁺, Ca²⁺ and K⁺. The distribution of total water soluble cations increased with decreasing topography. The CO₃²⁻ was absent in water soluble anions in saturation extract, while Cl⁻ was dominant followed by HCO₃⁻. The HCO₃⁻, Cl⁻ and SAR increased gradually with decreasing topography.

The soils were low in available N and P₂O₅ and medium in available K₂O. The available N decreased with decrease in elevation, while reverse trend was observed in case of available P₂O₅. The soils were high in available Fe, Mn, Zn and Cu micronutrient cations.

The soils were classified as Lithic Ustorthents, Typic Ustorthents, Vertic Ustochrepts, Typic Ustochrepts, Typic Ustrophepts, Fluventic Ustrophepts, Fluventic Calcistepes and Calcic Ustrophepts at sub groups level. Now Ustochrepts are named as Haplustepes as per Soil Survey Staff (2003).

The pH and EC of underground water increased with decreasing elevation. The pH and SAR of underground water increased with increase in EC. As per the limits proposed by Richards (1954), the underground water for irrigation over hill slope, upper piedmont and lower piedmont, was placed under safe class of C₂S₁ and C₃S₁ while the piedmont plain and coastal plain were in the doubtful class of C₄S₂ and C₄S₃. In general, the irrigation water of whole southern Saurashtra was placed under C₃S₁ water quality class except that of the coastal plain. The guidelines for its suitability and management strategy are discussed in detail in the text.

The climatic condition of southern Saurashtra was recorded. The natural soil, water and climatic constraints were also identified in the study area. The soils of pedon P₁ were in sustainable class S₂, while the pedons P₂ to P₈, P₁₀ to P₁₃ and P₁₅ were in sustainable with high input (S₃) class. However, the soils of pedons P₉, P₁₄ and P₁₆ were under class S₄, i.e. sustainable with alternate land use. The mean score of weight factors of four toposequences were found in order of Hiran (26) < Shingoda (27) < Machhundri (28) < Rayadi (29) indicating that the soils constraints / limitations increased from west to east direction in southern Saurashtra. The soils of hill slope and piedmont plain area were facing overall relatively less soil constraints as compared to upper piedmont, lower piedmont and coastal plain areas. The remedial measures were discussed to overcome the soil and water constraints in different land slopes for soil sustainability.

The reserve water and water balance varied from 0.136 to 0.518 and -0.203 to +0.653 m ha⁻¹ with the mean of 0.308 and +0.253 m ha⁻¹, respectively. The negative water balance in piedmont plain (-0.323 m ha⁻¹) and coastal plain (-0.203 m ha⁻¹) lead to ground water depletion every year and ultimately resulted in the ingress of seawater.

Alternate land use plans for various land forms under study have been suggested for their better management. Thus, rabi sorghum is most suitable in Borvav (P₂) and sugarcane, mustard and sorghum in Devali (P₇) village were found to be highly suitable (S₁) crops. Whereas, soils in Jamwala (P₅), Maljinjava (P₃), Kareda (P₆), Judavadali (P₁₀), Chotara (P₁₅), Devali (P₇) and Chauhani Khan (P₈) villages were suited for soybean, while in soils of Maljinjava (P₃), Chotara (P₁₅), Devali (P₇), Chauhani Khan (P₈) and Rampara (P₁₂) villages, sunflower can be introduced as these soils have been moderately suitable (S₂).

DR. J.D. GUNDALIA

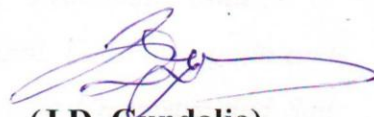
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CERTIFICATE

This is to certify that the thesis entitled “**Characterization, Classification and Evaluation of Soil and Water Resources across the Toposequences of Southern Saurashtra**” submitted by **MR. SAVALIA SHANTILAL GORDHAN** in partial fulfillment of the requirement for the award of the degree of **DOCTOR OF PHILOSOPHY (Agriculture)** in **AGRICULTURAL CHEMISTRY AND SOIL SCIENCE** to the Junagadh Agricultural University is a record of bonafide research work carried out by him under my guidance and supervision and the thesis has not previously formed the basis for the award of any degree, diploma or other similar title.

Place : Junagadh

Date : 25th February, 2005



(J.D. Gundalia)

Major Advisor

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ACRONYMS

%	- Per cent
θ	- Theta
$^{\circ}\text{C}$	- Degree celcius
$\text{\AA}$	- Angstrom
A ₂	- Horizon just below surface
A _p	- Plow layer
AWC	- Available Water Capacity
B.D.	- Bulk Density
BC	- Transitional horizon
B.S.	- Base Saturation
BSP	- Base Saturation Percentage
C ₁	- Unaltered material below solum
CEC	- Cation Exchange Capacity
Ck	- Horizon with secondary accumulation of CaCO ₃
cm	- Centimeter
dS	- Desi siemens
DTPA	- Diethylene Triamine Penta Acetic acid
EC	- Electrical Conductivity
ECe	- Electrical Conductivity at Saturation Extract
ESP	- Exchangeable Sodium Percentage
FC	- Field Capacity
Fig.	- Figure
I.R.	- Infiltration Rate
m	- Meter
MSL	- Mean Sea Level
MWHC	- Maximum Water Holding Capacity
P.D.	- Particle Density
PAWC	- Plant Available Water Capacity
PET	- Potential Evapotranspiration

pHs	-	pH at Saturation extract
PWP	-	Permanent Wilting Point
SAR	-	Sodium Adsorption Ratio
Sat. H.C.	-	Saturated Hydraulic Conductivity
Sbk	-	Subangular blocky
USDA	-	United State Department of Agriculture
USSL	-	United State Salinity Laboratory
v/v	-	volume/volume
w/v	-	weight/volume
WSC	-	Water Storage Capacity

CHAPTER – I

INTRODUCTION

Estimates indicate that the world population will reach the 9 billion mark by 2050 A.D. To meet the requirements of food, fibre, fuel, fruits for the increasing population, farm land development is often extended even to the areas unsuitable to agriculture and when the land for agriculture is shrinking the existing cultivated area is subjected to greater burdens in many cases (Minami, 1990). Success in agriculture depends on the land quality and soil characteristics. At this juncture, our efforts for increasing productivity should aim at the optimum utilization of natural resources of soil, water and climate without impairing the environment. In this context, the need for both basic and applied researches are to be focused in the intensively cultivated area to generate scientific information or utilize it to formulate appropriate technology for sustainable agriculture production at improved levels of soil productivity and land quality.

Pedogenesis is a complex process involving sequence, translocation and rearrangement of soil constituents within a soil body under natural conditions (Simonson, 1959 and Sehgal, 1970). The pedogenic studies help in understanding the magnitude of changes that might have taken place during the development of different soils. In order to understand the complex nature of soils developed under different environment, it is essential to determine the nature and properties of soils for predicting their behaviour under different management systems.

Soil properties vary laterally with topography, such variations are attributable to the orientation of the hill slopes on which soil form, affecting the micro climate and steepness of the slope and thereby the soil properties, as the rates of surface water runoff and erosion vary with slope. In areas of rolling terrain, soil properties vary because lower area are likely to be the areas of accumulation of water, and runoff sediments derived from surrounding higher

area. Further, low areas might also be influenced by a high water table, which could have considerable influence on the soil characteristics. Specific statements about the relationships to soil properties can be made only within specified geographic area. This is probably due to variations in intensity and nature of the other soil forming factors.

In India, number of studies have been conducted on soil physiographic relationship (Dhir and Kolarkar, 1977; Ahuja *et al.*, 1978; Lodha *et al.*, 1982; Minhas and Bora, 1982; NBBS and LUP, 1982; Saxena and Singh, 1982; Sharma and Dev, 1985a; Sharma and Dev, 1985b and Sharma, 1994).

For the better utilization of land resource and to tackle soil problems a systematic study of landscape is necessary. The morphology of the soil profile and the basic interactions, which lead to the development of the particular soil have been evaluated within the limitations of present techniques and methodology. The study of pedogenesis involves the identification and characterization of the bed rock followed by examination of the characteristics, properties of parent materials and their variations with depth in their natural environment. Further, there is a considerable need to correlate the pedogenic characteristics with soil profile development.

The soils of Saurashtra region have been attracting the attention of several authors. The information about geomorphology and soils of different command area and of North Saurashtra regions are available (NBSS & LUP, 1980). So far the information on the soils of different toposequences of the South Saurashtra region is scanty. In order to develop some understanding on the nature of the problems and/or the potentials for agriculture production such evaluation will help in the future planning for optimum use of natural resources. In order to suggest suitable management practices and remedial measures to tackle soil constraints, both field and laboratory studies of soils of the area are essential. A thorough and scientific appraisal about the soils of different toposequences of this area is thus very much essential for sustainable agriculture. Keeping this in view, the present investigation on

Characterization, Classification and Potential of arable Land Across some Toposequences of Southern Saurashtra” was under taken with the following objectives.

1. To characterize and classify the soils in toposequences across the land forms of the southern Saurashtra.
2. To characterize and classify the water resources of toposequences across the land forms of the southern Saurashtra.
3. To identify land quality constraints and suggest remedial measures.
4. To evaluate the soils for their suitability for different crops.

CHAPTER – II

REVIEW OF LITERATURE

A compendium of recent research work that has been carried out in India and abroad on the aspect of the characterization, classification and evaluation of soils and water resources across the toposequences have been reviewed in this chapter. This would elucidate the situation clearly and help the investigation under study. Since the work done on this aspect in Gujarat is very meagre and scattered, the review has been strengthened by incorporating the work elsewhere on related aspect wherever deemed necessary. The review of work done on various aspects of the present investigation have been presented in the following sub heads :

- 2.1 Toposequence Concept of Pedons
- 2.2 Morphological Characteristics
- 2.3 Mineralogical Characteristics
- 2.4 Physical Characteristics
- 2.5 Chemical Characteristics
- 2.6 Soil Fertility
- 2.7 Soil Classification
- 2.8 Quality of Irrigation Water
- 2.9 Sustainability of Soil and Land Evaluation for Alternate Land Use

2.1 TOPOSEQUENCE CONCEPT

Various studies of pedons have shown that many soil characteristics are related to the gradient of the slope as well as to the particular position of the soil on a slope. Though most soil catenas are depicted as a two dimensional cross section. Milne (1935a and 1935b) proposed the term catena to describe this lateral variability on a hill slope and emphasized that each soil along a slope bears a distinct relationship to the soils above and below it, so called toposequence for variety of physiographic and pedologic reasons. Yalon (1975) has reviewed many of the topofunctions derived from various areas in

the world. Conacher and Dalrymple (1977) discuss soil slope reaction in considerable detail and propose a nine unit land surface model defined on process and response.

Within soil catenas, Vertisols are situated on flat land indicating the major role of relief in vertical formation (Sanchez, 1976 and Prasad *et al.*, 1977). Abtahi *et al.* (1980) studied the effect of physiography and discussed accordingly to toposequence with different cronosequence stages of calcareous soils of Iran. Murthy *et al.* (1982) indicated that the Vertisols and Vertic subgroups in India were closely associated with three major land forms viz., (i) gently sloping extensive erosional surface, (ii) level to very gently sloping piedmont plain and flood plains and (iii) the deltas and coastal plain. Jordon (1984) studied the weathering of igneous rocks and found two types of profiles; namely one in plateau and the other in valley as governed by topography.

Ibrahimi *et al.* (1986) reported that the geographical distribution of soils had relationship with the landscape as there were occurrences of Ustochrepts (Aquic and Typic) in terraces, Ustipsamments (Typic) in sand dunes and Ustifluvents (Typic) in flood plains (indicating a strong topographic bias).

Alok Kumar and Tripathi (1987) observed that in general, as elevation and slope decreased, the soil texture became finer improving the water retention capacity, hydraulic conductivity and infiltration rates. Sharma and Roychowdhury (1988) observed that soils on higher topographic situations are shallow to moderately deep while those on lower topographic situations are deep to very deep exhibiting good profile development.

Variations in topography were responsible for soil heterogeneity as they regulated the hydrological conditions, modifying the climate which inturn influence the pedogenic processes and the differences in moisture and drainage conditions as a consequence of topography are likely to be instrument changes in soil properties (Tiwary *et al.*, 1989). Honey Cutt *et al.* (1990) found that depth of maximum clay and argilic horizon thickness generally increased from the summit to lower landscape positions within a given climatic zone,

indicating increased effective precipitation in this same direction. Jha *et al.* (1990) inferred that low land became waterlogged and remains saturated whereas oxidizing environments predominate in light textured upland soils. Several attempts have been also made (Sharma and Roychowdhury, 1988; Ramana murthy and Sharma, 1992; Deshmukh and Bapat, 1993; Singh *et al.*, 1994; Sharma, 1994; Kaswala *et al.*, 1996; Singh, 1999; Sharma, 2000; Sarkar *et al.*, 2002 and Sharma and Bhaskar, 2003) to establish relationship between landscape and land use.

2.2 MORPHOLOGICAL CHARACTERISTICS

The dominant soil morphological characteristics like soil depth, colour texture and structure are depend upon various soil forming factors and processes.

2.2.1 Soil Colour

Among different morphological features of soils, their colour is an important macro-morphological property and is the resultant of various factors.

Joshi (1950) opined that black or dark colour of regur soils was due to clay, organic matter and calcium in the soils. Prasad *et al.* (1977) observed the soils colour in moist condition are very dark brown (10YR 2/2) in surface and subsurface horizons in an area around Junagadh of Saurashtra region. Jha and Sharma (1989) reported that the gray colour of the soils was due to the presence of high amount of calcium carbonate.

Narmada Water Resource and Water Supply Department, Gujarat State (NWR & WSD, 1998) reported the soil colour of the command area of Machhundri in southern Saurashtra varies from very dark gray (10YR 3/1M) to grayish (10YR 5/2M) in surface, whereas in subsurface it varies from very dark gray (10YR 3/1M) to pale brown (10YR 6/3M). Singh *et al.* (1999) observed the colour of soils derived from lime stone ranges from light gray to gray

brown due to pigmenting effect of calcium carbonate. Soil Survey Unit (2000) observed the soil colour to vary from very dark grayish brown to yellowish brown in 10 YR hue in different physiographic units of Mendarda taluka of Junagadh district. Sarkar *et al.* (2002) reported that the dark gray (10YR 4/1) colour in the lower layer of soils indicates poor drainage condition.

2.2.2 Soil Depth

Number of studies show that soil depth in a toposequence is related to the slope (Gaikwad *et al.*, 1974; Sharma and Roychowdhury, 1988 and degree of erosion (Prasad *et al.*, 1989). Biswas *et al.*, 1966) reported an increase in the depth of the soil down to the slope. Soils at higher elevation are less developed as compared to lower elevation of landscape (Deshmukh and Bapat, 1993). Similarly, Kaushal *et al.* (1986) and Sharma (1994) reported that soils at higher topographic situations are shallow to deep while those on lower or plain topographic situation are deep to very deep. The variability in soil depth according to Singh *et al.* (1994) is the manifestation of undulating topography of basaltic rock and extent of erosion. Mandal *et al.* (2003) found that the soils of pediment surfaces are very shallow (26 cm) of medium depth (55 cm) in upper piedmont, while the soils of lower piedmont and valley plain are deep to very deep (>120 cm).

2.2.3 Soil Texture

Most of the soil properties vary widely depending on soil texture. Wambeke (1959) concluded that among the mechanical components, silt/clay ratio gave a measure of the stage of weathering. Singh *et al.* (1962) observed the heavier texture increasing with decreasing the topography. Sidhu *et al.* (1976) found that the clay content in the B horizon is significantly more than in A and C horizons.

The black soils formed under semi-arid climate over Deccan trap were found to be heavy textured ranging in clay content from 59 to 70 per cent (Desog and Hadimani, 1980 and Bharambe *et al.*, 1990). Ahuja and Khanna (1983) revealed that the decline of silt/silt clay ratio implied a better development and advance weathering of soils. Kaswala and Deshpande (1983a) emphasized that difference in amount of coarse fraction could be attributed to the parent material. A large number of investigations available (Sharma and Dev, 1985a; Sharma and Roychowdhury, 1988; Ramana Murthy and Sharma, 1992) showed relationship between soil texture and position occupied by the soil at the slope. Even Vertisols developed *in situ* from basalt rock have higher clay content compared to Vertisols derived from basaltic alluvium (Singh *et al.*, 1995). Sodic Vertisols of Maharashtra have been examined with greater clay content irrespective to parent materials (Challa, 1985). Moderate degree of variability in the sand, silt and in clay content has been reported by Canararchi and Simota (1986). Oestli and Schmidhalter (1990) have reported higher degree of variability for coarse sand. Co-efficient of variations, with respect to sand, silt and clay have been reported to the tune of 59%, 18% and 25%, respectively, in alluvial plains of Ohio. The clay content of the pedons Moraj and Luvari Moli soil series (Piedmont slope) of Veraval taluka of Junagadh district were found to be heavy textured varied between 62.97 to 68.44 per cent (Soil Survey Unit, 1996). Sharma *et al.* (1999) observed that as the slopes become more gentle, more quantities of finer particles get deposited. Sharma *et al.* (2004) indicated that generally, subsurface horizons exhibit higher clay content as compared to surface ones and may be due to the illuviation process occurring during soil development.

2.2.4 Soil Structure

Dubey *et al.* (1985) found coarse and prismatic structure breaking into moderate, medium, subangular and angular blocks in salt affected flood plains.

Douglas *et al.* (1986) concluded that silty soils are usually weakly structured, have limited potential to shrink and swell and compact easily. Bharambe *et al.* (1990) observed that the mean weight diameter of water stable aggregates of the soils are comparatively low and decreased with the depth. Ramana Murthy and Sharma (1992) observed granular structure to be more common at high altitudes as against at low altitudes, which were subangular blocky structure. However, Singh *et al.* (1991) did not report variation in the soil structures in relations to altitudes while studying the pedochemical characterization of soils in relation to altitude of Mizoram. Coloumbe *et al.* (1996) reported granular to massive soil structure depending upon land use system. Fine granular blocky structure has been reported in upper 10 cm of soil surface in highly clayey soils composed of montmorillonite. Savalia *et al.* (2000) reported moderate to strong medium subangular blocky structure in calcareous black soils of Uben command area of Saurashtra region. Sarkar *et al.* (2002) concluded that structure of the soils was mainly subangular blocky except in the lower layers of the plain land soils of Loktak catchment area of Manipur. Datta *et al.* (2004) concluded that soils have weak granular structure in the upper horizons of the Darjeeling region of Himalayas, which in the lower horizons attained moderate, subangular blocky structure.

2.3 MINERALOGICAL CHARACTERISTICS

2.3.1 Sand and Silt Mineralogy

In a salt affected soil sequence of the Sarvestan basin of Iran, Abtahi *et al.* (1980) reported that potash feldspar and plagioclases dominated the light sand fraction followed by quartz and muscovite. In the heavy fraction epidote, hornblende and garnet were dominant with small amounts of tourmaline, zircon, augite and zoisite. Quartz was the dominant mineral in the silt fraction. Feldspar showed a variable distribution and seemed to be more abundant in the soils of alluvial plains. Mica, chlorite, palygorskite were other minerals present in silt fraction. Kaswala and Deshpande (1983b) emphasized that the coastal

soil series of Valsad district of south Gujarat contained a predominance of quartz and feldspar in the silt fraction. Ahuja *et al.* (1984) reported that quartz followed by muscovite were predominant in the light fine sand fraction of salt affected soils of Ghaggar river basin. Other light minerals present were albite-oligoclase, orthoclase, microcline, serilite and calcite.

Barua *et al.* (1990) stated that light minerals consist bulk of the sand fraction varying from 93 to 96 per cent in salt affected soils of Punjab and different minerals identified in the light sand fractions were muscovite, quartz, K-feldspar, plagioclase and calcite. Thakre *et al.* (1998) concluded that the presence of considerable amount of high grade metamorphic minerals viz., garnet and rutile in the fine sand fraction indicates metamorphic provenance. Ferruginous matrix in silt stone may be due to interstitial haemetite. Mukhopadhyay and Sidhu (2000) noted that beach sands of Gujarat constitute ilmenite, zircon, rutile, monazite, sillimanite, garnet, staurolite and tourmaline.

2.3.2 Clay Mineralogy

The soils of Himmatnagar and Halol, the montmorillonite dominated while chlorite and illite dominated the clay fraction of Sevalia and Ankleshwar, respectively. The presence of the mineral halloysite and septachlorite was also detected in the soils of different districts of Gujarat (Patel, 1975). Mineralogical survey of several soil series of Valsad district of south Gujarat indicated that the coastal soil series contained relatively higher amount of mica than the low land soils. However, in all the soil series of this region, a predominance of smectite was observed in the clay fraction (Keswala and Deshpande, 1983b). Chitale and Guven (1987) found that an endmember natroalunite of composition (K 0.04 Na 0.96) (Al_{2.98} Fe 0.02) (SO₄)₂(OH)₆ occurs in Saprolitic clays in a laterite profile developed over Deccan trap basalt at Matanumad, Kutch in Gujarat.

Gupta and Tripathi (1993) reported that the soils of rice growing area of north-west Himalayan region (Kangra district, HP) contained relatively

maximum amount of mica of illite clay minerals followed by chlorite, kaolinite and mixed layers. Pacharne *et al.* (1996) found that in ferruginous Inceptisols, smectite is dominant followed by kaolinite whereas Vertisols are predominantly smectitic in the Saptadhara watershed of Nagpur district of Maharashtra. The similar results were obtained by Pillai *et al.* (1996) X-ray analysis of clay indicate the dominance of kaolinite and smectite in soils developed on sand stone and shale around Chandrapur, Maharashtra, respectively (Thakre *et al.*, 1998). The dominant clay minerals such as kaolinite > chlorite > mica and associated clay minerals such as gibbsite, anatase, rutile and halloysite were observed in lateritic based soils of south zone of Konkan. The soils from north Konkan coastal zone were non-lateritic in origin and dominant clay minerals observed in such soils were smectite > chlorite > mica whereas associated clay minerals were categorized as kaolinite, halloysite, amphiboles, anatase, gibbsite, quartz and rutile (Patil and Meisheri, 2004).

2.4 PHYSICAL CHARACTERISTICS

Soil physical properties namely bulk density, hydraulic conductivity, moisture retention characteristics and co-efficient of linear extensibility are the reflections of moisture content and genetic characteristics. These properties influence several other properties, such as leaching, deep drainage and inter flow and susceptibility to drought. Interacting with pedo-climate and land use, these properties produce aridic conditions in shallow soils and humid conditions in deep soils (Virmani *et al.*, 1982).

2.4.1 Bulk Density

Bulk density is commonly used as an index of soil physical conditions and may become a mechanical barrier, if its value exceeds above 1.4 Mg m^{-3}

(Grossman *et al.*, 1985). Sangwan (1978) reported higher bulk density in lower horizon which may be attributed to the finer fraction and heavy minerals illuviated from the surface horizon. Further, Yeresheemi *et al.* (1997) indicated that bulk density values, which showed negative correlation with organic carbon tended to increase with depth and were relatively, higher in low organic matter content soils than in comparison to those recorded in the normal soils of the same region studied earlier by Doddamani *et al.* (1994). Coloumbe *et al.* (1996) studied the impact of land use in surface soils of Texas and observed greater bulk density in the surface soils under restored meadow. Karim and David (1992) and Mandal *et al.* (2003) observed greater bulk density in subsurface horizon due to over burden pressure and compaction.

2.4.2 Particle Density

Rathore (1993) and Sharma (1994) observed particle density of active flood plain profile to be lower than profiles situated at hill top, side slope, foot slope and alluvial plain. Verma (1995) observed small variation in particle density and reported a higher value in lower horizons than surface ones.

2.4.3 Total Porosity

There was a sharp decrease in non-capillary porosity with depth in the lower parts of the B horizons. The layers with low capillary porosity come closer to the land surface from the crest to the foot of the slope in the toposequence (Wicklund and Whiteside, 1959). Datta *et al.* (1990) observed that the low land soils have more total pore space than those from the upland, while Rathore (1993) did not observe any relationship of total porosity with slope. Sharma (1994) observed inverse relationship between porosity and bulk density.

2.4.4 Maximum Water Holding Capacity

Shukla and Roychoaudhury (1966) and Sharma (1994) observed that the maximum water holding capacity of the soil is generally related to the texture of the soil and increase with increase in clay content. However, Rathore (1993) did not find any relationship between maximum water holding capacity and slope in catenary sequence. Savalia *et al.* (2000) that the surface horizons (Ap) have higher water holding capacity than subsurface horizons (A1-1) of Vertic Calciustepts of Uben command area of Saurashtra region. The water holding capacity of the soils of Jetpur taluka of Rajkot district varies from 41.26 to 70.91 per cent (Soil Survey Unit, 2003).

2.4.5 Water Retention Characteristics

Studies on water retention are useful for efficient water utilization, estimation of total moisture in the root zone, moisture depletion and soil water relationship. Water content between 0.03 and 1.5 MPa is a measure of available water capacity (Atter, 1988). Typic Chromusterts contain higher moisture both at 0.03 and 1.5 MPa compared to Vertic Ustochrepts in Chambal command area of Rajasthan (Nagar *et al.*, 1995). Yadav and Vyas (1998) observed that moisture retention at different tensions and available water content showed highly positive and significant correlations with silt, clay, silt + clay and bulk density of soils, while these showed a negative and significant correlation with sand content. Prasad *et al.* (1998) concluded that the moisture retention at 0.033 and 1.5 MPa in black and alluvial soils was a resultant function of two sets of factors influencing in opposite direction, with one set of factors, CEC, organic carbon, clay, CaCO_3 and exchangeable bases on the exchange complex influencing positively, while the other sand fraction influencing negatively. Consequently, the available water content was also influenced by the same set of factors and in a similar manner. Exchangeable Ca^{2+} , Mg^{2+} and Na^+ had shown grater influence than exchangeable K^+ on moisture retention characteristics. Ali *et al.* (1966) for black soils and Abrol *et al.* (1968) for semi arid soils also reported similar findings. Savalia *et al.*

(2000) observed that moisture retention of calcareous black soils of Uben command area of Saurashtra region at 0, 33 and 1500 KPa ranged from 0.380 to 0.633, 0.214 to 0.379 and 0.111 to 0.176 cm³cm⁻³, respectively, which decrease with soil depth. The amount of available water content of pedons were found between 0.09 to 0.238 cm³ cm⁻³. Sharma and Bhaskar (2003) found that the mean values for water retention at -33 KPa and -1500 KPa and plant available water is high in soils of lower piedmont surfaces of Rajkot district of Saurashtra region.

2.4.6 Hydraulic Conductivity

Hydraulic conductivity is important parameter of assess soil water storage, surface runoff, erosion and evapotranspiration. Low hydraulic conductivity, in clayey soils of Karnataka (Mathunjaya and Gowda, 1993) and in Typic Chromusterts (3.34×10^{-7} m/s) of Chambal command area of Rajasthan (Singh *et al.*, 1994), have been reported. Higher degree of variability in hydraulic conductivity is reported between Typic Chromusterts and Typic Pellusterts subgroups of Vertisols soil order (Bouma and Loveday, 1988).

Hydraulic conductivity is negatively correlated with clay content (Mathen and Mahendran, 1993) and amount of expandable clay minerals (Diwakar and Singh, 1992). Adverse impact of disperse clay and silt on hydraulic conductivity is also reported by So and Cook (1993). High exchangeable Na adversely affects the hydraulic conductivity (Mathen and Mahendran, 1993; Khan and Afzal, 1993) due to plugging of pores by disperse organic matter and clay. Hydraulic conductivity is positively correlated with organic carbon, electrical conductivity, total porosity, drainage porosity and capillary porosity (Mathen and mahendran, 1993). Texture structure (Singh *et al.*, 1988) and bulk density (Ghazy *et al.*, 1988) also hydraulic conductivity. Kadu *et al.* (2003) demonstrated that evaluation of cracking clay soils like Vertisols for deep rooted crops on he basis of hydraulic conductivity alone may

help in planning and management of soils, not only in Indian semi-arid tropics but also in similar climatic areas elsewhere.

2.4.7 Infiltration Rate

Preparation of any management plan in the sphere of soil and water conservation, irrigation scheduling and management, drainage and solute irrigation and development of various hydrological models require basic information on infiltration characteristics. Mathen (1991) observed the initial infiltration (0-30 minutes) in the four soil profiles of alfisols ranged from 15.0 to 19.5 cm hr⁻¹ which decreased to 1.6 to 5.0 cm hr⁻¹ as a steady final infiltration rate. This again confirmed the observation that a lower horizon hard pan existed. Singh and Bhargava (1993) concluded that due to the presence of deep cracks, the clay and the clay loam soils had high initial infiltration rates (2.933×10^{-4} and 3.350×10^{-4} ms⁻¹) but the steady state infiltration rate reached after 328 minutes were 1.666×10^{-6} and 5.0×10^{-6} ms⁻¹ for clay and clay loam soils of the Central Gujarat region, respectively. Hirekurubar *et al.* (1993) observed the initial infiltration (5 minutes) in the five soil profiles of northern Karnataka ranges from 15.2 to 33.3×10^{-6} ms⁻¹, which decreased to 0.83 to 11.1×10^{-6} ms⁻¹ as steady state final infiltration rate. Gupta (2002) reported the terminal infiltration rates of black clay soil region of Peninsular India are generally low ranging from 0.2 to over 29 mm hr⁻¹. The infiltration rates in the soils command area of Machhundri (NWR & WSD, 1998), Hiran-II (NWR & WSD, 1999) and Shingoda (NWR & WSD, 2000) of southern Saurashtra region varies between 0.12 to 1.42, 0.25 to 0.87 and 1.04 to 1.57 cm hr⁻¹, respectively. Sharma (2001) reported that the infiltration rate of black clay soil regions of Central India under saturated condition is very low ranging from 0.2 to 29.0 mm hr⁻¹.

2.5 CHEMICAL CHARACTERISTICS

2.5.1 Soil reaction and Electrical Conductivity

Pathak and Patel (1980) observed that the coastal alluvial soils of Gujarat were alkaline, with pH values ranging from 7.5 to 8.9 together with an irregular trend in pH with depth. Majority of Vertisols have been reported neutral to alkaline in reactions with pH value, ranging between 7.4 to 8.1 (Murthy, 1988). In general, pH increased with depth (Arnold and Venkateshwarlu, 1982) due to higher calcium carbonate and soluble salts under irrigated conditions, pH values have been reported 9.0 to 9.5 mainly due to high ESP (Murthy *et al.*, 1982 and Murthy, 1988). The pH of the soils decreases with an increase in the altitude (Singh *et al.*, 1991 and Sharma *et al.*, 1996) and increases down the slope (Tiwarly *et al.*, 1989 and Datta *et al.*, 1990). Sharma and Roychowdhury (1988) found that more accumulation of soluble salts occurring on flood plain and adjoining piedmont and valley was mainly due to their relatively poor drainage and high water table conditions that was associated with high evaporative demand from the soil, which regulate the salt regime (E.C.).

Dubey and Sharma (1988) while studying the coastal soils of Ahmedabad, observed that the pH in all the pedons ranged between 8.0 to 8.9 and no definite trend with either depth or with increase / decrease in exchangeable sodium percentage could be detected. This may be ascribed to the presence of dominant neutral salts mainly sodium, chloride and sodium sulphate. Pedon P₁ had low salt content with E_{Ce} ranging between 2.8 to 5.2 dSm⁻¹. However, pedon 2 and 3 were highly saline in nature. This may be ascribed to their proximity to the sea and to their physiographic position in the terrain. Kumar and Kumar (1993) while working with soils of Gangetic alluvial tract in Western U.P. reported that the neutral pH in Siwaya-I soils was due to low amount of exchangeable sodium and the dominance of neutral soluble salts. The higher pH values of Siwaya-II and Siwaya-III may be attributed to the presence of high amount of exchangeable sodium and the presence of relatively high proportion of soluble salts dominated with sodium bicarbonate

and carbonate in soils. Maliwal (1996) reported that in Bharuch district, the soil pH ranges from 8.6 to 9.5 and EC (1:2.5) from 0.22 to 8.1 dSm⁻¹ and increase with depth. Bhaskar and Nagaraju (1998) also reported similar results while working with soils of A.P. The soils were neutral to strongly alkaline in reaction and pH values (7.5 to 9.1) showed an invariable increase with the profile depth possibly owing to decrease in E.C. and rise in ESP with depth. Comparatively higher pH values (9.0) in some profiles could be due to higher exchangeable and water soluble sodium in those profiles (Yeresheemi *et al.*, 1997). Similarly, Mandal and Sharma (1997) in a study of salt affected soils of Indira Gandhi Nahar Pariyojna Command Area, Rajasthan noted that the soils are neutral to slightly alkaline in nature. The ECe values varied from 5.1 to 142.6 dSm⁻¹ and pedon-1 located at Lunkaransar Lift Command suffering from salinity and water logging recorded the highest value of ECe (142.6 dSm⁻¹). ECe values were high in surface horizons and decreased with depth. During dry period the water table moves below the root zone leaving the salts near the surface leading higher concentration of soluble salts near the surface. Similar findings were also reported by Pathak and Patel (1980) while working in Kaira district of Gujarat. Savalia *et al.* (2000) found that the soils of Uben command area of Saurashtra region are moderately alkaline (pHs 7.9 to 9.0) in reaction and non-saline (ECe 0.4 to 0.9 dSm⁻¹). Sarkar *et al.* (2002) observed the soil pH varies from 4.5 to 5.8 and generally increases with depth. Higher pH in the soils of gently sloping plain may be due to deposition of exchangeable bases brought by runoff water.

2.5.2 Calcium Carbonate

Gaikwad *et al.* (1974) observed increase in the percentage of the calcium carbonate along with the decreasing slope. Pathak and Patel (1980) found higher amount of CaCO₃ (4 to 6 %) in lower layers of most of the salt affected soils of all areas in Kaira district of Gujarat. Sharma and Dev (1985a) reported a variation from 1.5 to 10.5 per cent calcium carbonate in the channel,

where as those in the upper and lower terrace posses only small amount of it. Sharma and Bhargava (1993) noted that the soils are characterized by a 15 to 25 cm thick calcium carbonate concretion layer at around one meter from the surface. Sharma (1994) observed that the CaCO_3 increases down the slope. Bhattacharya *et al.* (1994) reported that soils having more than 15 cm thick horizon with carbonate content equivalent to more than 15 per cent CaCO_3 and containing appreciable amount of soft powdery lime indicate the presence of calcic horizon placed these soils in Calciusterts great group. Patel *et al.* (1996) reported that about 50 per cent soils of Gujarat contain CaCO_3 greater than 5 per cent. The distinction between pedogenic and lithogenic CaCO_3 is necessary to identify process that have been important for soil development, especially pedogenic CaCO_3 which limits water movement and root penetration (West *et al.*, 1988). Gundalia *et al.* (2000) observed that the CaCO_3 content in the soils of Saurashtra region ranged between 3.0 to 70.0 per cent with an average value of 25.35 per cent indicating highly calcareousness of these soils. The CaCO_3 content in calcareous soils of Gujarat was found to range between 0.86 to 70.00 per cent with a mean value of 10.5 per cent. The lithogenic nature of calcareousness (observed at the piedmont slopes) is evident as the CaCO_3 content is higher in the “C” horizon and is lower in the layers above. While the pedogenic nature of calcareousness (found in soils over the flat plains) is evident on account of an observed carbonate rich layer in between lower carbonate content in layers both above and below. Intermediate development of calcareousness soils in occurs at the piedmont plains (Gundalia and Savalia, 2000). Sharma and Bhaskar (2003) concluded that the coefficient of variation for CaCO_3 content is high in soils of upper piedmonts as compared to lower piedmont of the soils of Rajkot district of Gujarat.

2.5.3 Organic Carbon

Patel *et al.* (1982) found the average organic carbon content of soils of south and north Saurashtra is to be 0.30 and 0.47% in surface soils, respectively, but it is higher near about 100cm depth (0.43 and 0.52%) in south and north

Saurashtra respectively. According to Chakraborty *et al.* (1984), the organic carbon content was in the range of 0.7 – 1.0 per cent in the top 75 cm of the soils of upland and intermediate land while it was 6.2 per cent in surface and 4.0 per cent upto a depth of 60-75 cm in the low land soils of Surma valley. A number of scientist (Singh *et al.*, 1991 and Ramana Murthy and Sharma, 1992) have clearly indicated an increase in organic matter content with an increase in the altitude. Further, the organic matter content was found to increase with a decrease in the slope (Gaikwad *et al.*, 1974). Similarly, high organic carbon content was observed in low land soils as compared to the overlaying counterparts (Datta *et al.*, 1990). Deshmukh and Bapat (1993) noted that the highest organic carbon content in plateau due to less erosion and forest vegetation and lowest in dissected flood plain due to more alluvium depositional activities, continuing erosion and less vegetative cover.

Besides, this low organic carbon content in hill soils can be attributed to truncation of upper soil layers under prevailing conditions of rugged topography, sparse vegetation and loose strata of hills (Sharma *et al.*, 1993). Trivedi and Desai (1996) reported that the organic matter in the soils of Gujarat varies between 5 to 11 g kg⁻¹. Sharma and Bhaskar (2003) found that the coefficient of variation for organic carbon content is high in soils of upper piedmont as compared to lower piedmont soils of Rajkot district of Gujarat. Sharma *et al.* (2004) recorded higher organic content in surface as compared to subsurface horizons in the soils of Darjeeling region of Himalays due to leaf fall/decay, soil forming factors (vegetation and parent material, low in bases, heavy rainfall, low temperature and topography) and manure application.

2.5.4 Cation Exchange Capacity

The cation exchange capacity of soils of also a very important property in relation to nutrient supplying power of the soil. Joffe and Kunin (1943) found that clay was only important fraction for CEC in the soils formed from igneous rock material.

Dubey and Sharma (1988) while working with salt affected soils of Ahmedabad observed that the CEC values carbonated well with the clay content and indicated dominance of smectite in the clay. Deshmukh and Bapat (1993) reported that the CEC values did not exceeds the total clay content and increased with depth. In general, both CEC and clay content are less at higher elevation than in the rest of the profiles occupying lower elevations. A similar trend was also observed by Sharma *et al.* (1993) and Biddappa and Venkata Rao (1973). The CEC has been found to increae with a decrease in the slope (Gawande *et al.* 1968; Gaikwad *et al.*, 1974 and Sen *et al.*, 1996). Further the CEC was found to decrease in to the profile (Singh *et al.*, 1991 and Ramana Murthy and Sharma, 1992). Further, several workers suggested that CEC values were significant related to clay per cent indicating major contribution for CEC from inorganic fraction than organic sources which is comparatively low in such soils (Sahu and Dash, 1993, Yeresheemi *et al.*, 1997). The CEC values in the soils of command area of Machhundri (NWR & WSD, 1998), Hiran-II (NWR & WSC, 1999) and Shingoda (NWR & WSD, 2000) of southern Saurashtra region from 11.00 to 49.5, 12.00 to 48.00 and 14.00 to 48.00 cmol (p⁺) kg⁻¹, respectively. Gupta *et al.* (2003) observed the CEC of some soil series of Madhya Pradesh ranged from 19.33 to 34.32 cmol (P⁺) kg⁻¹, were higher in subsurface horizon than in the surface. Sharma and Bhaskar (2003) concluded that the CEC values of the soils of Rajkot district vary from 34.5 cmol (P⁺) kg⁻¹ in soils of hummocks and ridges (P₁ and P₂) to 53.51 cmol (P⁺) kg⁻¹ in soils of lower piedmonts (P₈ and P₉) with coefficient of variation of 5.91 per cent. The little variation in CEC of soils due to local variations in soil organic carbon and clay content and also due to analytical difficulties encountered in highly calcareous materials (Bascomb, 1964).

2.5.5 Exchangeable Cations

Dominant exchangeable cations primarily depend upon the nature of parent materials, physiography and climatic. The variation in calcium,

magnesium and potassium content among profiles was found to depend on topography and parent material in a toposequence of the humid tropics of Costa Rica (Martini and Mosquera, 1972). Ramana Murthy and Sharma (1992) found that exchangeable bases to be high in the soil profiles, where large amount of biomass is returned to the soil surface in addition to the presence of phyllitia materials, rich in Ca and Mg.

Pathak and Patel (1980) while working on salt affected soils of Kaira district of Gujarat observed that for the Thasra area, in general, the order of exchangeable cations was $\text{Ca}^{2+} > \text{Na}^+ > \text{Mg}^{2+} > \text{K}^+$, while in soils of Matar, a coastal area, the order was $\text{Na}^+ > \text{Ca}^{2+} > \text{Mg}^{2+} > \text{K}^+$, indicating a considerable amount of Na^+ has gained entry into the soil exchange complex. Verma *et al.* (1995) while studying the soils of Etah district found Na^+ to be the dominant cation in all the mapping units and show followed a increasing trend from S_1 (low sodicity) to S_4 (higher sodicity). In general, among the cations, Ca^{2+} dominates over the rest on the exchange complex. The increase in clay content resulted in proportional increase in CEC and exchange Ca^{2+} of the soils in a toposequence over basaltic terrain in Rajasthan (Sharma *et al.*, 1996). Yeresheemi *et al.* (1997) while studying upper Krishna Command area in Karnataka found Ca^{2+} and Mg^{2+} together to account for greater portion of soil CEC, while exchangeable Na^+ was the next in order of dominance.

Sharma and Bhaskar (2003) found that among exchangeable bases, the coefficient of variation values were high for exchangeable Na^+ and exchangeable K^+ in the land classes of lower piedmonts and flood plains of Rajkot district where the exchange complex was dominated by Na^+ . Similar, observations were made by Chittleborough (1978) and Van Den Borek *et al.* (1981).

2.5.6 Exchangeable Sodium Percentage

The ESP of soils was below 10 in all soils except in brown soils (saline phase) where it exceeds 21 (Saxena and Singh, 1982). Sehgal *et al.* (1980) have observed low content of ESP (<5%) in soils of the Shahrazur area (NE-Iraq). While, studying the soils of Mahi command in Kaira district of Gujarat state, Pathak and Patel (1980) recorded the ESP varied between 1.28 to 46.9, 5.0 to 72.5 and 7.5 to 67.5 in the soils of Thasra, Matar and coastal area, respectively. Similarly, a higher value of ESP (> 15.0) were also reported by Sahu *et al.* (1986) in coastal saline soils of Orissa. Under irrigated conditions, Vertisols become sodic with ESP >15% (Soil Survey Staff, 1998), however, Balpande *et al.* (1996) have proposed 5 as lower limit of ESP for sodic Vertisols from Australia and India, respectively, due to higher clay content. Sharma (2000) concluded that the ESP values of the salt affected soils of sub-humid southern plains of Rajasthan were increases with an increase in salinity level but such relation existed only upto slightly saline (S₃) group of soils. A rise in salinity beyond S₃ group resulted into a definite decrease in the sodicity hazard.

2.5.7 Base Saturation

Brown and Olsen (1949) concluded that base saturation vary with the steepness of the slope. Maximum values of base saturation was observed on 6-12% slope and minimum on 2-6% slope, whereas, it was intermediate on 0-2% slope, high base saturation values were also observed in topographic depressions reported by Parsons and Balaster (1966). Tiwary *et al.* (1989) reported high base saturation particularly because of higher calcium followed by magnesium and less due to sodium and potassium content. Further, they observed that black soils had more base saturation in neutral and slightly alkaline pH condition, whereas, lower values were for the red and yellow soils under lower pH. A low base saturation in the upper horizon of the profile having slope 5-15 per cent than profiles occurring at the slope of 17-25 per cent

have been observed by Prill and Riecken (1958). Besides this, increase in the base saturation with depth without a corresponding increase in the clay content was reported by Martini and Mosquera (1972). Rathore (1993) also reported the similar results.

Deshmukh and Bapat (1993) while studying soils in relation to different soils in relation to different parent rock and land forms reported that all profiles except hills and ridges were highly base saturated indicating low leaching.

2.6 SOIL FERTILITY

Nutritional aspect is one of the focal point of modern research. In this section, status and availability of nitrogen, phosphorus, potassium and micronutrients are reviewed with respect to pedogenesis.

2.6.1 Available Nitrogen

The content of available nitrogen was found to be linearly related to elevation and its contents increased with the increase in elevation (Biddappa and Venkata Rao, 1973; Minhas and Bora, 1982). Goyal and Singh (1987) stated that nitrogen content decreased with depth in all profiles located in different land forms. In plains and plains with aeolin activity, the amount of available nitrogen was a little less and it was the least in the active fluvial plains of Sahibi river flood plain. According to Jha *et al.* (1988), the heavy textured low land profiles exhibited higher nitrogen contents, than the light textured upland profiles. Rathore (1993) reported that available nitrogen decreased with depth in the profile except in the active flood plain. Sharma (1994) found that available nitrogen content of the transect decreases down the slope as well as with an increase with depth in the profiles. Gundalia *et al.* (1996) reported that more than 50 per cent of the soils of Gujarat are low in available N whereas lower piedmont and plains of Saurashtra region exhibit

medium available N status. A few talukas viz., Malia, Talala, Una, Rajula, Khambha, Valia, Dediapada and Nandod have high available N.

2.6.2 Available Phosphorus

The maximum values of available phosphorus on 6 to 12 per cent slope and minimum on 2 to 6 per cent slope were reported by Brown and Olsen (1949). While, Gaikwad *et al.* (1974) observed increased available phosphorus with the descending slope and also showed a depth function in the profile. Jha *et al.* (1988) reported that the low land heavy textured soils had higher available P_2O_5 contents as compared to the light textured soils. Savalia and Mehta (1990) indicated the soils of Ustochrepts great group of south Gujarat were medium in capacity and rate of release with low intensity characteristics of phosphorus. Datta *et al.* (1990) concluded that the available phosphorus was found to vary from low to high in three topographic positions namely upland, low land and river valley located in three districts of Tripura. Similarly, Rathore (1993) reported irregular trend of available phosphorus with respect to slope and depth of profile. While, Sharma (1994) reported an increase in available phosphorus content with the descending slope. Increase in P loss (Harrison *et al.*, 1994) and lower P content in mid and lower slope position have been reported to be an function of soil development higher weathering and greater leaching intensity (Agbenin and Tiessen, 1994). Patel (1996) reported that hilly undulating, shallow and weathered soils are low in available phosphorus.

2.6.3 Available Potash

Gaikwad *et al.* (1974) observed that the amount of available potash increased along the descending slope and generally rich in the surface soils which may be due to management practices followed in the cultivated soils. Similarly, Rathore (1993) and Sharma (1994) reported that potash in surface

soils increased down the slope except in alluvial plain. However, Datta *et al.* (1990) reported low to medium variation in available potassium content.

2.6.4 Available Zinc

The distribution of available zinc within the profile was found to be influenced by physiography and the type of parent material was studied by Kumar *et al.* (1990). While studying the distribution of available micronutrient cations in some dominant soil series in different physiographic units of Bundelkhand region of Madhya Pradesh. Jha *et al.* (1984) observed that available Zn content (mean 1.5 ppm) was the highest in low land which was more than double that in any profile, while, Rathore (1993) reported that the available zinc content was found to decrease with an increase in the depth and the zinc content of the surface soils was also found to decrease down the slope. Gupta *et al.* (2003) reported that available zinc content decreased with depth in most of the soil series of northern Madhya Pradesh. The relatively high value of available Zn in surface layer may be due to variable intensity or pedogenic processes and more complexing with organic matter that provided chelating agents for completion of added Zn and reduces adsorption and precipitation.

2.6.5 Available Copper

The available copper was found to be more at the surface followed by a decrease in the lower layers (Tiwarly and Mishra, 1990). However, no definite trend with respect to depth wise distribution of available copper in the three profiles of the Maharashtra was reported by Kavimandan *et al.* (1964). Similar trend was also reported by number of soil scientists (Singh *et al.*, 1988; Kumar *et al.*, 1990 and Rathore, 1993). Jalali *et al.* (1989) found that available copper content ranged from 0.07 to 0.33 ppm. They further observed that high altitude soils had comparatively more available copper. Soil profiles contained adequate amounts of available Cu except Latapora (Karewa group). Gupta *et*

al. (2003) found that the available Cu content was maximum in 15-60 cm layer and then decreased with depth in all the soil series of northern Madhya Pradesh except Taton series.

2.6.6 Available Iron

The depth wise distribution of available iron was found to be influenced by physiography and parent material (Kumar *et al.*, 1990). Jalali *et al.* (1989) reported higher amount of available Fe in high altitude and valley basin soils than in Kerewa soils. Singh *et al.* (1988) observed the variation in the available iron in soils of different land forms.

The available iron was found mostly accumulated in the surface soils followed by progressively decrease in the lower horizons (Singh *et al.*, 1988; Tiwary and Mishra, 1990; Rathore, 1993 and Gupta *et al.*, 2003).

2.6.7 Available Manganese

The accumulation of available manganese in the surface soils followed by a progressive decrease in the lower horizons was reported by Singh *et al.* (1988), Prasad and Sahi (1989), Tiwary and Mishra (1990), Gupta and Srivastava (1990) and Gupta *et al.* (2003). The depthwise distribution of available manganese was found to be influence by physiography and parent matrial (Kumar *et al.*, 1990). Jalali *et al.* (1989) reported more amount of available manganese in high altitudes soils than valley basin soils. An average of the available manganese was found to range from 2.09 to 5.62 ppm but the variation did not follow the physiography of the tract though somewhat higher values could be observed in low land profile (Jha *et al.*, 1984).

2.7 SOIL CLASSIFICATION

Prasad *et al.* (1977) classified the soils of an area around Junagadh, Gujarat as Ustorthents, Ustochrepts and Chromusterts great group according to new U.S. System of soil classification. Gawande and Biswas (1977) studied the black soils from a major soil groups of India and classified them according

to Soil Taxonomy into sub groups of Lithic Ustorthents, Vertic Ustochrepts and Typic Chromusterts. Murthy *et al.* (1980) reviewed and classified the salt affected soils found in different parts of India. Salorthid, Natrargid, Halaquept and Ustochrepts great groups in Western India, Natrustalf, Natraqalf, Halaquept, Calciorthid, Haplargid, Camborthid, Ustochrept, Fluvaquent and Haplaquept great groups in northern alluvial plain, Halaquept and Haplaquept in eastern region and Pellustert, Chromustert, Ustifluvent and Halaquept great groups in peninsular India were recognized by them. Dubey *et al.* (1983) classified salt affected soils of south-west Mehsana, Gujarat into great groups of Typic Natrargids, Natric Combiorthids, NatrustalFs and Halaquepts. Dubey and Sharma (1988) categorized the salt affected coastal soil of Ahmedabad district in Gujarat and reported to characterized properties of Natric Cambiorthids sub group developed on the juncture of lower piedmont and flood plains. Typic Salorthids sub group developed on total deposits and Vertic Halaquepts sub group on mudflats are described. The black soils of Rajasthan were classified by Shyampura and Sehgal (1995) in three sub groups namely Typic Chromusterts, Typic Pellusterts and Ethic Chromusterts. The soils showing aberrant properties of Vertisols were placed in Vertic Ustochrepts sub group. Savalia *et al.* (2000) classified the calcareous black soils of Uben irrigation command area as Vertic Calciustepts (P₁ and P₂) due to presence of calcic horizons (containing more than 15% of CaCO₃). Tamgadge *et al.* (2000) classified granite/gneissic terrain in Deccan plateau, Satpura range of Madhya Pradesh as Lithic/ Typic Ustorthents in hilly terrain, Typic / Vertic Ustochrepts in slopping beds and Typic Haplusterts sub group in valleys. Soil Survey Unit (2000) classified the soils of different physiographic units of Mendarda taluka of Saurashtra region in to Lithic Troorthents, Lithic Ustropepts and Vertic Ustropepts sub groups. The cultivated soils of low hills zone of Neogal watershed in north-west Himalayas are classified in to orders Entisols and Inceptisols while those of mid hills zone belong to orders Entisols, Inceptisols and Alfisols (Sharma *et al.*, 2004).

2.8 QUALITY OF IRRIGATION WATER

Joshi (1956) used the pH and total salt concentration as criteria for judging the suitability of irrigation waters, but it is of limited use. Doneen (1962) introduced a new concept of effective salinity by taking total concentration of chloride and half that of sulphate ions in stead of the total salt concentration. Ayers and Wescot (1976) while describing water quality evaluation stated that quality should infer how well a water supply fulfills the need of the users and must be evaluated on the basis of its suitability for the intended use. They have suggested that the quality of water can be assessed more precisely from the adjusted “SAR” in place of SAR and RSC as the former account for the integrated effect of the latter.

About 4500 well waters samples collected from the entire Gujarat state covering different soil groups have been analyzed and their quality aspect has been studied (Pandya *et al.*, 1971-72) and found that majority of samples were in safe limit. The waters of deep black soil group had a problem of residual alkalinity. Whereas in case of well drained sandy soil 40 per cent of waters had a marginal unity from view point of residual alkalinity. Patel *et al.* (1982) found that more than 70 per cent of well waters were medium to high in sodicity. The coastal well waters had high salinity than interior ones, whereas reverse was true for residual alkalinity. The EC values in February and November sampling were lower in comparison with those of may sampling in a further monitoring study conducted under NARP by Department of Agril. Chemistry and Soil Science, GAU, Junagadh (DACS, 1988) on the assessment of the quality of well waters of the coastal area of Gujarat as compared to the interior areas. It emerged that to salinity and sodicity of the waters were found to be highly during pre monsoon sampling rather than the post monsoon sampling. The area covered under Amreli, Liliya and Lathi talukas of Amreli district was reported to have the problem of brakish ground irrigation water. The waters of the wells of these taluka, were found to have high salinity as well as alkalinity values. The soils irrigated with these waters also developed

salinity / alkalinity. The adjusted SAR values showed that the long term use of these waters may create permeability problem (Kanzaria *et al.*, 1985). Basak and Naziruddin (1987) reported that seasonal increase in salinity in the wells near the seashore is primarily due to salt water encroachment. Vadher and Gundalia (1999) studied the effect of well recharging on the quality of well waters of Junagadh district. The results revealed that as the distance from the sea increases, the better the initial quality of well water, lower elevation and prolonging the time of recharge has increasing impact on improving quality of well waters, which were found not suitable for irrigation purpose earlier became suitable for use in agriculture with recommended practices particularly in the thrust area where the problem was more acute. Mahendran and Arunachalam (2002) reported that the well waters of zones-I and II in the coastal belt of Radhapuram taluka of Tirunelveli district of Tamilnadu were affected by sea water intrusion as evidenced by the cation sequence following the order $\text{Na}^+ > \text{Mg}^{2+} > \text{Ca}^{2+} < \text{K}^+$ and the anion sequence $\text{Cl}^- > \text{SO}_4^{2-} > \text{HCO}_3^-$. The quality of water in these zones was highly deteriorated and thereby rendering these unsuitable for irrigation purposes.

2.9 SUSTAINABILITY OF SOIL AND LAND EVALUATION FOR ALTERNATE LAND USE

Lal (1994) proposed method for evaluating soil sustainability based on soil indicators. The method provides a fair understanding of constraints in achieving the goal of soil sustainability. Virmani *et al.* (1978) enumerated the constraints of Vertisols to be: high dispersible clay, greater erodibility, change of drought injury and restricted external and internal soil drainage. Deep fine textured Vertisols, having good structure are suitable for rainfed cotton, whereas very fine textured Vertisols have been reported critical for cotton cultivation (Sehgal, 1991). Among the soil qualities, soil depth, soil moisture, clay content, CEC and organic carbon are the factors that determine the yield of cotton (Gaikwad and Bhaskar, 1988). Based on the length of

growing periods, a double cropping (sunflower and sorghum) is possible in Vertisols and Vertic intergrades a single crop (sunflower) is possible in Lithic Ustorthents and Lithic Ustropepts (Challa, 1995). Tamgadge *et al.* (1996) reported that fine textured Vertisols were highly suitable for orange, cotton, soybean, wheat and sugarcane, however, Vertisols with greater content of P and silt have been reported well for rice, wheat, sugarcane and vegetables. Rao and Prasadini (1998) reported that suitable crop management practices could be adopted to minimize the risks of crop failure with the knowledge of water storage capacity of soil in addition to rainfall characteristics, soil land formation relationship of granite/gneissic remain in Deccan Satpura range, Madhya Pradesh was studied by Tamgadge *et al.* (2000). They reported that landscapes are mostly under dry deciduous mixed ferrous (higher elevation) kharif crops (paddy millets) (intermediate elevation) and wheat, gram, linseed at lower elevations. Savalia and Gundalia (2004) found that soil-site characteristics such as drainage, texture and soil fertility appeared to be the most striking factors influencing the groundnut yield in the soils of Uben irrigation command area in Saurashtra.

CHAPTER – III

MATERIALS AND METHODS

In order to characterize and classify the soil and water resources of four toposequences viz., Hiran toposequence (T_1), Shingoda toposequence (T_2), Macchundri toposequence (T_3) and Rayadi toposequence (T_4) in south Saurashtra region, representative pedons in each land slopes viz., hill slope, upper piedmont, lower piedmont, piedmont plain and coastal plain (Fig. 3.1) were selected to study the relationship between soils and land slope. The details of the study area and materials and methods adopted for field investigations and the laboratory analysis of the soil samples collected are presented in this chapter.

3.1 DESCRIPTION OF STUDY AREA AND SELECTION OF SITE:

Description of study area with respect to location, geology, physiography, relief, climate, drainage and present land use has a great significance in any pedogenic investigation not only from the view point of categorization but also for the interpretation of the data observed.

3.1.1 Location of The Study Area :

The study area lies between $20^{\circ}44'$ to $21^{\circ}10'$ N latitude and $70^{\circ}25'$ to $71^{\circ}26'$ E longitude encompassing parts of Junagadh and Amreli districts of southern Saurashtra. During the traverse, four toposequences viz., Hiran toposequence (T_1), Shingoda toposequence (T_2), Machhundri toposequence (T_3) and Rayadi toposequence (T_4) were identified with five land forms, namely: hill slope (LS-1), upper piedmont (LS-2), lower piedmont (LS-3), piedmont plain (LS-4) and coastal plain (LS-5) in southern Saurashtra. The sixteen representative pedons in the toposequences across the land slopes were selected according to heterogeneity, change in morphological characteristics including the colour. The location map of the study area is depicted in Fig. 3.1.

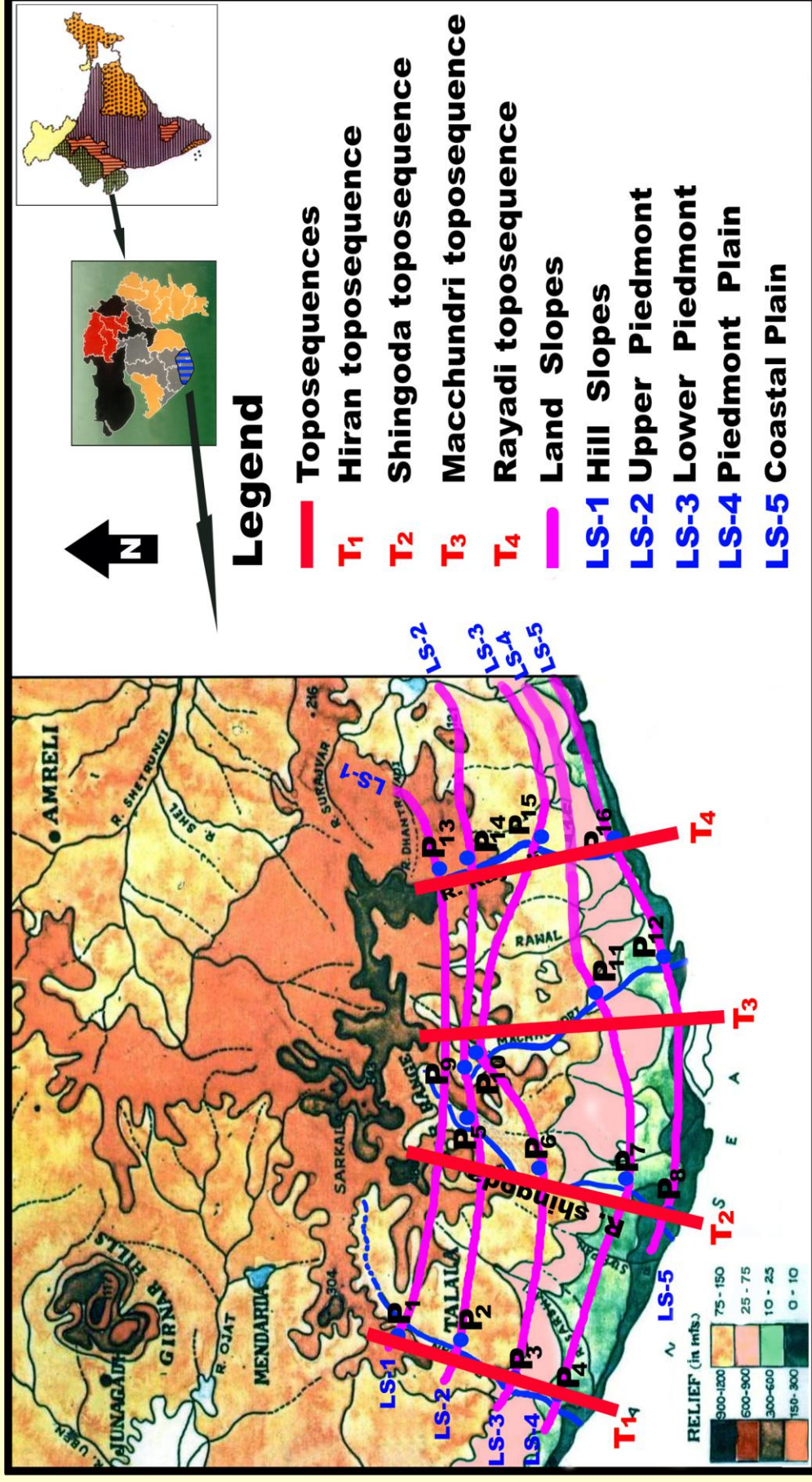


Fig 3.1 Site of Pedons in Southern Saurashtra

Geology :

Geohydrologically, the southern Saurashtra area can be divided in to four groups.

1. Deccan trap rock.
2. Gaj lime stone and clays
3. Milliolic lime stone
4. Recent alluvium

Deccan traps form the mainland of southern Saurashtra, which are exposed every where and occur about 10 to 15 km. inland from the coastal area. Grey clay and fossiliferous lime stone Gajbeds, milliolic lime stones and recent alluvium form along the sea coast of southern Saurashtra.

The genesis of southern Saurashtra Deccan trap which is commonly found can be traced to be of palaeocene to upper cretaceous age (eocene era) and extend upto the lower piedmont land form, the Gajbed which belongs to the intermediate era follow the trap along the piedmont plain area and are particularly more prominent in Hiran and Shingoda toposequences as compared to Machhundri and Rayadi toposequences. The milliolic lime stone which are of recent origin and cover the piedmont plain areas in Hiran toposequence and coastal area of Shingoda and Machhundri and Rayadi toposequences.

Geohydrological Situation :

The geohydrological situation of the southern Saurashtra (Public Work Department, Gandhinagar, PWD, 1978) is depicted in Fig. 3.2

The stratigraphic sequence in the coastal areas of southern Saurashtra is defined by PWD (1978) and Irrigation Department, Govt. of Gujarat (ID, 1983) as under.

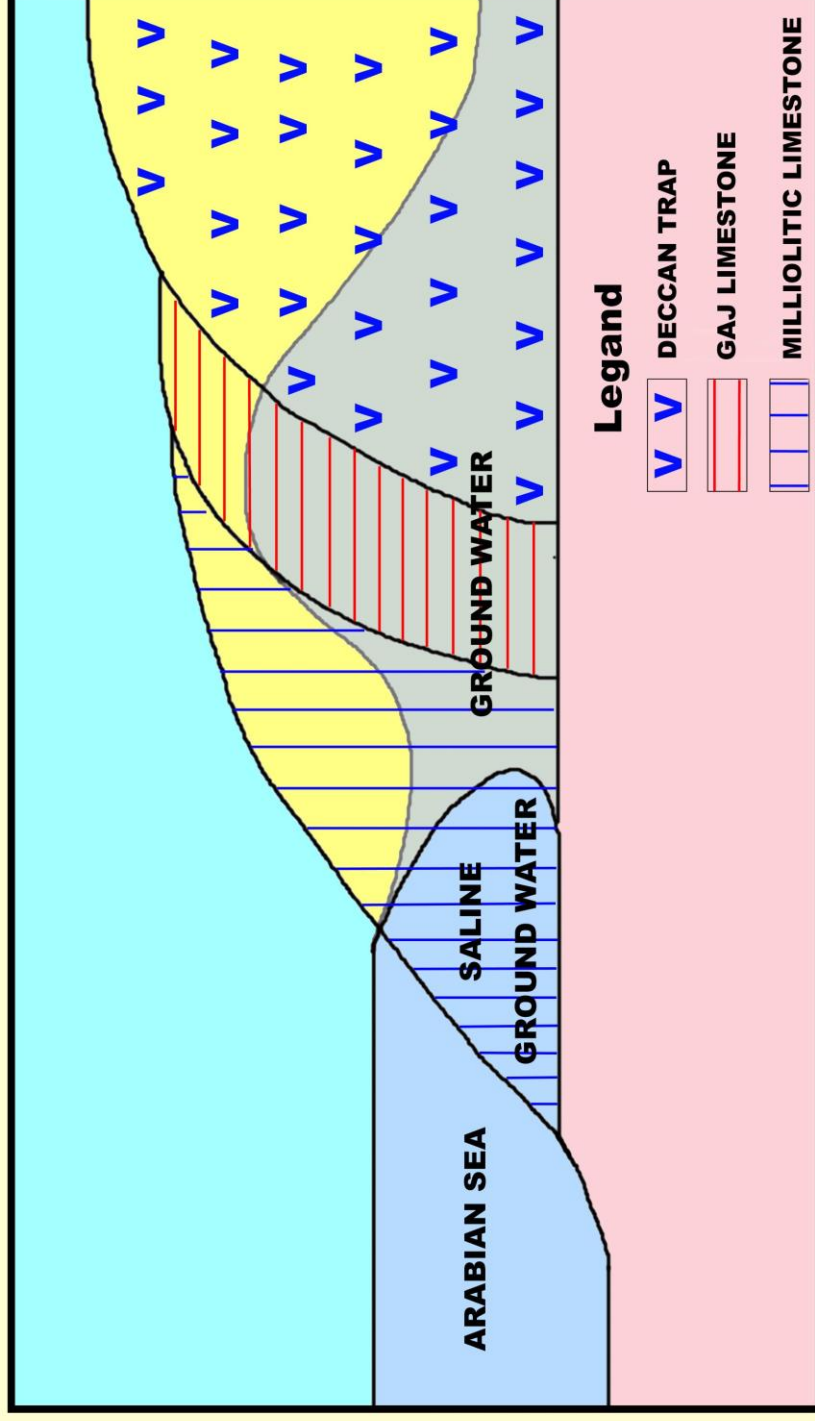


Fig.3.2 Geohydrological situation of southern saurashtra

Formation	Lithology	Thickness	<u>Age</u>
Deccan trap	Plutonic masses with dykes intrusive in trap flows	--	Cretaceous
Gaj Beds	Grey clay and fossiliferous lime stone	--	Miocene
Milliolitic lime stone	White to pale brown, Oolitic sandy lime stone, occasionally grits and conglomerates	30 to 45 Mt	Pliocene
Alluvium	Soil, coastal sand, saline, marshy land and oyster beds	5 to 20 Mt	Recent

The rock units occurring in the southern Saurashtra area are described as under.

DECCAN TRAP:

The Deccan traps forming the main land of southern Saurashtra are exposed all along 10 to 15 kms in land from the sea coast.

Deccan trap rocks are generally classified as :

- (1) Basaltic
- (2) Doleritic

(1) Basaltic: It is a hard basic igneous rock. The basalt may be defined as mafic lavas in which plagioclase feldspars and other mafic minerals occur in approximately equal quantities. The mafic minerals are augite, olivine and iron oxide, hypersthene and hornblende. Biotite, occurs only in the term basalt is applied to the simple mixture of labradorite, augite and iron oxide. Basalt is generally found in three forms (PWD, 1978):

- (i) Weathered basalt
- (ii) Compact and massive basalt
- (iii) Amygdaloidal and vesicular basalt

Weathered basalt is generally light brown to light gray in colour and thickness of about 5 to 15m. Weathered basalt is loose, friable and is also found between two comparatively harder basalt flows.

The compact and massive basalt is very hard and generally greenish gray to dark gray in colour and forms basement rock in the area.

- (2) **Dolerite:** Dolerite is a dark heavy, crystalline, igneous rock. Dolerite is composed of loabradorite, augite and iron oxides. The characteristics texture being ophitic

GAJ BEDS:

The Gaj beds are exposed in elongated patches all along the coast about 8 kms inland. The formation is marked by typical yellow coloured constituents, namely impure fossiliferous lime stone, conglomerates and yellowish and gray sticky clays. The alternate basalts of yellow clays and lime stone are dominating units of this formation. The clay content in Gaj beds is predominantly high. The clays are exposed on the surface and are also seen in well sections. Gaj beds are overlain by trap basalts of miocene age.

MILLIOLITIC LIME STONE :

Milliolite lime stone is composed of the remains of foramennifers and other fossils embedded in calcareous matrix of pliestoncene age over lying the Guj beds. The rock consists of bands of shale and hard compact lime stone of varying thickness. It attains a thickness of 40 to 45 meters near the seashore. Milliolitie lime stone at the surface contains numerous cavities to varying dimensions. The amount of shales in shaley lime stone bands and solution cavities in compact lime stone are responsible for higher permeability of milliolitie lime stone. Solution cavities plays an important role in absorption movement and storage of rain water under the ground water. The determination of exact quantum of ground water flow through these cavities has not been possible due to irregular distribution and branching of cavities (PWD, 1978 and ID, 1983).

ALLUVIUM:

Recent to sub-recent formation of alluvium occurs near the sea coast consisting of sand dunes, consolidated shore sands, river laid sands, raised beaches tidal sands, etc. The thickness of alluvium varies between 10 to 25m overlying the milliolite lime stone.

3.1.2 Physiography and Relief :

For better understanding of the results, the soils categorized into four toposequences along the land slopes from hill to seacoast (Table 3.1). The thematic diagram of Hiran, Shingoda, Machhundri and Rayadi toposequences are depicted in Fig. 3.3, 3.4, 3.5 and 3.6, respectively. The Hiran and Rayadi toposequences have the hill slopes of the Gir forest while the Shingoda and Machhundri not covered the hill slopes as they possess the intermediate range. The Hiran toposequence has not the coastal plain as the salinity not ingress in this area as compared to rest of the sequences. Whereas the Rayadi toposequence has not distinguished in lower piedmont as compared to rest of the sequences.

3.1.3 Climate :

For pedogenic studies, climate is considered to be one of the important active soil forming factor. Precipitation and temperature are the two important components of climate and play an important role in soil formation (Appendix-I). The places of study area enjoy the typical sub-tropical climate characterized by moderately high temperature, fairly cold and dry winter, hot and dry summer, moderately humid monsoon and low wind velocity. The rainy season starts in the second fortnight of June and ends in September. July and August are the months of heavy precipitation. It is south-west monsoon season (rainfall 589 to 870 mm) while the months of October and November

constitute the post monsoon period. Partial failure of monsoon once in three to four years

Table 3.1. Location of profiles in different toposequences and land slopes in the southern Saurashtra.

Sr. No.	Land Slopes	Toposequences			
		T ₁ : Hiran	T ₂ : Shingoda	T ₃ :Machhundri	T ₄ : Rayadi
1	LS-1 Hill Slope	Pedon-1 (P ₁) Sasan (Gir) Tal. Talala Dig. Junagadh	--	--	Pedon-13 (P ₁₃) Dedan Tal. Khambha Dist. Amreli
2	LS-2 Upper piedmont	Pedon-2 (P ₂) Borvav (Gir) Tal. Talala Dist. Junagadh	Pedon-5 (P ₅) (Jamwala (Gir)) Tal. Una Dist. Junagadh	Pedon-9 (P ₉) Fatsar Tal. Una Dist. Junagadh	Pedon-14 (P ₁₄) Dedan Tal. Khambha Dist. Amreli
3	LS-3 Lower piedmont	Pedon-3 (P ₃) Maljinjava Tal. Talala Dist. Junagadh	Pedon-6 (P ₆) Kareda Tal. Kodinar Dist. Junagadh	Pedon-10 (P ₁₀) Judavadali Tal. Una Dist. Junagadh	Pedon-15 (P ₁₅) Chotara Tal. Rajula Dist. Amreli
4	LS-4 Piedmont plain	Pedon-4 (P ₄) Kajali Tal. Veraval Dist. Junagadh	Pedon-7 (P ₇) Devali Tal. Kodinar Dist. Junagadh	Pedon-11 (P ₁₁) Delawada Tal. Una Dist. Junagadh	--
5	LS-5 Coastal plain	--	Pedon-8 (P ₈) Chauhani Khan Tal. Kodinar Dist. Junagadh	Pedon-12 (P ₁₂) Rampara Tal. Una Dist. Junagadh	Pedon-16 (P ₁₆) Kadiyali Tal. Jafrabad Dist. Amreli

is of common occurrence in this region. Winter sets in the month of November and continuous till the month of February. January is the coldest month of winter. Summer season commences in the second fortnight of February and ends in the middle of June, April and May are the hottest month of summer.

Rainfall :

The water balance of study area are depicted in Fig. 3.7. The average annual rainfall (1991-1999) is highest i.e. 870.1 mm at Sasan (P₁), Borvav (P₂), Jamwala (P₅), Fatsar (P₉), Judvadali (P₁₀) and Dedan (P₁₄) and lowest i.e.

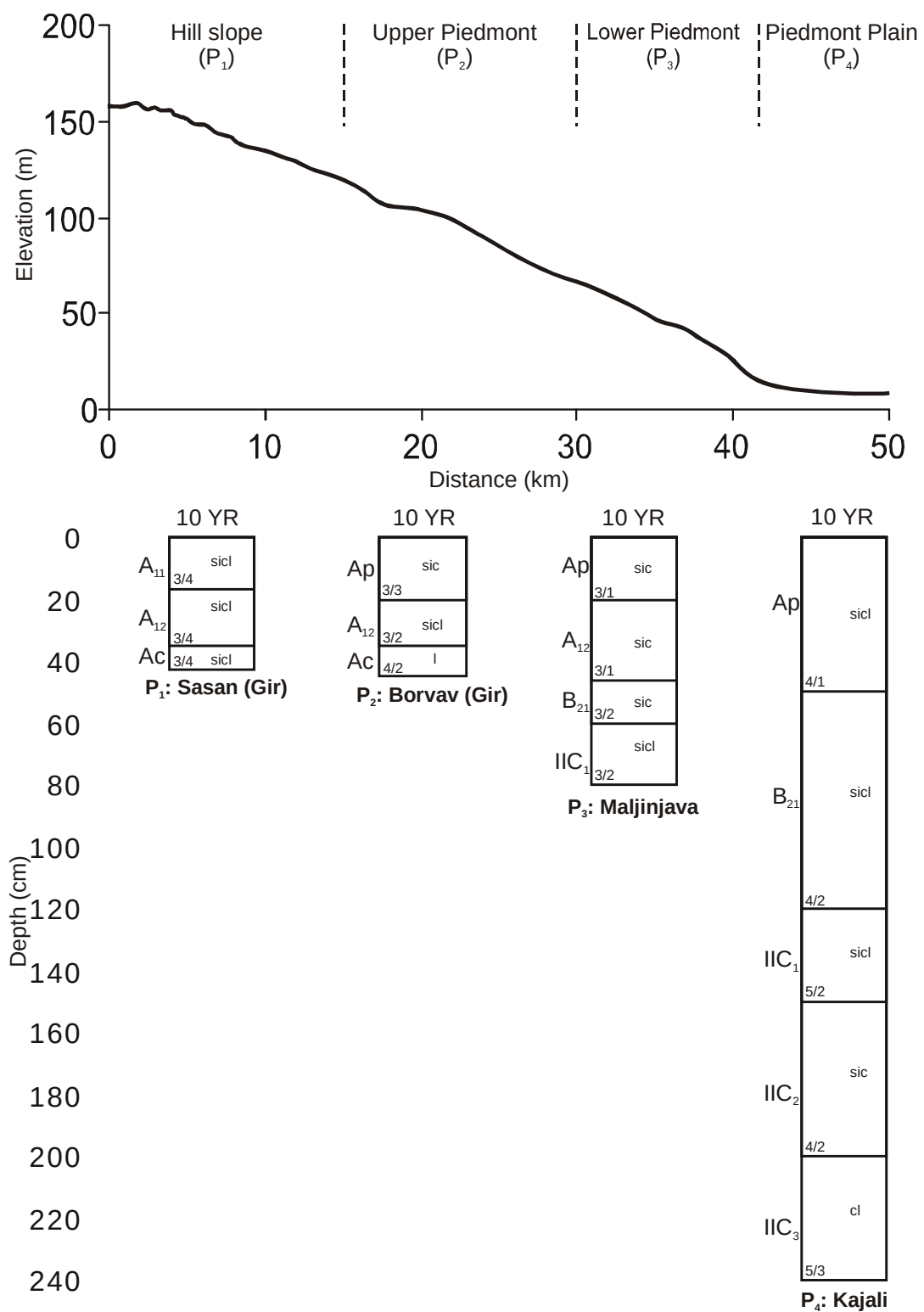


Fig. 3.3 Themic diagram of dominant soil-physiographic relationship in Hiran toposquence.

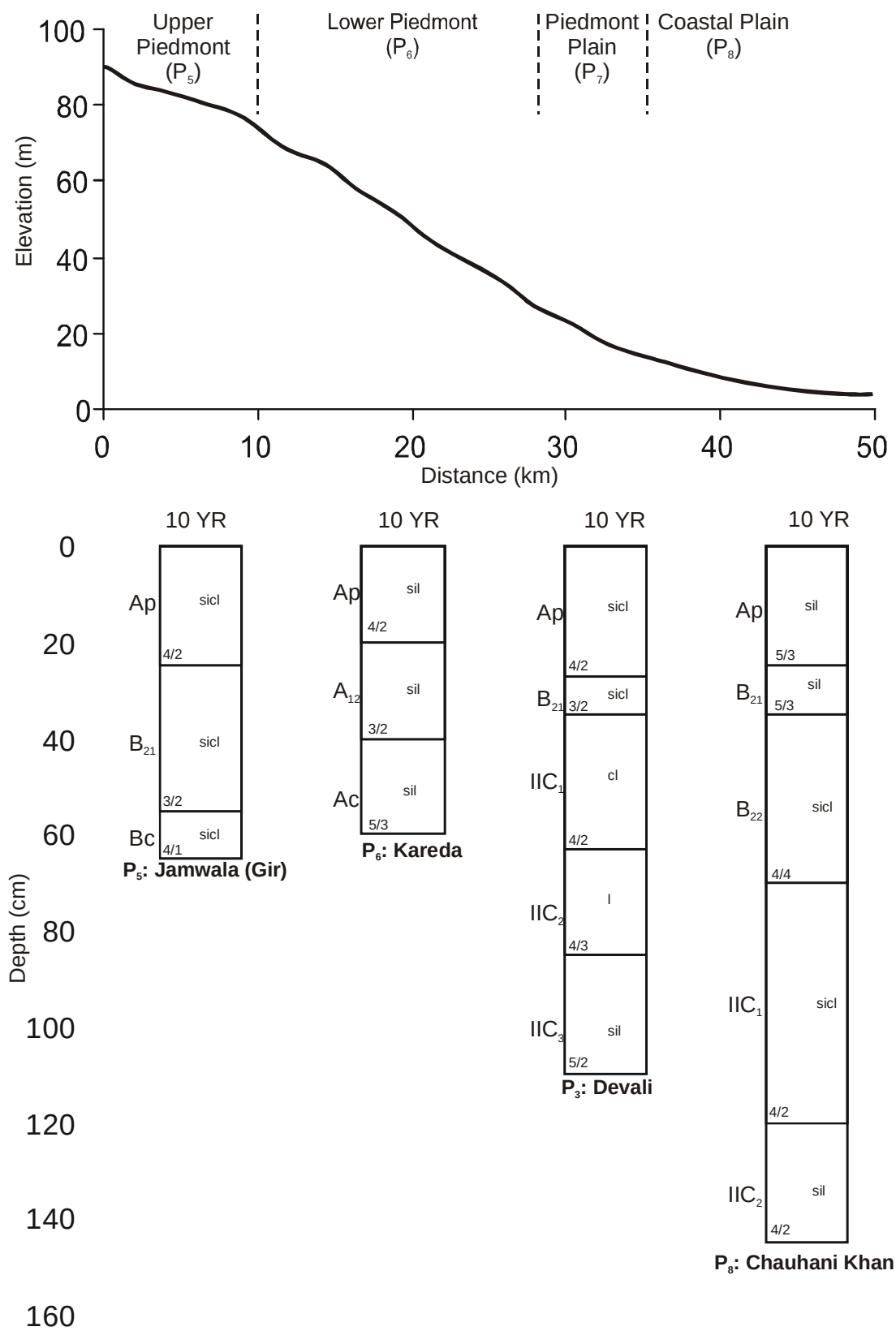


Fig. 3.4 Themic diagram of dominant soil-physiographic relationship in Shingoda toposequence.

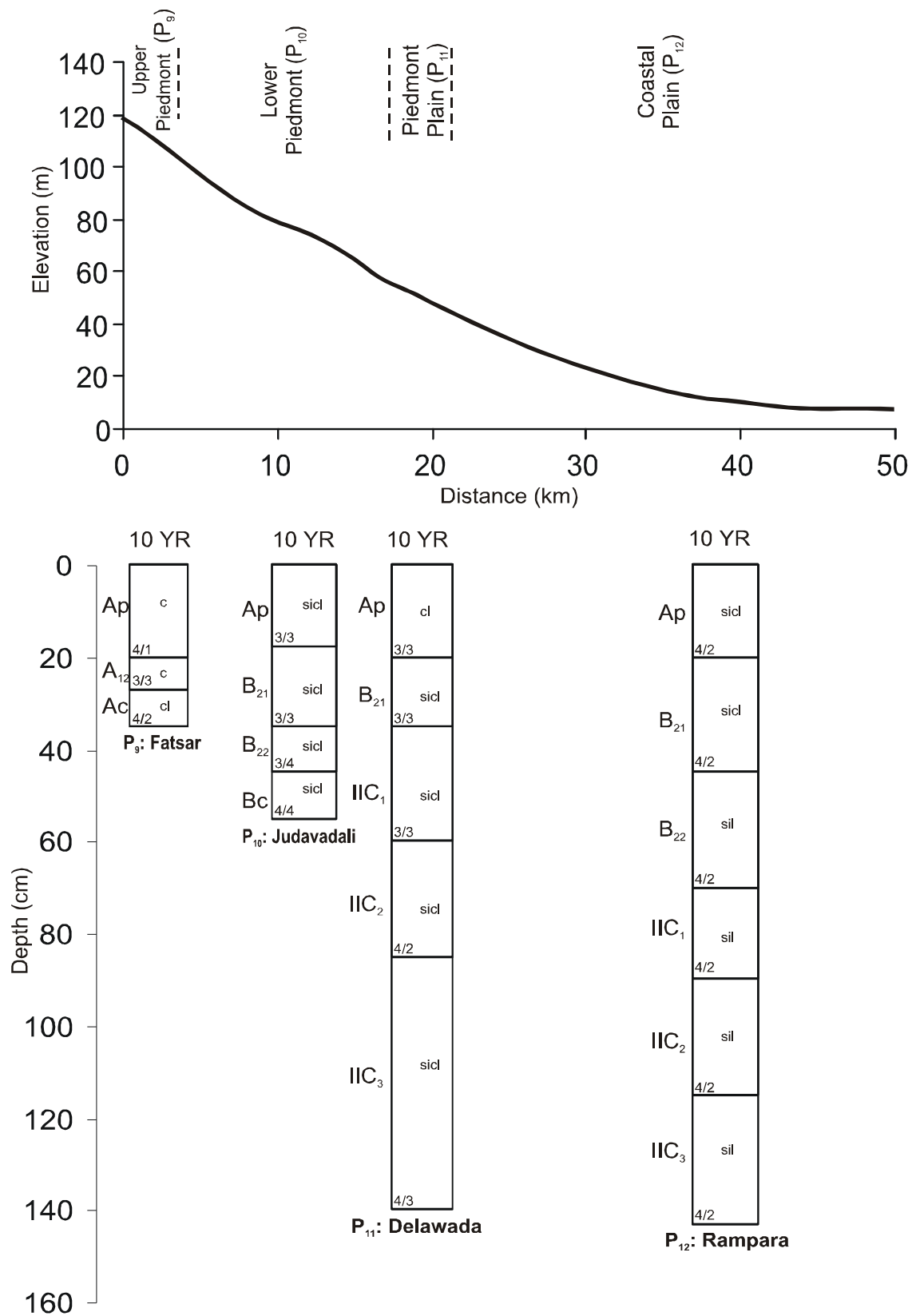


Fig. 3.5 Themic diagram of dominant soil-physiographic relationship in Machhundri toposequence.

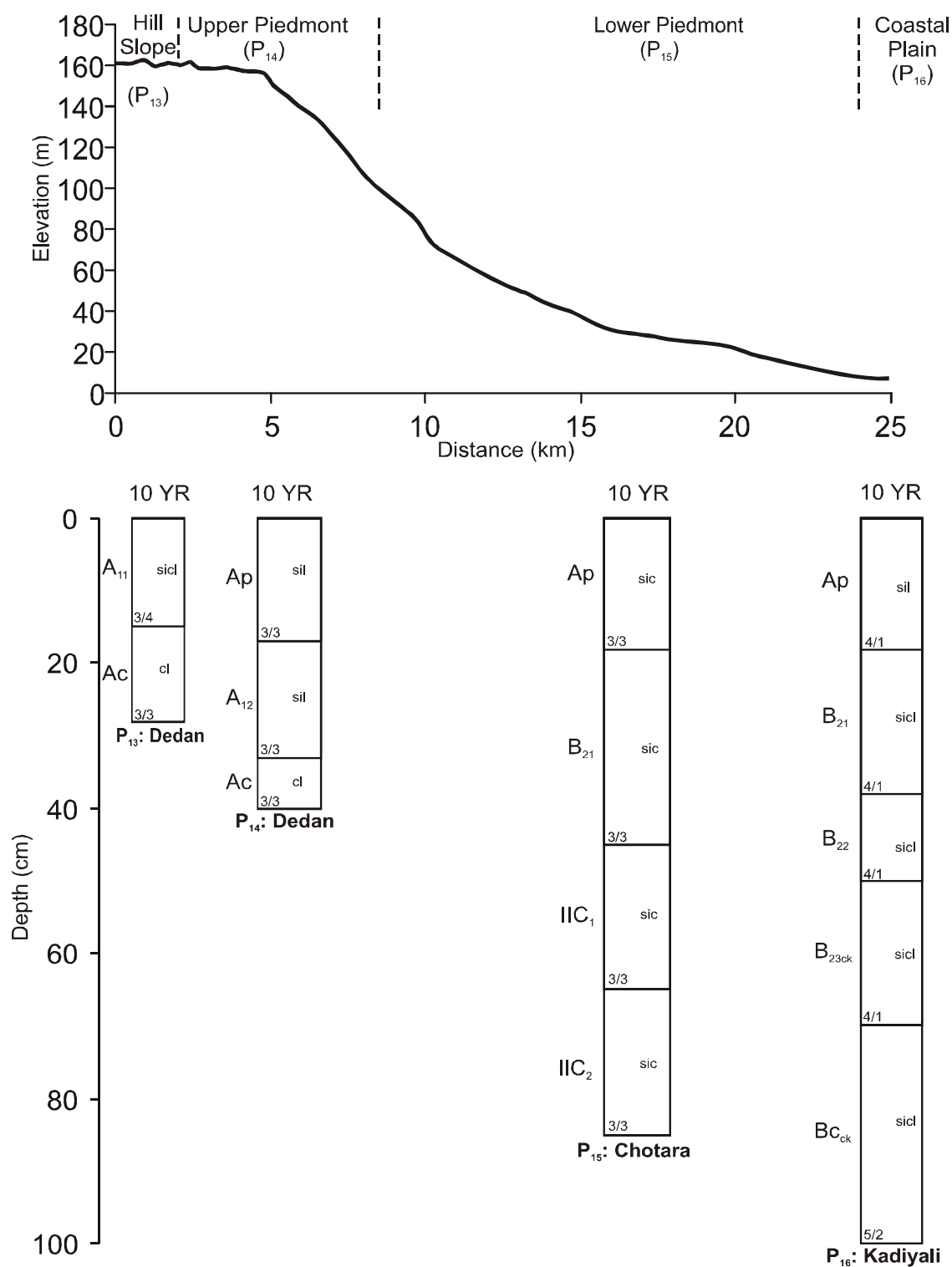


Fig. 3.6 Themic diagram of dominant soil-physiographic relationship in Rayadi toposequence.

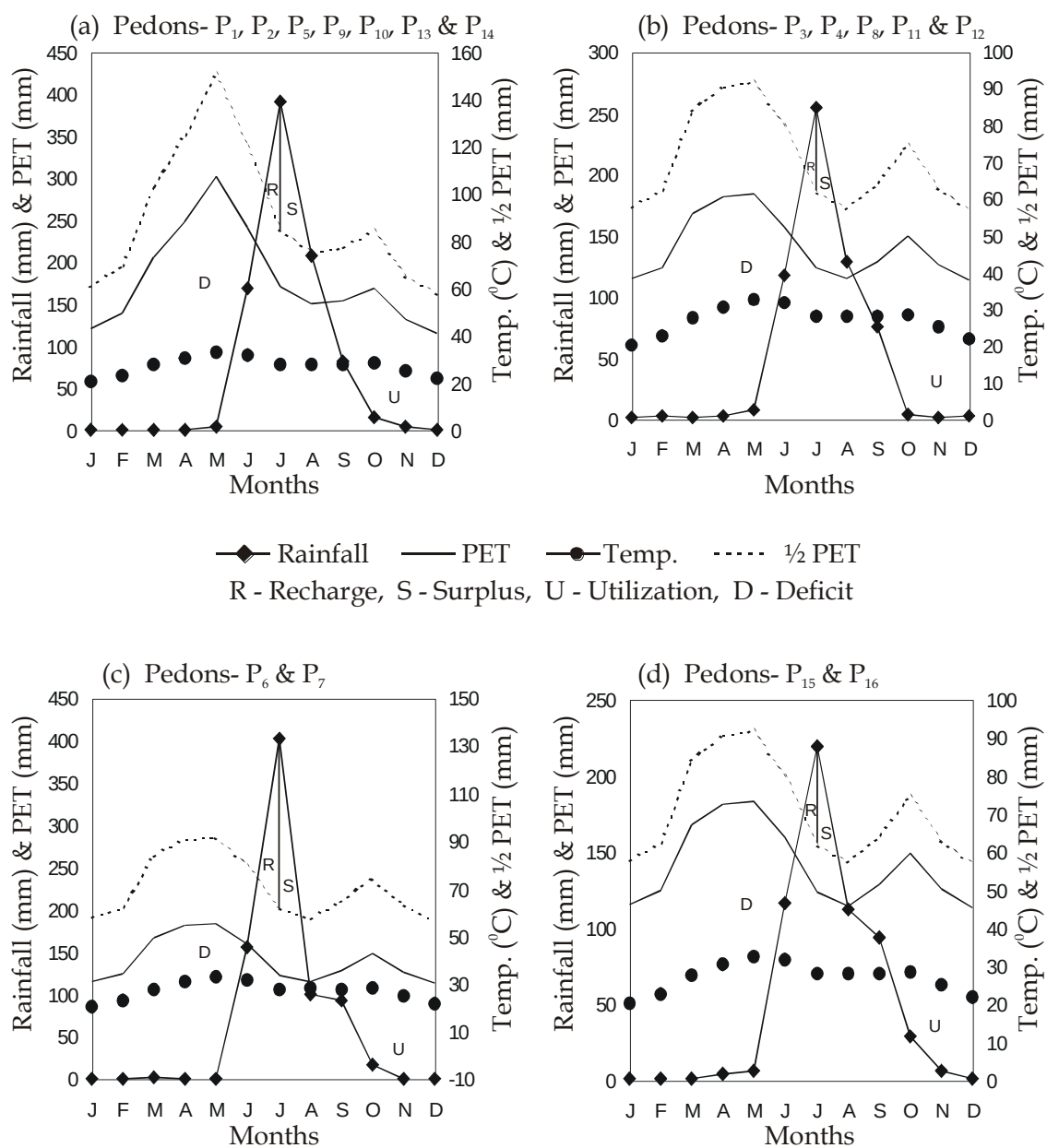


Fig. 3.7 Representative water balance diagrams of the study area.

588.80mm at Chotara (P₁₅) and Kadayali (P₁₆), while rainfall is 594.1 mm in Maljinjava (P₃), Kajali (P₄), Chahani Khan (P₈), Delawada (P₁₁) and Rampara (P₁₂) and 769.0mm at Kareda (P₆) and Devali (P₇) (SWMR and NBSS & LUP, 2000).

Temperature :

The mean annual temperature is 27.0⁰C. The hottest month is May (41⁰C) while the coldest month is January (11⁰C). The mean summer temperature (April to July) is 30.6⁰C. While the mean winter temperature (November to February) is 22.4⁰C (Appendix-I and Fig. 3.7) (SWMR and NBSS & LUP, 2000).

Humidity :

The air generally dry except during the south-west monsoon. In summer monsoon, the relative humidity is low.

Based on the climate indices such as aridity, moisture and humidity indices (Table 3.2) the area is classified as semi-arid (dry) according to FAO (1977).

Table 3.2 Climate of the area based on FAO indices.

Location Pedon No.	<i>Aridity index</i>	Moisture index	Humidity index	Climate
P ₁ , P ₂ , P ₅ , P ₉ , P ₁₀ P ₁₃ and P ₁₄	65.39	-59.42	5.97	Semi-arid (dry)
P ₆ and P ₇	61.97	-54.31	7.65	- ‘ ’ -
P ₃ , P ₄ , P ₈ , P ₁₁ and P ₁₂	65.00	-67.74	1.16	- ‘ ’ -
P ₁₅ and P ₁₆	67.76	-65.76	2.71	- ‘ ’ -

(SWMR & NBSS & LUP, 2000)

3.1.4 Surface Drainage :

The major part of study is drained by the Hiran, Shingoda and Machhundri rivers of Junagadh district and Rayadi river of Amreli district. The drainage is generally formed to be north to south direction. The rivers and their tributaries are mostly seasonal.

3.1.5 Natural Vegetation :

Vegetation is an important factor and plays an important role in the soil formation. Its effect can be noted in the area where dense forests and pastures exist. Vegetation also minimized the erosional hazards. The common vegetation occurring in the study area are as under :

1. Deshibaval	9. Boradi
2. Neem	10. Akado
3. Palas	11. Avad
4. Timru	12. Vikaro
5. Pipal	13. Dharo
6. Khijado	14. Chidho
7. Sag	15. Cactus
8. Mango	

Details of the common vegetation occurring in study area alongwith its botanical names are given in Appendix-III.

3.1.6 Present Land Use and Agriculture :

There are two main crop seasons kharif and rabi. Kharif season begins in June and ends in September to October, while rabi season starts in October and ends in April. Main crops during kharif seasons are groundnut, cotton, sugarcane, sorghum pearl millet, sesamum and the crop like wheat, gram and mustard are the main crops of the rabi season.

3.2 FIELD INVESTIGATION :

3.2.1 Excavation and Description of Pedons :

After delineating the sites, sixteen representative pedons of the size of 1.5 x 1.5 m were excavated at the selected sites (Appendix-VIII) and extended down to the parent bed rock or up to 1.5 m. which was earlier. Eastern wall of the profile was cut out vertically, while on the western side steps were made for easy approach. Demarcation of the boundaries of various horizons was made and the morphological description (Table 4.1 to 4.16) was recorded according to the soil survey manual (Soil Survey Staff, 1998). East facing wall of each profile, having grater incidence of sunlight was studied for morphological description. Soil-site characteristics such as slope, land form, geology, parent material, elevation, natural vegetation, land use and related data were also recorded (Table 4.1 to 4.16).

3.2.2 Collection and Preparation of Soil Samples :

Two to three kilograms of soil clods were collected in cotton bags from each horizon of the pedons under study and labelled properly. In all 63 soil samples (2 to 6 samples from each pedon depending upon the horizon differentiation) were collected from the 16 profiles. Soil samples collected were air dried. Some of the clods were used for bulk density determination and remaining were gently crushed (ground) with a wooden mortar with pestle and passed through the 2mm sieve for physical, chemical and mineralogical analysis.

3.3 SOIL ANALYSIS :

The soils samples from various horizons were analysed by following standard procedure described below :

3.3.1 Physical Characteristics :

1. Particle Size Distribution :

The particle size distribution analysis was carried out as per the International pipette method (Piper, 1950) and reported as total clay, silt, coarse sand and fines and expressing the values in percentage. The texture of the soil sample was computed from the soil separates by using the triangular chart.

2. Bulk Density :

This was determined as per the method give by Page *et al.* (1986) by coating the undisturbed, oven-dried clode with coating paraffin wax and expressed in Mg m^{-3} .

3. Particle Density :

Pycnometer was used to determine the particle density of the soil as per the method described by Richards (1954).

4. Total Porosity :

Per cent pore space was computed by using the following formula. (Richards, 1954).

$$\text{Per cent porosity} = 100 (1 - D_b/D_p)$$

Where, D_b = Bulk density and D_p = Particle density)

5. Maximum Water Holding Capacity (MWHC) :

Keen Raczkowski method was adopted to determine the maximum water holding capacity of the soil. (Piper, 1950) and express in percentage.

6. Expansion of Soil :

Expansion of soil was followed as outlined by Piper (1950).

7. Moisture Retention Characteristics :

Moisture retention at different tensions from 0.03 MPa (field capacity) to 1.5 MPa (permanent wilting point) pressure were determined by using pressure plate membrane apparatus as per the methods described by Richards (1965). (Plate-1)

8. Available Water Content (AWC):

The available water content was determined by computing the difference between gravimetric water content at 0.03 MPa (FC) to the gravimetric water content at 1.5 MPa (PWP) as outlined by Richards (1965).

9. Saturation Percentage :

This was determined as per the method give by Richards (1954).

10. Infiltration Rate (cm hr^{-1}) :

The double cylinder infiltrometer test observation was used to determine the infiltration rate of soils *in situ* as per standard procedure laid down by Richards (1954). (Plate-2)

11. Saturated Hydraulic Conductivity (cm hr^{-1}) :

The saturated hydraulic conductivity of disturbed soils samples as outlined was measured by Constant head method ad outlined by Klute (1965). (Plate-3)

3.3.2 Chemical Characteristics :

1. Soil Reaction (pH):

The pH was determined in the 1:2.5 soil-water suspension using glass electrode as described by Richards (1954).

2. Electrical Conductivity :

It was estimated from the above suspension, using a conductivity bridge as per the method of Richards (1954).

3. Organic Carbon :

Walkley and Black rapid titration method was followed as outlined by Jackson (1958).

4. Calcium Carbonate :

Acid neutralization method as outlined by Allison and Moodi (1965) was adopted to determine the calcium carbonate.

5. Cation Exchange (CEC) :

CEC was determined by using neutral normal sodium acetate method as described by procedure given by Bower *et al.* (1952).

6. Exchangeable Cations :

- (i) **Exchangeable calcium :** In the normal sodium acetate leachate (pH 8.3) the calcium was determined by titrating it with versenate reagent as per the method described by Richards (1954).
- (ii) **Exchangeable magnesium :** The exchangeable magnesium was computed by substracting the value of Ca^{2+} from the value of $\text{Ca}^{2+} + \text{Mg}^{2+}$ determined in the sodium acetate leachate following versenate method as suggested by Richards (1954)
- (iii) **Exchangeable sodium :** In neutral normal ammonium acetate extract (pH 7.0) sodium was determined using flame photometer as per method given by Richards (1954).
- (iv) **Exchangeable potassium :** In neutral normal ammonium acetate extract (pH 7.0) potassium was determined using flame photometer as per the method suggested by Richards (1954).

7. Saturation Extract Analysis :

The saturation extract was obtained by preparing a saturated paste of soil, then vacuum filtering to obtain the saturated extract and saturation

percentage estimated by the method outlined in U.S.D.A. Hand book No. 60 (Richards, 1954). The extract was analysed for Na^+ and K^+ by using systronics flame photometer and for Ca^{2+} and Mg^{2+} by Versenate titration method (Richards, 1954). Carbonates and bicarbonates in the saturation extract was analysed by sulphuric acid titration as outlined in U.S.D.A. Hand book, No. 60. Chlorides were determined by titrating with 0.01 N silver nitrate solution using potassium chromate as an indicator (Richards, 1954).

8. Available Nutrients :

- a) **Available nitrogen :** Available nitrogen was estimated using alkaline potassium permanganate method as suggested by Subbiah and Asija (1956).
- b) **Available phosphorus :** The available phosphorus in soil was extracted with 0.5 M NaHCO_3 (pH 8.5) as described by Olsen *et al.* (1954) and was estimated colorimetrically following the method of Dickman and Bray (1940).
- c) **Available potassium :** Available potassium in soil was determined by using neutral normal ammonium acetate extraction method as described by Richards (1954).
- d) **Available micronutrients (Zn, Cu, Fe and Mn):** Available Zn, Cu, Fe and Mn were determined by extraction with 0.005 M DTPA and 0.01 M CaCl_2 and estimated by atomic absorption spectrophotometer following the procedure given by Page *et al.* (1986).

3.3.3 Mineralogical Analysis :

Separation of sand, silt and clay : Soil samples from selected pedons and horizons were used for mineralogical investigation. Physical and chemical characteristics were the selection criteria. In order to minimize the risk of alteration of sensitive minerals, chemical pretreatments were avoided during the fractionation of soils. Soil suspensions in deionized water (with soil: water

ratio of 1:1) were treated ultrasonically for 15 minutes followed by horizontal shaking after further dilution. The sand fractions (0.05 to 2 mm) were separated by wet sieving. Coarse sand (0.25 and 2.0 mm) and fine sand (0.05 to 0.25 mm) fractions were separated by dry sieving. The silt fractions (0.002 to 0.05 mm) were separated by sedimentation. The clay suspension (<0.002 mm) was siphoned off after requisite settling time.

Sand mineralogy : The sand fraction was separated into heavy and light fractions using bromoform (Sp. Gravity = 2.82). The samples were finely ground with mortar and pestle and random powder X-ray diffraction patterns were obtained by packing the samples in aluminum sample holder.

Silt mineralogy : Samples were finely ground with mortar and pestle. Random powder X-ray diffractograms were obtained for identification and quantification of minerals in this fraction.

Clay mineralogy : A portion of clay suspension was saturated with magnesium using 1M $MgCl_2$. Likewise, a second portion of clay was flocculated with potassium using 1M KCl. The excess salts were removed by washing with distilled water. Basally oriented slides of clay samples were prepared by air-drying the suspension on glass slides at room temperatures.

Magnesium saturated samples were X-rayed at room temperature, glycolated and X-rayed again. Potassium saturated samples were X-rayed after air drying, and then heated to 400⁰C for one hour and X-rayed again.

X-ray diffractograms were obtained using a Philips PW-1050 vertical goniometer, PW-1130 generator and PW-1370 recorded under following machine conditions :

Tube	Cu K-C
Voltage	40 Kv
Amperage	25 mA
Detector	Scintillation detector at 1000 volts
Goniometer speed	2 ⁰ per minute
Chart speed	5 mm per minute

Full scale deflection	1000 counts per second
Time constant	4 seconds
Attenuation	4

Semi-quantitative estimation of clay mineral was made by the procedure proposed by Klages and Hopper (1982).

3.4 TAXONOMIC CLASSIFICATION OF SOILS :

The classification of soils was carried out as described in Soil Taxonomy (Soil Survey Staff, 1998).

3.5 GROUND WATER QUALITY :

Underground water samples from forty eight existing wells/tube wells adjoining to selected profiles (Appendix-IX) were also collected in plastic bottles in the month of May before monsoon for maintaining proper records and the water table depth also measured.

3.5.1 Water Analysis :

Different methods of analysis used to determine various parameters of water samples are enlisted in Table 3.3.

Table 3.3. Methods employed for the different characteristics of underground water.

Item of analysis	Method	Reference
pH	pH meter	Richards (1954)
Electrical conductivity	Solubridge	Richards (1954)
Sodium and potassium	Flame photometer	Richards (1954)
Calcium and magnesium	Versenate titration	Richards (1954)
Chloride	Silver nitrate titration	Richards (1954)
Carbonate and bicarbonate	Acid neutralization	Richards (1954)

3.5.2 Water Quality Evaluation :

The well waters were categorized for their salinity classes according to the USSL Staff (Richards, 1954) (Table 3.4 and Appendix-VII). These guidelines are practical and usable, in general, for irrigated agriculture. The water quality guidelines suggested are intended to cover a wide range of conditions in irrigated agriculture and incorporate the newer concept in soil-water-plant relationship.

3.6 COMPUTATION OF SOME PHYSICAL PARAMETERS :

The computation of some physical parameters are presented in Table 3.4

Table 3.4. Computation of water storage capacity and water balance of the profile.

No.	<u>Physical parameters</u>	Computation	Reference
1	PAWC (cm ha^{-1} /horizon)	$\text{AWC (m}^3\text{m}^{-3}) \times \text{Depth of horizon (cm)}$	Sharma (2000)
2	Total PAWC of Profile (m ha^{-1})	$\text{Sum of PAWC (cm ha}^{-1}) \text{ of each horizon} \div 100$	Sharma (2000)
3	MWHC v/v (%)	$\text{MWHC (\%)} \times \text{B.D. (Mg m}^{-3})$	DACS (2001)
4	Moisture retention (cm ha^{-1})	$\text{MWHC v/v (\%)} \div 100 \times \text{Depth of horizon (cm)}$	DACS (2001)
5	Total water storage capacity (WSC) (m ha^{-1}) of profile	$\text{Sum of moisture retention (cm ha}^{-1}) \text{ of each horizons of profile} \div 100$	DACS (2001)
6	Reserve water of the profile	$\text{Total WSC (m ha}^{-1}) - \text{Total PAWC (m ha}^{-1})$	--
7	Water balance (Runoff/percolation loss) of the profile	$\text{Annual rainfall (m ha}^{-1}) - \text{Total WSC of profile (m ha}^{-1})$	--

3.7 SOIL SUSTAINABILITY :

It is based on evaluating the constraints of soils and are accomplished by using scoring method, as outlined by Lal (1994).

3.8 SOIL-SITE SUITABILITY EVALUATION FOR THE CROPS

It is presented in different categories : orders, classes, sub-classes and units. There are two orders (S-suitable, N-non-suitable), reflecting kinds of suitability with three classes (S_1 - S_3) under the order S and 2 classes (N_1 - N_2) within the order N, reflecting degrees of suitability (FAO, 1976 as described by Sys *et al.*, 1991) and slight modifications was carried out by NBSS & LUP (1994). Sub class shows the kind(s) of limitation of improvement measures needed within class. The limitations are c : climatic limitation; t : topographic limitation; w : wetness; n : salinity & alkalinity; f : soil fertility; s : physical limitation. They are indicated by the symbol, using lower case letters, following the Arabic numeral used for classes. The framework comprises of following activities :

- a) Selection of relevant kinds of land use and its requirement.
- b) Description of land units and assessment of land qualities.
- c) Matching, comparison and land uses requirements with land qualities for each land use on each soil unit.
- d) Provisional suitability classification.
- e) Economic and social analysis.
- f) Final suitability classification.

Land qualities are usually rated on a scale, ranging from 1 (very good) to 5 (very poor). These ratings are compared with requirements of a given land use. Requirements are expressed as suitability class limits per land quality. Overall suitability is accounted as :

Order 'S' suitable : Land on which sustained use of the land under consideration is expected to yield benefits, which justify the inputs without unacceptable risk to land resources.

S₁ – Highly suitable – optimum condition for plant growth (S₁₋₂) have slight limitation, no more than one correctable moderate limitation.

S₂ – Moderate suitable – land units, representing nearly optimal conditions; affect productivity by 20% or less; have slight and no limitation or more than 3 moderate limitations.

S₃ – Marginally suitable – land units, representing moderate conditions; affect productivity significantly but still marginally economical, have more than 3 moderate limitations and no more than one severe limitation (correctable) that, however, do not exclude the use of land.

Order N – not suitable : land which has qualities that appears to preclude its sustained use.

N₁ – Currently not suitable (Actually unsuitable but potentially suitable) – land unit(s), having limitations, which may be surmountable with times, have a severe limitation that excludes the use of the land or more than one severe limitation that can not be corrected.

N₂ – Permanently not suitable (Actually and potentially unsuitable) – land unit(s), having limitations, which appear, so severe as to preclude any possibilities of successful sustained use of land in a given manner.

The soils under study have been rated for horticultural crops, six field crops of kharif (groundnut, cotton, sesame, sorghum, maize and soybean) and five crops of rabi (wheat, sugarcane, mustard, pearl millet and sunflower) for

soil-site suitability evaluation. Land suitability for different crops and land quality ratings as suggested by Sys *et al.* (1991) and Natarajan and Gajbe (1983) for horticultural crops, FAO (1976) and Sys *et al.* (1991) for groundnut, sesame and sunflower. Sys *et al.* (1991) and NBSS & LUP (1994) for cotton, sorghum, maize, soybean, wheat, sugarcane, mustard and pearl millet.

CHAPTER – IV

RESULTS AND DISCUSSION

With the aim to characterize, classify and potential of arable land across the toposequences of southern Saurashtra, an investigation was carried out to study the morphological, mineralogical, physical, hydrological and chemical characteristics of the soils, soil classification and quality of irrigation water, soil-water and climatic constraints, evaluation of soil and water resources and soil-site suitability evaluation for different crops in the southern Saurashtra. Results obtained have been thoroughly examined, discussed and are presented in relevant table under the following heads:

- 4.1 Morphological Characteristics
- 4.2 Soil Mineralogical Characteristics
- 4.3 Soil Physical Characteristics
- 4.4 Chemical Characteristics
- 4.5 Available Nutrient Status
- 4.6 Soil Taxonomic Classification
- 4.7 Characteristics of Water Resources
- 4.8 Climatic Conditions in the Study area of Southern Saurashtra
- 4.9 Natural Soil, Water and Climate Resource Constraints
- 4.10 Evaluation of Soil and Water Resources
- 4.11 Soil-site Suitability Evaluation for Different Crops of Southern Saurashtra

4.1 SOIL MORPHOLOGY

The soil morphology includes examination of soil colour, texture, structure, depth, consistency, horizon designation, horizon boundary, calcareousness, root distribution and some other special features. The site

characteristics and morphological properties of sixteen representative pedons from the four toposequences across the land slopes were examined in the present investigation and have been described and shown in Table 4.1 to 4.16 as per following subheads:

4.1.1 Hiran toposequence

4.1.2 Shingoda toposequence

4.1.3 Machhundri toposequence

4.1.4 Rayadi toposequence

4.1.5 Land slopes

4.1.1 Hiran Toposequence

The site characteristics and morphological properties of the pedon-1 to 4 are shown in Table 4.1 to 4.4 and Plate 4 to 10.

Pedon 1 (Sasan (Gir)) from the hill slope : The morphological properties of pedon 1 (Sasan (Gir)) situated on hill slope (Plate 4 and 5) are given in Table 4.1 explicates that the soils were shallow, somewhat excessively drained, dominantly associated with rock out crops. The soils were fine loamy skeletal in nature, moderately alkaline in reaction severely eroded, have rapid runoff and subjected to severe erosion. The soils have dark yellowish brown (10 YR 3/4M) colour. Taxonomically the soils have been tentatively classified as members of find loamy, mixed (calcareous), hyperthermic family of Lithic Ustorthents.



Plate - 4 : Site view of hill slope of Hiran toposequence [T₁] .



**Plate - 5 : Cross section of Pedon - 1, Sasan [Gir] [T₁]
Taluka : Talala .**



Plate - 6 : Site view of upper piedmont area of Hiran toposequence [T_1] .

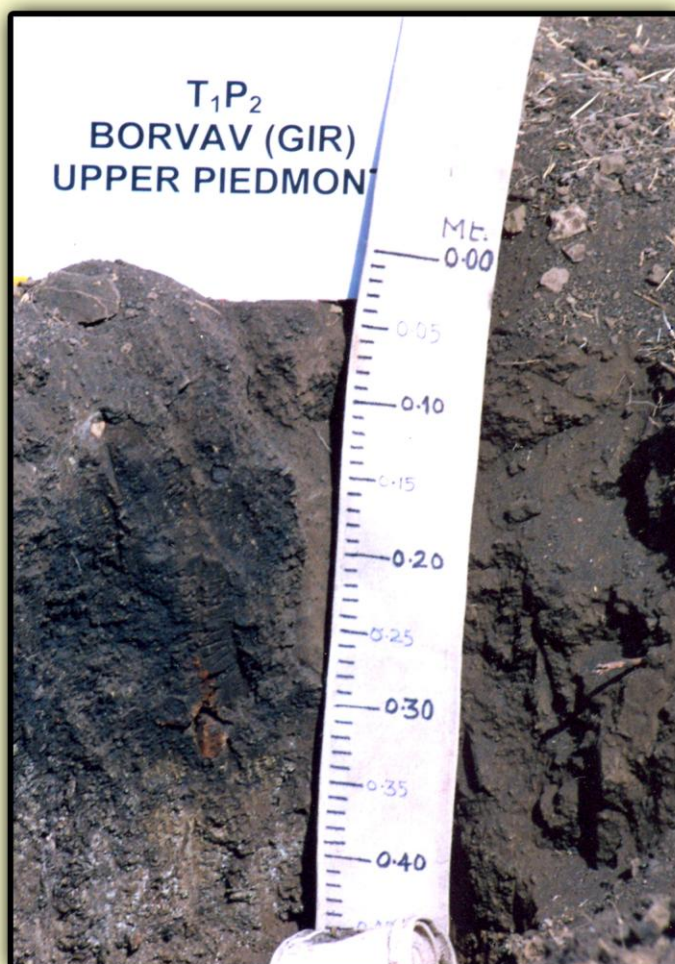


**Plate - 7 : Cross section of Pedon - 2, Borvav [Gir] [T_1]
Taluka : Talala .**

Table 4.1. Site characteristics and morphological properties of pedon-1 (Sasan (Gir)) of Hiran toposequence

A : Site Characteristics

Location	:	About 2 km away on South site of Sasan (Gir) village of Talala taluka of Junagadh district. (About 100 m away on west side from Sasan-Talala road)
Latitude & Longitude	:	20 ⁰ 10' N and 70 ⁰ 35' E
Physiographic Unit	:	Hill Slope (Plate-4)
Climate	:	Semi arid (dry)
Slope Gradient	:	8 to 15 per cent
Parent Material	:	Partial weathered casalt
Drainage & Permeability	:	Well drained soil with moderate permeability
Vegetation	:	Teak, Babul, Bordi, Mango, Khakhara, Timaru, Cactus, Neem, Coconut, etc. (Appendix-III)
Land Use	:	Forest with sparse vegetation and grassland
Date of Study	:	2 nd May, 2002

B : Morphological Properties of Pedon-1 (Plate-5)

Depth (cm)	Horizon	Morphological Features
0-17	A ₁₁	Dark yellowish brown (10YR 4/4D), dark yellowish brown (10YR 3/4M), silty clay loam, medium, moderate, subangular blocky structure, dry hard, moist friable, sticky and plastic, fine, many roots, slight effervescence, clear and smooth boundary (pH 7.90).
17-35	A ₁₂	Dark yellowish brown (10YR 4/4D), dark yellowish brown (10 YR 3/4M), silty clay loam, medium, moderate, sub angular blocky structure, dry hard, moist friable, wet sticky and plastic, fine, common roots, slight effervescence, clear and smooth boundary (pH 7.60).

35-43	AC	Yellowish brown (10YR 5/4D), dark yellowish brown (10YR 3/4M), silty loam, slight effervescence, boulder of basalt 40-45% by volume, clear and smooth boundary (pH 7.48).

Pedon 2 (Borvav (Gir)) from the upper piedmont : The morphological characters of the soils associated with pedon 2 (Borvav (Gir)) of Hiran toposequence (T₁) situated at the upper piedmont (Plate 6 and 7) are presented in Table 4.2. The result reveal that the soils of this pedon have developed from partially weathered trap basalt. The soils were shallow, well drained and have silty clay to silty clay loam texture. The soils were moderately alkaline in reaction and calcareous (slight effervescence at surface and sub surfaces) in nature. The soils exhibited dark brown (10 YR 3/3M) to very dark grayish brown (10 YR 3/2M) colour. Taxonomically these soils have been tentatively classified as members of fine, mixed (calcareous) hyperthermic family of Lithic Ustorthents.

Table 4.2. Site characteristics and morphological properties of pedon-2 (Borvav) of Hiran toposequence

A : Site Characteristics

Location	:	About 1½ km away on east side of Borvav (Gir) village of Talala taluka of Junagadh district. (About 100 m away from the Talala-Borvav road on east side)
Latitude & Longitude	:	21 ⁰ 05' N and 70 ⁰ 34' E
Physiographic Unit	:	Upper piedmont (Plate-6)

Climate	:	Semi arid (dry)
Slope Gradient	:	1 to 3 per cent and 3 to 8 per cent
Parent Material	:	Partially weathered trap basalt
Drainage & Permeability	:	Well drained soil with moderately slow permeability
Vegetation	:	Babul, Neem, Pipal, Khijra, Mango, Coconut, etc. (Appendix-III)
Land Use	:	Mostly cultivated in kharif and rabi. The most common crops are groundnut, wheat, sugarcane, pigeonpea, black gram, banana, etc.
Date of Study	:	2 nd May, 2002

B: Morphological Properties of Pedon-2 (Plate-7)

Depth (cm)	Horizon	Morphological Features
0-20	Ap	Brown (10YR 4/3D), dark brown (10YR 3/3M), silty clay, medium, moderate, subangular, blocky structure, dry hard, moist firm, wet sticky and plastic, fine, few roots, slight effervescence, clear and smooth boundary (pH 8.07).
20-30	A ₁₂	Brown (10YR 4/3D), very dark grayish brown (10 YR 3/2M), silty clay loam, medium, strong, subangular blocky structure, dry hard, moist firm, wet sticky and plastic, very fine, few roots, slight effervescence, clear and smooth boundary (pH 8.06).
30-45	AC	Light brownish gray (10YR 6/2D), dark grayish brown (10YR 4/2M), slight, effervescence, 1 to 5 mm size lime concretions about 5% by volume, clear and smooth boundary (pH 7.95).

Pedon 3 (Maljinjava) from lower piedmont : The site characteristics (Plate-8) and morphological description of pedon 3 (Plate-9) are presented in Table 4.3 unveils that these soils which have developed from the basaltic and limestone materials and moderately shallow, imperfectly drained and clay in texture. The soils were slightly alkaline in reaction and calcareous (strong effervescence at surface and sub surfaces) in nature. The soils were very dark grayish brown (10 YR 3/2M) colour in surface and sub surface. The 2.0 to 2.5 cm wide cracks extended upto the depth of 42 cm. These soils were tentatively classified as members of fine, smectitic (calcareous), hyperthermic family of Vertic Ustochrepts. Now, Ustochrepts are named as Haplustepts as per Soil Survey Staff (2003).

Table 4.3. Site characteristics and morphological properties of pedon-3 (Maljinjava) of Hiran toposequence

A : Site Characteristics

Location	: About ½ km away on South side of Maljinjava village of Talala taluka of Junagadh district.
Latitude & Longitude	: 21 ⁰ 01' N and 70 ⁰ 31' E
Physiographic Unit	: Lower Piedmont (Plate-8)
Climate	: Semi arid (dry)
Slope Gradient	: 1 to 3 per cent
Parent Material	: Basaltic and limestone materials
Drainage & Permeability	: Imperfectly drained soil with slow permeability
Vegetation	: Mango, Neem, Pipal, Khijara, Babul, Coconut, Avad, Bordi, etc. (Appendix-III)
Land Use	: Mostly cultivated in kharif and rabi. The most common crops are groundnut, sorghum, cotton, sugarcane, etc.
Date of Study	: 2 nd May, 2002



Plate - 8 : Site view of lower piedmont area of Hiran toposequence [T 1] .



**Plate - 9 : Cross section of Pedon - 3, Maljinjava [T 1]
Taluka : Talala .**



**Plate - 10 : Cross Section of Pedom - 4 Kajali [T₁]
Taluka : Veraval .**

B : Morphological Properties of Pedon-3 (Plate-9)

Depth (cm)	Horizon	Morphological Features
0-20	Ap	Very Dark grayish brown (10YR 3/2D), very dark grayish (10YR 3/1M), silty clay, medium, strong, subangular blocky structure, dry hard, moist firm, wet sticky and plastic, fine, many roots, strong effervescence, 2 to 2.5 cm wide cracks, clear and smooth boundary (pH 8.11).
20-40	A ₁₂	Dark brown (10YR 4/1D), very dark grayish (10YR 3/1M), silty clay, medium, strong, subangular blocky structure, dry extremely hard, moist firm, wet sticky and very plastic, fine, few roots, strong effervescence, 2 to 2.5 cm wide cracks, clear and smooth boundary (pH 7.87).
40-60	B ₂₁	Dark brown (10YR 4/1D), very dark grayish brown (10YR 3/2M), silty clay, medium, strong, subangular blocky structure, dry extremely hard, moist firm, wet very sticky and very plastic, strong effervescence, clear and smooth boundary (pH 7.94).
60-80	II C ₁	Dark brown (10YR 4/1D), very dark grayish brown (10YR 3/2M), slight effervescence, 2 to 5 mm size lime concretions about 10% by volume, clear and smooth boundary (pH 8.05).

Pedon 4 (Kajali) from the piedmont plain : The site characteristics and morphological properties of the pedon 4 (Plate-10) are presented in Table 4.4 shows that the soils developed from the alluvium parent material very deep, poorly drained and have silty clay loam in texture. The soils were moderately alkaline in reaction and highly calcareous (strong effervescence in surface and

sub surfaces) in nature. The soils were dark brown (10 YR 4/1M) to dark grayish brown (10YR 4/2M) colour in surface and sub surface, respectively. These soils were tentatively classified as members of fine, smectite (calcareous) isohyperthermic family of Fluventic Calciustepts.

Table 4.4. Site characteristics and morphological properties of pedon-4 (Kajali) of Hiran toposequence

A : Site Characteristics

Location	: About ½ km away on West side of Kajali village of Veraval taluka of Junagadh district. (About 1 km away from the Veraval – Kodinar road on South side)
Latitude & Longitude	: 20 ⁰ 53' N and 70 ⁰ 25' E
Physiographic Unit	: Piedmont Plain
Climate	: Semi arid (dry)
Parent Material	: Alluvium
Slope Gradient	: 0 to 1 per cent
Drainage & Permeability	: Poorly drained soil with slow permeability
Vegetation	: Neem, Babul, Pipal, Avad, Bordi, Khakhara, Thorn, Coconut, etc. (Appendix-III)
Land Use	: Groundnut, wheat, black gram, green gram, vegetables, etc.
Date of Study	: 2 nd May, 2002

B : Morphological Properties of Pedon-4 (Plate-10)

Depth (cm)	Horizon	Morphological Features
0-50	Ap	Gray (10YR 5/1D), dark brown (10YR 4/1M), silty clay loam, medium, subangular blocky structure, dry hard, moist friable, wet sticky and plastic, fine, few roots, strong effervescence, clear and smooth boundary (pH 8.35).

50-120	B ₂₁	Grayish brown (10YR 5/2D), dark grayish brown (10YR 4/2M), silty clay loam, medium, subangular blocky structure, dry hard, moist firm, wet sticky and plastic, strong effervescence, clear and smooth boundary (pH 7.91).
120-150	IIC ₁	Light brownish gray (10YR 6/2D), grayish brown (10YR 5/2M), silty clay loam, medium moderate, subangular blocky structure, dry very hard, moist firm, wet sticky and plastic, strong effervescence, fine lime nodules, clear and smooth boundary (pH 7.98).
150-200	IIC ₂	Brown (10YR 4/3D), dark grayish brown (10YR 4/2M), silty clay, medium, moderate, subangular blocky structure, dry hard, moist firm, wet sticky and plastic, strong effervescence, fine lime nodules, clear and smooth boundary (pH 7.92).
200-	IIIC ₃	Pale brown (10YR 6/3D), brown (10YR 5/3M), strong effervescence, 5 to 20 mm size lime nodules 10% by volume, clear and smooth boundary (pH 7.84).

4.1.2 Shingoda Toposequence

The site characteristics and morphological properties of the pedon-5 to 8 are presented in Table 4.5 to 4.8 and Plate 11 to 17.

Pedon 5 (Jamwala) from the upper piedmont : The site characteristics (Plate-11) and morphological properties of pedon 5 (Plate-12) situated at upper piedmont of Shingoda toposequence have developed from weathered basaltic

and lime stone materials (Table 4.5). The soils were moderately shallow, well drained and silty clay loam in texture. The soils were moderately alkaline in reaction and highly calcareous (strong and violent effervescence in surface and sub surface, respectively) in nature. The soils exhibited dark grayish brown (10 YR 4/2M) to very dark grayish brown (10YR 3/2M), respectively. These soils have been tentatively classified as members of fine loamy, smectite (calcareous) hyperthermic family of Typic Ustochrepts.

Table 4.5. Site characteristics and morphological properties of pedon-5 (Jamwala (Gir)) of Shingoda toposequence

A : Site Characteristics

Location	: About 1 km away on West side of Jamwala (Gir) village of Una taluka of Junagadh district. (About 4 km away from Junagadh-Talala road on east side)
Latitude & Longitude	: 20 ⁰ 58' N and 70 ⁰ 46' E
Physiographic Unit	: Upper Piedmont (Plate-11)
Climate	: Semi arid (dry)
Slope Gradient	: 1 to 3 per cent and 3 to 8 per cent
Parent Material	: Weathered basaltic and lime stone material
Drainage & Permeability	: Well drained soil with moderate permeability
Vegetation	: Pipal, Neem, Avad, Babul, Khakhara, Khijara, Bordi, Mango, etc. (Appendix-III)
Land Use	: Mostly cultivated in kharif and rabi. Most common crops are groundnut, pearl millet, sugarcane, wheat, etc.
Date of Sampling	: 2 nd May, 2002



Plate - 11 : Site view of upper piedmont area of Shingoda toposequence [T₂] .

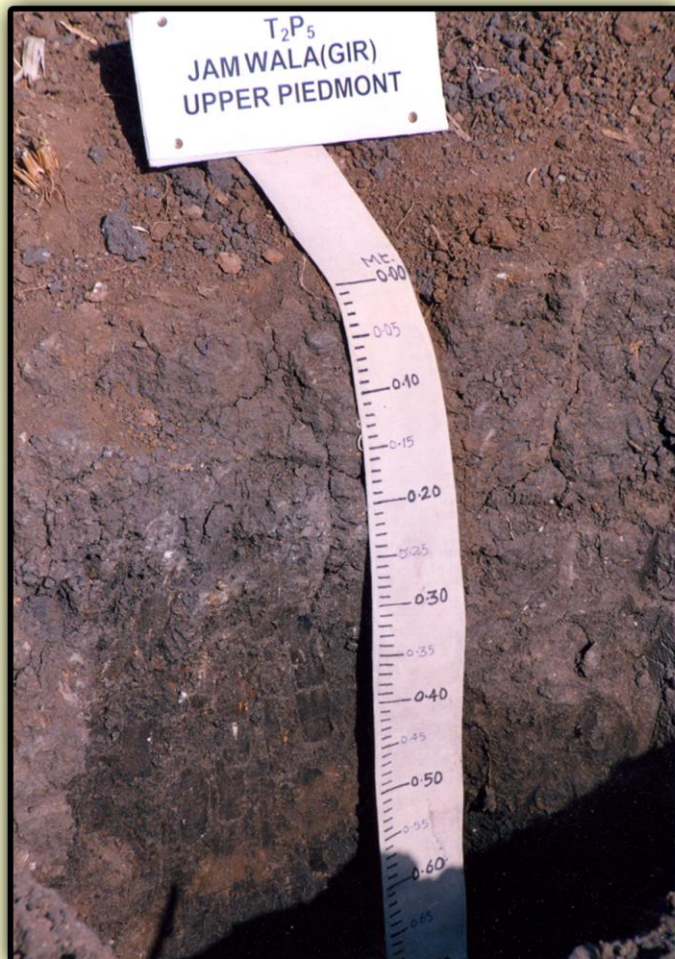


Plate - 12 : Cross section of Pedon - 5 , Jamwala [Gir] [T₂] , Taluka : Una .

B : Morphological Properties of Pedon-5 (Plate-12)

Depth (cm)	Horizon	Morphological Features
0-25	Ap	Brown (10YR 4/3D), dark grayish brown (10YR 4/2M), silty clay loam, medium, strong, subangular blocky structure, dry very hard, moist firm, wet very sticky and very plastic, fine common roots, strong effervescence, clear and smooth boundary (pH 8.05).
25-55	B ₂₁	Dark gray (10YR 4/1D), very dark grayish brown (10YR 3/2M), silty clay loam, medium, strong, subangular blocky structure, dry very hard, moist firm, wet very sticky and very plastic, few very fine roots, violent effervescence, clear and smooth boundary (pH 8.17).
55-65	BC	Brown (10YR 4/3D), dark gray (10YR 4/1M), violent, effervescence, 2 to 7 cm size lime concretions about 5 to 6% by volume, clear and smooth boundary (pH 8.19).

Pedon 6 (Kareda) form the lower piedmont : The site characteristics (Plate-13) and morphological properties of pedon 6 (Plate-14) situated on lower piedmont given in Table 4.6. These soils have developed from the basaltic parent material, moderately shallow, well drained and all have silty loam in texture. The soils were moderately alkaline in reaction and highly calcareous (strong effervescence in surface and sub surface) in nature. The soils exhibit dark grayish brown (10 YR 4/2M) to dark grayish brown (10 YR 3/2M) colour in surface and sub surface, respectively. These soils have been tentatively classified as members of coarse loamy, smectite (calcareous) hyperthermic family of Typic Ustorthents at sub group level.

Table 4.6. Site characteristics and morphological properties of pedon-6 (Kareda) of Shingoda toposequence

A : Site Characteristics

Location	: About 1½ km away on East side of Kareda village of Kodinar taluka of Junagadh district. (About 1 km away from Kodinar-Jamwala road on east side)
Latitude & Longitude	: 20°47' N and 70°46' E
Physiographic Unit	: Lower Piedmont (Plate-13)
Climate	: Semi arid (dry)
Slope Gradient	: 1 to 3 per cent
Parent Material	: Basaltic material
Drainage & Permeability	: Well drained soil with moderate permeability
Vegetation	: Pipal, Neem, Avad, Babul, Khakhara, Bordi, Khijaea, etc. (Appendix-III)
Land Use	: Mostly cultivated in kharif and rabi. Most common crops are groundnut, pearl millet, cotton, sorghum, sesame, sugarcane, wheat and vegetables.
Date of Study	: 3 rd May, 2002

B : Morphological Properties of Pedon-6 (Plate-14)

Depth (cm)	Horizon	Morphological Features
0-20	Ap	Yellowish brown (10YR 5/4D), dark grayish brown (10YR 4/2M), silty loam, medium, moderate, subangular blocky structure, dry hard, moist friable, wets lightly sticky and slightly plastic, fine, common roots, strong effervescence, clear and smooth boundary (pH 8.10).



Plate - 13 : Site view of lower piedmont area of Shingoda toposequence [T ₂] .



Plate - 14 : Cross section of Pedon - 6 , Kareda [T ₂] , Taluka : Kodinar .

		20-40 A ₁₂ Pale brown (10YR 6/3D), dark grayish brown (10YR 3/2M), silty loam, medium moderate, subangular blocky structure, dry slightly hard, moist friable, wet slightly sticky and slightly plastic, very fine roots, strong effervescence, clear and smooth boundary (pH 8.23).
40-60	AC	Light gray (10YR 7/2D), brown (10YR 5/3M), weathered basalt with milliolite lime stone material, strong effervescence, medium basalt fragments with 2 to 7 cm size lime concretions 20 to 25 % by volume, clear and smooth boundary (pH 8.13).

Pedon 7 (Devali) from the piedmont plain : The site characteristics (Plate-15) and morphological properties on pedon 7 (Plate-16) situated on piedmont plain are depicted in Table 4.7 explicates that the soils have developed from alluvium parent material moderately deep, well drained and silty clay loam texture. The soils were moderately alkaline in reaction and highly calcareous (strongly effervescence in surface and sub surface) in nature. The soils have dark grayish brown (10 YR 4/2M) to (10YR 3/2M) colour in surface and sub surface, respectively. These soils have been tentatively classified as members of fine loamy, smectite (calcareous), isohyperthermic family of Typic Ustropepts. Now, Ustropepts are named as Haplustepts (Iso-hyperthermic) as per Soil Survey Staff (2003).

Table 4.7. Site characteristics and morphological properties of pedon-7 (Devali) of Shingoda toposequence

A : Site Characteristics

Location : About 3 km away on East side of Devali village of Kodinar taluka of Junagadh district. (About 2 km away from Kodinar-Una road on north side)



Plate - 15 : Site view of piedmont plain area of Shingoda toposequence [T₂] .

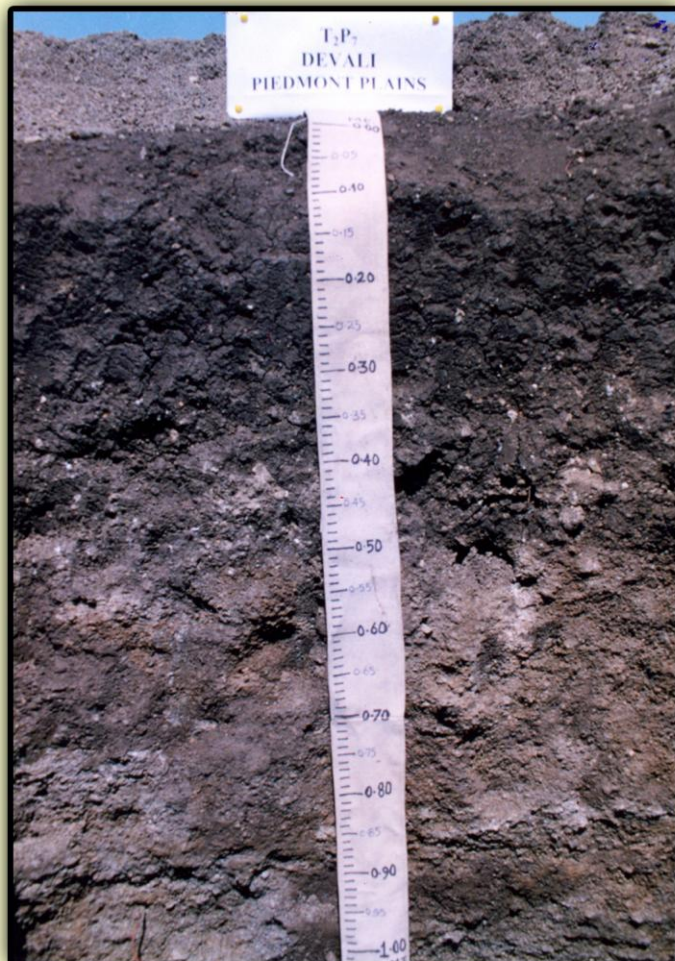


Plate - 16 : Cross section of Pedon - 7, Devali [T₂] , Taluka : Kodinar .

	Latitude & Longitude	: 20 ⁰ 46' N and 70 ⁰ 45' E
Physiographic Unit	:	Piedmont Plain (Plate-15)
Climate	:	Semi arid (dry)
Parent Material	:	Alluvium
Slope Gradient	:	Less than 1 per cent
Drainage & Permeability	:	Moderately well drained soil with moderately rapid permeability.
Vegetation	:	Babul, Neem, Pipel, Piludi, Thor, Bordi, Avad, Akado, Mango, etc. (Appendix-III)
Land Use	:	Mostly cultivated in kharif and rabi. Most common crops are groundnut, pearl millet, sugarcane, wheat, etc.
Date of Study	:	3 rd May, 2002

B: Morphological Properties of Pedon-7 (Plate-16)

Depth (cm)	Horizon	Morphological Features
0-27	Ap	Brown (10YR 4/3D), dark grayish brown (10YR 4/2M), silty clay loam, medium, moderate, subangular blocky structure, dry hard, moist friable, wet sticky and plastic, common fine roots, strong effervescence, clear and smooth boundary (pH 8.30).
27-35	B ₂₁	Brown (10YR 4/3D), dark grayish brown (10YR 3/2M), silty clay loam, medium, moderate, subangular blocky structure, dry hard, moist firm, wet sticky and plastic, few, very fine roots, strong effervescence, clear and smooth boundary (pH 8.21).
35-63	IIC ₁	Grayish brown (10YR 5/2D), dark grayish brown (10YR 4/2M), clay loam, medium

		moderate, subangular blocky structure, dry slightly hard, moist firm, wet slightly sticky and slightly plastic, few, very fine roots, strong effervescence, fine lime nodules, clear and smooth boundary (pH 8.26).
63-85	IIC ₂	Light grayish brown (10YR 6/2D), brown (10YR 4/3M), loam, medium moderate, subangular blocky structure, dry hard, moist firm, wet slightly sticky and non plastic, strong effervescence, fine lime nodules, clear and smooth boundary (pH 8.31).
85-110	IIIC ₃	Light gray (10YR 7/2D), grayish brown (10YR 5/2M), strong effervescence, 1 to 5 mm size white soft powdery lime concretions about 5 to 6 % by volume, clear and smooth boundary (pH 7.89).

Pedon 8 (Chauhani Khan) from coastal plain : The site characteristics and morphological properties of pedon 8 (Plate-17) are presented in Table 4.8 pointout that the soils have developed from alluvium. These soils were imperfectly drained and have silty loam to silty clay loam texture, moderately alkaline in reaction and highly calcareous (strong effervescence in surface and sub surface). The soils have (10 YR 5/3M) colour in surface and sub surface. These soils have been tentatively classified as members of fine loamy, smectite (calcareous), isohyperthermic family of Fluventic Ustropepts.



**Plate - 17 : Cross Section of Pedom - 8, Chauhani Khan
[T 2] , Taluka : Kodinar .**

Table 4.8. Site characteristics and morphological properties of pedon-8 (Chauhani Khan) of Shingoda toposequence

A : Site Characteristics

Location	:	About ½ km away on East side of Chauhani Khan village of Kodinar taluka of Junagadh district. (About ½ km away from Kodinar-Mul Dwarka road on west side)
Latitude & Longitude	:	20 ⁰ 45' N and 70 ⁰ 46' E
Physiographic Unit	:	Coastal Plain
Climate	:	Semi arid (dry)
Parent Material	:	Alluvium
Slope Gradient	:	Less than 1 per cent
Drainage & Permeability	:	Imperfectly drained soil with slow permeability
Vegetation	:	Babul, Neem, Pipal, Piludi, Thor, Bordi, Avad, Akado, etc. (Appendix-III)
Land Use	:	Mostly cultivated in kharif and rabi. Most common crops are groundnut, sugarcane, wheat, pearl millet etc.
Date of Study	:	3 rd May, 2002

B : Morphological Properties of Pedon-8 (Plate-17)

Depth (cm)	Horizon	Morphological Features
0-25	Ap	Yellowish brown (10YR 5/4D), brown (10YR 5/3M), silty loam, medium, moderate, sub-angular blocky structure, dry slightly hard, moist friable, wet slightly sticky and slightly plastic, common, fine roots, strong effervescence, clear and smooth boundary (pH 8.05).
25-35	B ₂₁	Yellowish brown (10YR 5/4D), brown (10YR 5/3M), silty loam, medium, moderate, sub-angular blocky structure, dry hard, moist friable, wet sticky and slightly plastic, few, very fine

		roots, strong effervescence, clear and smooth boundary (pH 8.06).
35-70	B ₂₂	Brown (10YR 5/3D), dark yellowish brown (10YR 4/4M), silty clay loam, medium, moderate, subangular blocky structure, dry hard, moist friable, wet sticky and slightly plastic, few, very fine roots, slight effervescence, clear and smooth boundary (pH 7.99).
70-120	IIC ₁	Brown (10YR 5/3D), dark grayish brown (10YR 4/2M), silty clay loam, medium, moderate, subangular blocky structure, dry hard, moist friable, wet sticky and slightly plastic, slight effervescence, very fine lime nodules, clear and smooth boundary (pH 8.02).
120-145	IIC ₂	Brown (10YR 5/3D), dry and dark grayish brown (10YR 4/2M), slight effervescence, 1 to 5 mm size lime concretions 1 to 2% by volume, clear and smooth boundary (pH 8.21).

4.1.3 Machhundri Toposequence

The site characteristics and morphological properties of the pedon-9 to 12 are depicted in Table 4.9 to 4.12 and Plate 18 to 25.

Pedon 9 (Fatsar) from upper piedmont : The site characteristics (Plate-18) and morphological properties of pedon 9 (Plate-19) situated on upper piedmont are given in Table 4.9. The soils have developed from weathered basaltic parent material, shallow, well drained and clayey in texture. The soils were moderately alkaline in reaction and highly calcareous (strong effervescence in surface and sub surface). These soils exhibit dark gray (10 YR 4/1M) to dark brown (10 YR 3/3M) colour in surface and sub surface, respectively. The soils

have been tentatively classified as members of fine, smectite (calcareous) hyperthermic family of Lithic Usorthents.

Table 4.9. Site characteristics and morphological properties of pedon-9 (Fatsar) of Machhundri toposequence

A : Site Characteristics

Location	: About ½ km South of Fatsar village of Una taluka of Junagadh district. (About 5 km away from Jamwala-Una road on east side)
Latitude & Longitude	: 20°54' N and 70°51' E
Physiographic Unit	: Upper Piedmont (Plate-18)
Climate	: Semi-arid (dry)
Slope Gradient	: 0 to 1 per cent and 1 to 3 per cent
Parent Material	: Weathered basaltic material
Drainage & Permeability	: Well drained soil with moderately slow permeability
Vegetation	: Babul, Bordi, Khakhra, Thor, Mango, etc. (Appendix-III)
Land Use	: Mostly cultivated in kharif and rabi. The most common crops are groundnut, wheat, pearl millet, cotton, cumin, etc.
Date of Study	: 5 th May, 2002



Plate - 18 : Site view of upper piedmont area of Machhundri toposequence [T₃] .



Plate - 19 : Cross section of Pedon - 9, Fatsar [T₃] , Taluka : Una .

B : Morphological Properties of Pedon-9 (Plate-19)

Depth (cm)	Horizon	Morphological Features
0-20	Ap	Dark grayish brown (10YR 4/2D), dark gray (10YR 4/1M), clayey, medium, moderate, sub- angular blocky structure, dry hard, moist friable, wet sticky and plastic, common fine roots, slight effervescence, clear and smooth boundary (pH 8.12).
20-27	A ₁₂	Dark gray (10YR 4/1D), dark brown (10YR 3/3M), clayey, medium, moderate, subangular blocky structure, dry hard, moist friable, wet slightly sticky and slightly plastic, common fine roots, slight effervescence, clear and smooth boundary (pH 8.13).
27-35	AC	Brown (10YR 4/3D), dark grayish brown (10YR 4/2M), slight effervescence, 1 to 5 mm size lime concretions about 1 to 2% volume, clear and smooth boundary (pH 8.16).
35+	R	Hard unconsolidated basalt rock

Pedon 10 (Judavadali) from lower piedmont : The site characteristics (Plate-20) and morphological properties of pedon 10 (Plate-21) are presented in Table 4.10 denote that the soils have developed from weathered basaltic and lime stone material. The soils were moderately shallow, moderately well drained and silty clay loam texture. The soils of this pedon were moderately alkaline in reaction and highly calcareous (strong effervescence in surface and sub surfaces). These soils have dark brown (10 YR 3/3M) colour in surface and sub surface layers. The soils were tentatively classified as members of fine loam, smectite (calcareous), hyperthermic family of Typic Ustochrepts.

Table 4.10. Site characteristics and morphological properties of pedon-10 (Judavadali) of Machhundri toposequence

A : Site Characteristics

Location	:	About 1 km West side of Judvadali village of Una taluka of Junagadh district. (About 1 km away from Jamwala-Una road on east side)
Latitude & Longitude	:	20 ⁰ 53' N and 70 ⁰ 52' E
Physiographic Unit	:	Lower Piedmont (Plate-20)
Climate	:	Semi arid (dry)
Slope Gradient	:	0 to 1 per cent and 1 to 3 per cent
Parent Material	:	Weathered basaltic and lime stone material
Drainage & Permeability	:	Moderately well drained soil with moderately slow permeability.
Vegetation	:	Babul, Bordi, Khakhra, Tadi, Pipal, etc. (Appendix-III)
Land Use	:	Mostly cultivated in kharif and rabi. The most common crops are groundnut, sugarcane, wheat, sorghum, pearl millet, etc.
Date of Study	:	5 th May, 2002.

B : Morphological Properties of Pedon-10 (Plate-21)

Depth (cm)	Horizon	Morphological Features
0-18	Ap	Dark grayish brown (10YR 4/2D), dark brown (10YR 3/3M), silty clay loam, medium, moderate, subangular blocky structure, dry hard, moist friable, wet sticky and plastic, common fine roots, strong effervescence, clear and smooth boundary (pH 8.21).



Plate - 20 : Site view of lower piedmont area of Machhundri toposequence [T₃] .

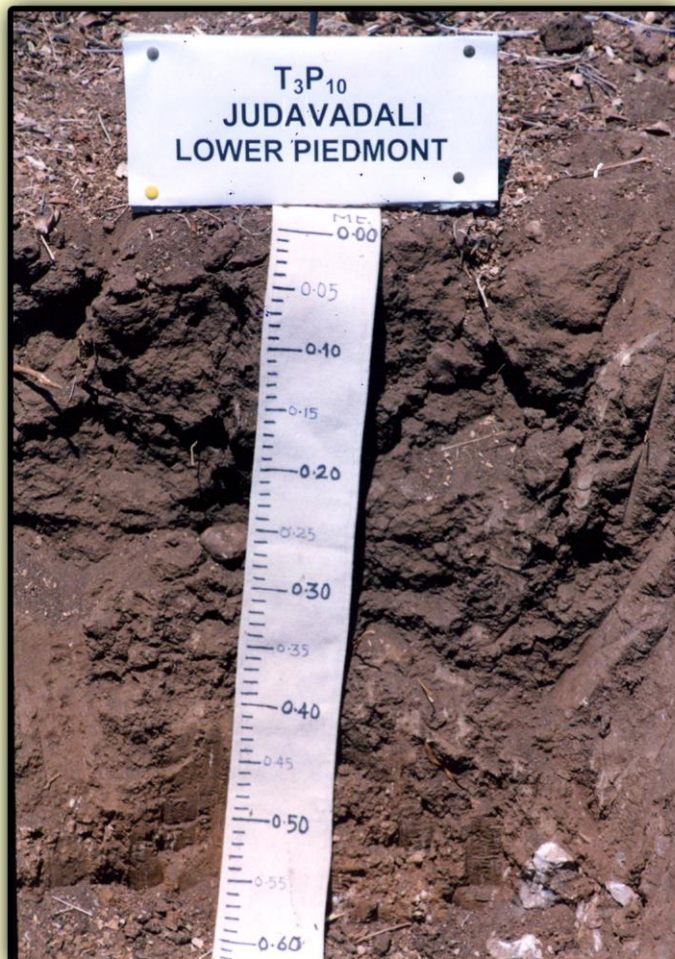


Plate - 21 : Cross section of Pedon - 10, Judavadali [T₃], Taluka : Una .

	18-35	B ₂₁	Dark yellowish brown (10YR 4/4D), dark brown (10YR 3/3M), silty clay loam, medium, moderate, subangular blocky structure, dry very hard, moist firm, wet very sticky and plastic, common fine roots, violent effervescence, clear and smooth boundary (pH 8.17).
	35-45	B ₂₂	Dark yellowish brown (10YR 4/4D), dark yellowish brown (10YR 3/4M), silty clay loam, medium, moderate, subangular blocky structure, dry hard, moist firm, wet very sticky and plastic, few, very fine roots, violent effervescence, clear and smooth boundary (pH 8.14).
	45-55	BC	Yellowish brown (10YR 5/6D), dark yellowish brown (10YR 4/4M), violent effervescence, 3 to 4 cm size lime concretions about 20 to 25% by volume, clear and smooth boundary (pH 8.10).

Pedon 11 (Delawada) from piedmont plain : The site characteristics (Plate-22) and morphological properties of pedon 11 (Plate-23) are depicted in Table 4.11 indicate that the soils were deep, poorly drained and have clay loam to silty clay loam texture. These soils were moderately alkaline in reaction and highly calcareous (strong effervescence in surface and sub surface). These soils exhibit dark brown (10 YR 3/3M) colour in surface and sub surface. These soils have been tentatively classified as members of fine loam, smectite (calcareous) isohyperthermic family of Fluventic Ustropepts.

Table 4.11. Site characteristics and morphological properties of pedon-11 (Delawada) of Machhundri toposequence

A : Site Characteristics

Location	:	About 1 km East side of Delwada village of Una taluka of Junagadh district. (About 5 km away from Una-Nava Bandar road on east side)
Latitude & Longitude	:	20 ⁰ 46' N and 71 ⁰ 80' E
Physiographic Unit	:	Piedmont Plain
Climate	:	Semi arid (dry)
Slope Gradient	:	0 to 1 per cent
Parent Material	:	Alluvium
Drainage & Permeability	:	Poorly drained soil with slow permeability.
Vegetation	:	Bordi, Tad, Babul, Khakhra, Saragavo, Avad, Neem, Coconut, etc. (Appendix-III)
Land Use	:	Mostly cultivated in kharif and rabi. The most common crops are groundnut, pearl millet, cotton, maize and banana.
Date of Study	:	4 th May, 2002.

B : Morphological Properties of Pedon-11 (Plate-23)

Depth (cm)	Horizon	Morphological Features
0-20	Ap	Brown (10YR 5/3D), dark brown (10YR 3/3M), clay loam, medium, strong, subangular blocky structure, dry hard, moist firm, wet sticky and slightly plastic, fine roots, slight effervescence, clear and smooth boundary (pH 8.33).
20-35	B ₂₁	Brown (10YR 5/3D), dark brown (10YR 3/3M), silty clay loam, medium, moderate, subangular blocky structure, dry hard, moist friable, wet sticky and plastic, few fine roots, slight



Plate - 22 : Site view of piedmont plain area of Machhundri toposequence [T₃] .

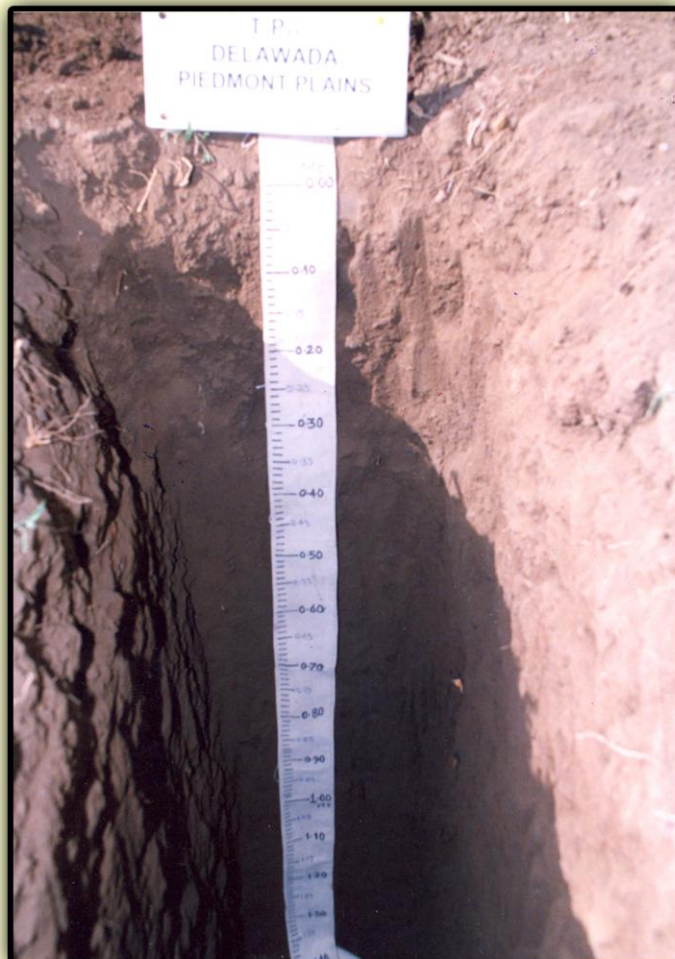


Plate - 23 : Cross section of Pedon - 11, Delawada [T₃], Taluka : Una .

		effervescence, clear and smooth boundary (pH 8.35).
35-60	IIC ₁	Brown (10YR 5/3D), dark brown (10YR 3/3M), silty clay loam, medium, moderate, subangular blocky structure, dry hard, moist firm, wet sticky and slightly plastic, slight effervescence, very fine lime nodule, clear and smooth boundary (pH 8.22).
60-85	IIC ₂	Brown (10YR 5/3D), dark grayish (10YR 4/2M), silty clay loam, medium, moderate, subangular blocky structure, dry hard, moist firm, wet slightly sticky and slightly plastic, slight effervescence, very fine lime nodules, clear and smooth boundary (pH 8.18).
85-140	IIIC ₃	Brown (10YR 5/3D), dark brown (10YR 4/3D), silty clay loam, slight effervescence, 1 to 5 mm size lime concretions 1 to 2% by volume, clear and smooth boundary (pH 8.22).

Pedon 12 (Rampara) from coastal plain : The site characteristics (Plate-27) and morphological properties of pedon 12 (Plate-25) are depicted Table 4.12 insinuated that the soils of this pedon have developed from alluvium. The soils were deep, poorly drained and silty clay loam to silty loam in texture. These soils were moderately alkaline in reaction and highly calcareous (strong effervescence in surface and sub surface). These soils have dark grayish brown (10 YR 4/2M) colour throughout the profile. These soils have been tentatively classified as members of fine loamy, smectite (calcareous), isohyperthermic family of Fluventic Ustropepts.

Table 4.12. Site characteristics and morphological properties of pedon-12 (Rampara) of Machhundri toposequence

A : Site Characteristics

Location	: About ½ km West side of Rampara village of Una taluka of Junagadh district. (About 1 km away from Jamvala-Una road on east side)
Latitude & Longitude	: 20 ⁰ 44' N and 70 ⁰ 90' E
Physiographic Unit	: Coastal Plain (Plate-24)
Climate	: Semi arid (dry)
Parent Material	: Alluvium
Slope Gradient	: 0 to 1 per cent
Drainage & Permeability	: Imperfectly drained soil with moderately slow permeability
Vegetation	: Babul, Khakhra, Bordi, Tad, Neem, Avad, Coconut, Mango, etc. (Appendix-III)
Land Use	: Mostly cultivated in kharif and rabi. The most common crops are groundnut, pearl millet, cotton, sesame, wheat, banana.
Date of Study	: 4 th May, 2002.

B : Morphological Properties of Pedon-12 (Plate-25)

Depth (cm)	Horizon	Morphological Features
0-20	Ap	Brown (10YR 5/3D), dark grayish brown (10YR 4/2M), silty clay loam, medium, strong, subangular blocky structure, dry very hard, moist very firm, wet sticky and plastic, few fine roots, slight effervescence, clear and smooth boundary (pH 8.11).



Plate - 24 : Site view of coastal plain area of Machhundri toposequence [T₃] .



Plate - 25 : Cross section of Pedon - 12 , Rampara [T₃] , Taluka : Una .

		20-45 B ₂₁ Brown (10YR 5/3D), dark grayish brown (10YR 4/2M), silty clay loam, medium, moderate, subangular blocky structure, dry hard, moist firm, wet sticky and plastic, very few fine roots, strong effervescence, clear and smooth boundary (pH 8.20).
45-70	B ₂₂	Brown (10YR 5/3D), dark grayish brown (10YR 4/2M), silty loam, medium, moderate, subangular blocky structure, dry hard, moist firm, wet slightly sticky and slightly plastic, strong effervescence, clear and smooth boundary (pH 8.26).
70-90	IIC ₁	Brown (10YR 5/3D), dark grayish brown (10YR 4/2M), loam, medium moderate, subangular blocky structure, dry slightly hard, moist firm, wet slightly sticky and slightly plastic, strong effervescence, fine lime nodules, clear and smooth boundary (pH 8.48).
90-115	IIC ₂	Brown (10YR 5/3D), dark grayish brown (10YR 4/2M), clay loam, medium, moderate, subangular blocky structure, dry hard, moist firm, wet slightly sticky and slightly plastic, strong effervescence, fine lime nodules, clear and smooth boundary (pH 8.62).
115-143	IIC ₃	Brown (10YR 5/3D), dark grayish brown (10YR 4/2M), silty loam, strong effervescence, 5 to 10 mm size lime concretion, about 5 to 6% by volume, clear and smooth boundary (pH 8.60).

4.1.4 Rayadi Toposequence

The site characteristics and morphological features of the pedon-13 to 16 are presented in Table 4.13 to 4.16 and Plate 26 to 33.

Pedon-13 (Dedan) from hill slope : The site characteristics (Plate-26) and morphological properties of the soils associated with pedon 13 (Plate-27) are shown in Table 4.13 indicates that the soils of this pedon have developed from weathered basaltic materials. These soils were shallow, excessively drained, silty clay loam (skeletal) soils occurring on moderately sloping side slopes. They were moderately alkaline in reaction and non calcareous (no effervescence). The soils exhibit dark yellowish brown (10 YR 3/4M) colour in surface. These soils have been tentatively classified as members of fine loamy skeletal, mixed, hyperthermic family of Lithic Ustorthents.

Table 4.13. Site characteristics and morphological properties of pedon-13 (Dedan) of Rayadi toposequence

A : Site Characteristics

Location	: About ½ km West side of Dedan village of Khambha taluka of Amreli district. (About ½ km away from Dedan-Jamaka road on north side)
Latitude & Longitude	: 21 ⁰ 03' N and 71 ⁰ 19' E
Physiographic Unit	: Hill slope (Plate-26)
Climate	: Semi arid (dry)
Parent Material	: Weathered basaltic material
Slope Gradient	: 8 to 15 per cent
Drainage & Permeability	: Well drained soil with moderate permeability
Vegetation	: Babul, Bordi, Neem, Khakhara, Khijara, Pipal, Avad, etc. (Appendix-III)
Land Use	: Grass land uncultivated
Date of Sampling	: 21 st May, 2002.



Plate - 26 : Site view of hill slope of Rayadi toposequence [T 4] .



Plate - 27 : Cross section of Pedon - 13 , Dedan [T 4] , Taluka : Khambha .

B : Morphological Properties of Pedon-13 (Plate-27)

Depth (cm)	Horizon	Morphological Features
0-15	A ₁₁	Dark yellowish brown (10YR 4/4D), dark yellowish brown (10YR 3/4M), silty clay loam, medium, weak, subangular blocky structure, dry slightly hard, moist very friable, wet slightly sticky and slightly plastic, common fine roots, clear and smooth boundary (pH 7.88).
15-28	AC	Dark yellowish brown (10YR 4/4D), dark brown (10YR 3/3M), clay loam, 2.5 to 7.5 cm size coarse basalt about 40% by volume, clear and smooth boundary (pH 7.86).

Pedon 14 (Dedan) from upper piedmont : The site characteristics (Plate-28) and morphological features of pedon 14 (Plate-29) are depicted in Table 4.14 implies that the soils of this pedon have developed from weathered basaltic material. The soils were shallow, well drained and silty clay texture. The soils were moderately alkaline in reaction and slightly calcareous (slight effervescence in surface and sub surface). These soils were dark brown (10 YR 3/3M) in colour throughout the profile. These soils were tentatively classified as members of fine clayey, smectite (calcareous), hyperthermic family of Lithic Ustrothents.

Table 4.14. Site characteristics and morphological properties of pedon-14 (Dedan) of Rayadi toposequence

A : Site Characteristics

Location : About ½ km South side of Dedan village of Khambha taluka of Amreli district. (About ½ km away from Jafrabad-Amreli road on north side)



Plate - 28 : Site view of upper piedmont area of Rayadi toposequence [T 4] .



Plate - 29 : Cross section of Pedon - 14 , Dedan [T 4] , Taluka : Khambha .

Latitude & Longitude	: 21 ⁰ 03' N and 71 ⁰ 19' E
Physiographic Unit	: Upper Piedmont (Plate-28)
Parent Material	: Weathered basaltic material
Slope Gradient	: 3 to 8 per cent
Drainage & Permeability	: Well drained soil with moderately slow permeability.
Vegetation	: Babul, Bordi, Neem, Khakhara, Khijara, Pipal, etc. (Appendix-III)
Land Use	: Mostly cultivated in kharif and rabi. Most common crops are groundnut, cotton, wheat, cumin.
Date of Study	: 21 st May, 2002.

B : Morphological Properties of Pedon-14 (Plate-28)

Depth (cm)	Horizon	Morphological Features
0-17	Ap	Dark grayish brown (10YR 4/2D), dark brown (10YR 3/3M), silty clay, medium, subangular blocky structure, dry very hard, moist firm, wet sticky and plastic, common fine roots, slight effervescence, clear and smooth boundary (pH 8.11).
17-33	A ₁₂	Dark grayish brown (10YR 4/2D), dark brown (10YR 3/3M), silty clay, medium moderate, sub angular blocky structure, dry hard, moist firm, wet sticky and plastic, few very fine roots, slight effervescence, clear and smooth boundary (pH 8.14).
33-40	AC	Dark grayish brown (10YR 4/2D), dark brown (10YR 3/3M), silty clay loam, slight effervescence, 1 to 5 m size lime concretion about 1 to 2% by volume, clear and smooth boundary (pH 8.17).

Pedon 15 (Chotara) from lower piedmont : The site characteristics (Plate-30) and morphological properties of pedon 15 (Plate-31) are depicted in Table 4.15 stipulate that the soils of this pedon have developed from basaltic parent material. The soils were moderately deep, imperfectly drained and silty clay in texture. These soils were moderately alkaline in reaction and slightly calcareous (slight effervescence in surface and sub surface). These soils exhibit dark brown (10 YR 3/3M) colour throughout the profile and cracks, 2 to 3 cm wide were observed upto depth of 40 cm. These soils were tentatively classified as members of fine, smectite (calcareous), hyperthermic family of Vertic Ustochrepts.

Table 4.15. Site characteristics and morphological properties of pedon-15 (Chotara) of Rayadi toposequence

A : Site Characteristics

Location	: About 1 km on West side of Chotara village of Rajula taluka of Amreli district. (About 1 km away from Khambha-Jafrabad road on west side)
Latitude & Longitude	: 21 ⁰ 02' N and 71 ⁰ 26' E
Physiographic Unit	: Lower Piedmont (Plate-30)
Climate	: Semi arid (dry)
Parent Material	: Basaltic material
Slope Gradient	: 1 to 3 per cent
Drainage & Permeability	: Imperfectly drained soil with slow permeability
Vegetation	: Babul, Khijara, Avad, Neem, Pipal, Khakhara, Saragavo, etc. (Appendix-III)



Plate - 30 : Site view of lower piedmont area of Rayadi toposequence [T 4] .



Plate - 31 : Cross section of Pedon - 15 , Chotara [T 4] , Taluka : Rajula .

Land Use : Mostly cultivated in kharif and rabi. Most common crops are groundnut, pearl millet, cotton, wheat, sesamum, sorghum, etc.

Date of Study : 21st May, 2002.

B : Morphological Properties of Pedon-15 (Plate-31)

Depth (cm)	Horizon	Morphological Features
0-18	Ap	Dark grayish brown (10YR 4/2D), dark brown (10YR 3/3M), silty clay, medium, moderate, subangular blocky structure, dry very hard, moist firm, wet sticky and slightly plastic, 2 to 3 cm wide cracks, fine few roots, slight effervescence clear and smooth boundary (pH 8.27).
18-45	B ₂₁	Dark yellowish brown (10YR 4/4D), dark brown (10YR 3/3M), silty clay, medium, strong, subangular blocky structure, dry very hard, moist firm, wet very sticky and plastic, 2 to 3 cm wide cracks, few very fine roots, slight effervescence clear and smooth boundary (pH 8.23).
45-65	IIC ₁	Dark yellowish brown (10YR 4/4D), dark brown (10YR 3/3M), silty clay, medium, strong, subangular blocky structure, dry very hard, moist firm, wet very sticky and plastic, clear and smooth boundary (pH 8.21).
65-85	IIC ₂	Dark yellowish brown (10YR 4/4M), dark brown (10YR 3/3M), silty clay, fine basalt, clear and smooth boundary (pH 8.14).

Pedon 16 (Kadiyali) from coastal plain : The site characteristics (Plate-3) and morphological properties of pedon-16 (Plate-33) are presented in Table 4.16 unveils that the soils of this pedon have developed from alluvium. These soils were moderately deep, poorly drained and silty loam to silty clay loam texture. These soils were moderately alkaline in reaction and very highly calcareous (strong effervescence in surface and sub surface). These soils exhibit dark gray (10 YR 4/1M) colour throughout the solum of profile. These soils were tentatively classified as members of fine loamy, smectite (calcareous), isohyperthermic family of Calcic Ustropepts.

Table 4.16. Site characteristics and morphological properties of pedon-16 (Kadiyali) of Rayadi toposequence

A : Site Characteristics

Location	: About 1 km on West side of Kadiyali village of Jafrabad taluka of Amreli district. (About ½ km away from Jafrabad-Amreli road on west side)
Latitude & Longitude	: 20 ⁰ 55' N and 71 ⁰ 23' E
Physiographic Unit	: Coastal plain (Plate-32)
Climate	: Semi arid (dry)
Parent Material	: Alluvium
Slope Gradient	: 0 to 1 per cent
Drainage & Permeability	: Poorly drained soil with very slow permeability
Vegetation	: Babul, Khijara, Gunda, Avad, Neem, Wad, Saragavo, etc. (Appendix-III)
Land Use	: Mostly cultivated in kharif and rabi. Most common crops are groundnut, pearl millet, cotton, wheat, sesamum, sorghum, etc.
Date of Study	: 21 st May, 2002.



Plate - 32 : Site view of coastal plain area of Rayadi toposequence [T 4] .



Plate - 33 : Cross section of Pedon - 16 , Kadiyali [T 4] , Taluka : Jafraabad .

B : Morphological Properties of Pedon-16 (Plate-33)

Depth (cm)	Horizon	Morphological Features
0-18	Ap	Gray (10YR 5/1D), gray (10YR 4/1M), silty loam, medium, moderate. subangular blocky structure, dry hard, moist firm, wet sticky and slightly plastic, fine few roots, strong effervescence, clear and smooth boundary (pH 8.73).
18-38	B _{21ck}	Gray (10YR 5/1D), dark gray (10YR 4/1M), clay loam, medium strong, subangular blocky structure, dry very hard, moist firm, wet very sticky and plastic, few very fine roots, strong effervescence, clear and smooth boundary (pH 8.62).
38-50	B _{22ck}	Gray (10YR 5/1D), dark gray (10YR 4/1M), clay loam, medium, strong, subangular blocky structure, dry very hard, moist firm, wet very sticky and very plastic, violent effervescence, clear and smooth boundary (pH 8.56).
50-70	B _{23ck}	Gray (10YR 5/1D), dark gray (10YR 4/1M), loam, medium, strong, subangular blocky structure, dry hard, moist firm, wet sticky and plastic, violent effervescence, clear and smooth boundary (pH 8.56).
70-100	BC _{ck}	Light gray (10YR 7/1D), grayish brown (10YR 5/2M), loam, violent effervescence, 2 to 7 cm size lime nodules about 25 to 30% by volume, clear and smooth boundary (pH 8.53).

4.1.5 Land Slopes

The general morphological features in different land slopes of southern Saurashtra have been derived from the Table 4.1 to 4.16 and described below.

(i) Soil depth : The increase in soil depth was witnessed from hill slope to the coastal plain. The soils of pedons P₁ and P₁₃ of the hill slope (LS-1) were shallow indicating the soils were less developed as there was a little chance. Deshmukh and Bapat (1993) also found that the soils at higher elevation are less developed as compared to lower elevation of land scape. The soils of pedons P₂, P₅, P₉ and P₁₄ of upper piedmont (LS-2) were moderately deep to deep while the pedons P₃, P₆, P₁₀ and P₁₅ of lower piedmont (LS-3) were deep. The soils of pedons P₄, P₇ and P₁₁ of piedmont plain (LS-4) and pedons P₈, P₁₂ and P₁₆ of coastal plain (LS-5) were very deep. Similar observations have been made by Velayutham *et al.* (1999) and Mandal *et al.* (2003). Number of studies showed that soil depth in a toposequences found to be related with slope (Gaikwad *et al.*, 1974; Sharma and Roychowdhury, 1988 and Prasad *et al.*, 1989).

(ii) Soil slope : Soil slope influences soil formation primarily through its effects upon drainage, runoff and erosion and secondary through variations in exposure to the sun, wind and in air drainage. There was wide variation in the slope gradient. The slope gradient in side slope, gently sloping, very gently sloping and nearly leveled plain areas were 8-15, 3-8, 1-3 and 0-1 per cent, respectively. The pedons P₁ and P₁₃ of hill slope (LS-1) developed on side slope. The soils of upper piedmont (LS-2) have developed on gently sloping (P₁₄), very gently to gently sloping (P₅), very gently sloping (P₂) and nearly level to gently sloping (P₉). While the soils of lower piedmont (LS-3) have developed on very gently sloping (P₃ and P₁₅) and nearly leveled to very gently sloping (P₆ to P₁₀). The soils of piedmont plain (LS-4) (P₄, P₇ and P₁₁) and coastal plain (LS-5) (P₈, P₁₂ and P₁₆) have developed on nearly leveled plain area of southern Saurashtra.

(iii) Parent material : Since the area has basalt as the dominant geological formation, the difference is only on the extent of weathering. On the hill slopes, the basalt was mostly consolidated rock or only partially weathered. As the slope became less extreme, the extent of weathering was greater. The parent material in the soils of different land slopes of the southern Saurashtra indicates that the weathered and partially weathered and partially weathered basaltic parent material were observed in hill slope (LS-1) area (P₁ and P₁₃). The upper piedmont (LS-2) and lower piedmont (LS-3) have partially weathered basalt, weathered basaltic, basaltic, weathered basaltic and lime stone both as well as basaltic and lime stone both materials while the piedmont plain (LS-4) and coastal plain (LS-5) have alluvium parent material.

(iv) Soil colour : The soils of hill slope exhibits dark yellowish brown (10 YR 3/4M) colour throughout the profile in the moist condition. The soils of the upper piedmont area exhibits dark brown (10 YR 3/3M) to dark grayish brown (10 YR 4/2M) colour in the surface while in the sub surface varies from very dark grayish brown (10 YR 3/2M) to dark brown (10 YR 3/3M) colour. The Deptt. of Agriculture, Guj. State, Soil Survey Unit (2000) also observed soil colour to vary from very dark grayish brown to yellowing brown in 10 YR hue of different physiographic units of Mendarada taluka of Junagadh district. The soils of the lower piedmont area were very dark grayish (10 YR 3/1M) to dark grayish brown (10 YR 4/2M) colour in the surface while in the sub surface varied from very dark gray (10 YR 3/1M) to dark grayish brown (10 YR 4/2M) colour in the surface while in the sub surface varied from very dark gray (10 YR 3/1M) to dark brown (10 YR 3/3M) colour. Similar results were also reported by Narmada Water Resources and Water Supply Department, Gujarat State (NWR & WSD, 1998) in medium black soils of the command area of Machhundri in southern Saurashtra. The soils of the piedmont plain area exhibit dark brown (10 YR 3/3M) to dark grayish brown (10 YR 4/2M) colour in the surface. While in the sub surface the colour varied from dark grayish brown (10 YR 3/2M) to dark brown (10 YR 3/3M) colour.

The colour of the soils of the coastal plain area varied from dark gray (10 YR 4/1M) to brown (10 YR 5/3M) colour in the surface.

(v) Structure : The moderate to strong sub angular structure was commonly observed in the soils associated in the pedons P₁ to P₁₆ indicating no variation in the soil structure in relations to altitude. Similar observation have been made by the Singh *et al.* (1991), Savalia *et al.* (2000) also reported moderate to strong sub angular blocky structure in calcareous black soils of Uben command area of Saurashtra region.

4.2 MINERALOGICAL COMPOSITION OF SOILS

Minerals in soils being the prime source of the much of the essential nutrients for plants. Mineralogical composition gives an indirect indication of fertility status of the soils as well as physical behaviour. The section deals with minerals assembling of sand, silt and clay fractions are presented and discussed as per the following subhead.

4.2.1 Mineralogical composition of selected toposequence

4.2.2 Mineralogical composition of different land slopes across the toposequences

4.2.1 Mineralogical Composition of Selected Toposequence

The X-ray diffraction (XRD) patterns of sand, silt and clay fractions of representative pedons of Hiran toposequence (T₁) from Junagadh district and Rayadi toposequence (T₄) from Amreli district of the Southern Saurashtra are presented in Table 4.17 to 4.19 and Fig. 4.1 to 4.6.

4.2.1.1 Hiran toposequence

The XRD patterns of sand, silt and clay fractions of pedons P₁ to P₄ of Hiran toposequence are presented in Table 4.17 to 4.19 and Fig. 4.1 to 4.3.

Sand Mineralogy

Qualitative data obtained from XRD patterns of sand fractions of pedons of the Hiran toposequence (T_1) of southern Saurashtra (Table 4.17) indicated that plagioclase was dominant mineral followed by vermiculite in the hill slope (LS-1) and upper piedmont (LS-2) area. This may be due to basaltic parent materials and plagioclase is an essential mineral present in basalt (Tiwary and Mishra, 1993). Quartz and olivine were the next prominent minerals present in hill slope and upper piedmont area. The other common associated minerals identified in hill slope and upper piedmont were augite, hematite and goethite. The olivine was present in hill slope and upper piedmont while the amphibole was present in hill slope only (Table 4.17). Thus, both these minerals were ferromagnesian minerals as they contain Fe and Mg in their structure and supply Fe and Mg in these soils. Amphibole is also an essential constituent of basaltic materials (Sehgal, 1986).

A critical perusal of the data (Table 4.17) shows that the dominant sand minerals were observed in the order of quartz > plagioclase > calcite in the solum of the pedon- P_3 (Maljinjawa) of lower piedmont (Fig. 4.1) and at the sub surface (B_{21}) of pedon- P_4 (Kajali) of piedmont plain. Quartz and plagioclase were dominant in Ap and B_{21} in pedon- P_4 (Kajali) of piedmont plain while the plagioclase was dominant in lower depths. The dominance of quartz in lower piedmont may be due to the transportation from hill slope and upper piedmont and of sediments to lower piedmont through surface runoff. The calcite was present in all the layers in pedon- P_3 of lower piedmont and pedon- P_4 of piedmont plain. The abrupt high dominance of calcite with quartz indicated different geological material below B horizons in plains (Singh, 1999). The other common associated minerals observed in lower piedmont and piedmont plain were augite, hematite, apatite, goethite and olivine. The weathering resistant of sand size minerals are quartz > plagioclase > augite > olivine > calcite (Sehgal, 1986).

Table 4.17. Relative abundance of dominant and associated minerals in sand fractions of the pedons from the selected toposequences.

Horizon	Depth (cm)	Dominant minerals	Associate minerals
T₁ : Hiran toposequences			
P ₁ : Hill slope, Sasan (Gir), Tal. Talala, Dist. Junagadh. MSL 162 m			
A ₁	0-17	Pl > V > Q	Ol > Au > Hm > Go > Amph
A ₁₂	17-35	Pl > V > Q	Au > Ol > Hm > Go > Amph
AC	35-43	Pl > Au > Q	Ol > V > Hm > Go > Ap
P ₂ : Upper piedmont, Borvav (Gir), Tal. Talala, Dist. Junagadh. MSL 125 m			
Ap	0-20	Pl > Q > Ol	V > Au > Go > Hm
A ₁₂	20-30	Pl > V > Q	Ol > Go > C > Au > Hm
AC	30-45	Pl > V > Ol	Au > Go > Hm
P ₃ : Lower piedmont, Maljinjava, Tal. Talala, Dist. Junagadh. MSL 70 m			
Ap	0-20	Q > Pl > C	V > Hm > Go > Au > Ap
A ₁₂	20-40	Q > Pl > C	V > Go > Hm > Ap > Au
B ₂₁	40-60	Q > Pl > C	V > Go > Ol > Au
IIC ₁	60-80	Q > C > V	Pl > Ol > Go > Au
P ₄ : Piedmont plain, Kajali, Tal. Veraval, Dist. Junagadh. MSL 11 m			
Ap	0-50	Q > Pl > Au	C > V > Hm > Ol > Ap
B ₂₁	50-120	Q > Pl > C	V > Au > Go > Hm > Ol
IIC ₁	120-150	Pl > Q > C	V > Go > Hm > Ol > Au > Ap
IIC ₂	150-200	Pl > C > V	Q > Au > Go > Ap
IIIC ₃	200-240	Pl > C > V	Q > Au > Hm > Go > Ol
T₄ : Rayadi toposequence			
P ₁₃ : Hill slope, Dean, Tal. Khambha, Dist. Amreli. MSL 160 m			
A ₁₁	0-15	Pl > Q > V	Au > Go > Ol > Hm > Ap
AC	15-28	Pl > Q > V	Ol > Au > Hm > Go > Ap
P ₁₄ : Upper piedmont, Dean, Tal. Khambha, Dist. Amreli. MSL 149 m			
Ap	0-17	Pl > Q > V	Au > Ol > Go > Hm
A ₁₂	17-33	Pl > Q > V	Au > Go > Hm > Ap
AC	33-40	Pl > Q > V	Au > Go > Hm > Ap
P ₁₅ : Lower piedmont, Chotara, Tal. Rajula, Dist. Amreli. MSL 74 m			
Ap	0-18	Pl > Q > V	Au > Go > Hm > Ap
B ₂₁	18-45	Q > Pl > Au	Go > Hm > Ap
IIC ₁	46-65	Q > Pl > Hm	Au > Go > Ap
IIC ₂	65-85	Q > Pl > Hm	Go
P ₁₆ : Coastal plain, Kadiyali, Tal. Jafrabad, Dist. Amreli. MSL 5 m			
Ap	0-18	Q > C > Pl	Hm > Go
B _{21ck}	18-38	Q > C > Pl	Hm > Go > V
B _{22ck}	38-50	Q > C > Pl	Hm > Go > V
B _{23ck}	50-70	Pl > C > Q	Hm > Go > V
BC _{ck}	70-100	Q > C > Pl	V > Go > Hm

Pl – Plagioclase, Au – Augite, V – Vermiculite, Q – Quartz, Go – Goethite, C – Calcite, Hm – Hematite, Ap – Apatite, Ol – Olivine, Amph – Amphibole

Table 4.18. Relative abundance of dominant and associated minerals in silt fractions of the pedons from the selected toposequences.

Horizon	Depth (cm)	Dominant minerals	Associate minerals
T₁ : Hiran toposequences			
P₁ : Hill slope, Sasan (Gir), Tal. Talala, Dist. Junagadh. MSL 162 m			
A ₁	0-17	Pl > Au > V	Q > Go > Ap > Ol > Hm
A ₁₂	17-35	Pl > Au > V	Q > Go > Ol > Hm
AC	35-43	Pl > V > Q	Go > Hm > Au > Ol
P₂ : Upper piedmont, Borvav (Gir), Tal. Talala, Dist. Junagadh. MSL 125 m			
Ap	0-20	Pl > Q > V	Go > Au > Hm > Ol
A ₁₂	20-30	Pl > Q > V	Go > Au > Hm > Ol
AC	30-45	Pl > V > Go	Amph > Hm > Au > Ap
P₃ : Lower piedmont, Maljinjava, Tal. Talala, Dist. Junagadh. MSL 70 m			
Ap	0-20	Q > Pl > V	Go > Au > Hm > Ap
A ₁₂	20-40	Q > Pl > V	Go > Au > Hm > Ap
B ₂₁	40-60	Q > Pl > V	Go > C > Au > Ol > Ap
IIC ₁	60-80	Q > Pl > V	Go > C > Au > Ol > Ap
P₄ : Piedmont plain, Kajali, Tal. Veraval, Dist. Junagadh. MSL 11 m			
Ap	0-50	Q > Pl > V	Au > Go > Hm > Ol > Ap
B ₂₁	50-120	Q > Pl > V	Au > Go > Hm > Ol > Ap
IIC ₁	120-150	P > Q > V	Au > Go > Hm > Ol > Ap
IIC ₂	150-200	Q > Pl > C	V > Ol > Au > Go > Ap
IIIC ₃	200-240	Q > Pl > V	Au > Ol > Hm > Go > Ap
T₄ : Rayadi toposequence			
P₁₃ : Hill slope, Dean, Tal. Khambha, Dist. Amreli. MSL 160 m			
A ₁₁	0-15	Pl > Q > V	Au > Hm > Ap > Go
AC	15-28	Pl > Q > V	Au > Hm > Go > Ap
P₁₄ : Upper piedmont, Dean, Tal. Khambha, Dist. Amreli. MSL 149 m			
Ap	0-17	Pl > Q > V	Au > Ol > Go > Hm > Ap
A ₁₂	17-33	Pl > Q > Au	V > Hm > Go > Ap
AC	33-40	Q > Pl > Au	V > Ol > Go > Hm
P₁₅ : Lower piedmont, Chotara, Tal. Rajula, Dist. Amreli. MSL 74 m			
Ap	0-18	Pl > Q > V	Au > Go > Hm > Ap
B ₂₁	18-45	Q > Pl > Au	V > Hm > Go > Ap
IIC ₁	46-65	Q > Pl > Au	V > Hm > Go > Ap
IIC ₂	65-85	Q > Pl > C	Au > Hm > Go > Ap
P₁₆ : Coastal plain, Kadiyali, Tal. Jafrabad, Dist. Amreli. MSL 5 m			
Ap	0-18	Q > Pl > C	Au > V > Hm > Go > Ap
B _{21ck}	18-38	Q > Pl > C	Au > V > Hm > Go > Ap
B _{22ck}	38-50	Q > Pl > C	Au > V > Hm > Go
B _{23ck}	50-70	Q > C > Pl	V > Au > Go > Hm > Ap
BC _{ck}	70-100	Q > C > Pl	Hm > Au > Go > Ap

Pl – Plagioclase, Au – Augite, V – Vermiculite, Q – Quartz, Go – Goethite, C – Calcite, Hm – Hematite, Ap – Apatite, Ol – Olivine, Amph – Amphibole

Table 4.19. Relative abundance of dominant minerals in clay fraction of the pedons from the selected toposequences.

Horizon	Depth (cm)	Sequence of clay minerals
1	2	3
T₁ : Hiran toposequence		
P ₁ : Hill slope, Sasan (Gir), Tal. Talala, Dist. Junagadh. MSL 162 m		
A ₁	0-17	Smectite > Kaolinite > Mixed layer
A ₁₂	17-35	Smectite > Kaolinite > Mixed layer
AC	35-43	Smectite > Vermiculite > Mixed layer > Kaolinite
P ₂ : Upper piedmont, Borvav (Gir), Tal. Talala, Dist. Junagadh. MSL 125 m		
Ap	0-20	Smectite > Vermiculite > Mixed layer > Kaolinite
A ₁₂	20-30	Smectite > Vermiculite > Mixed layer > Kaolinite
AC	30-45	Smectite > Vermiculite > Mixed layer > Kaolinite > Chlorite
P ₃ : Lower piedmont, Maljinjava, Tal. Talala, Dist. Junagadh. MSL 70 m		
Ap	0-20	Smectite > Kaolinite > Mixed layer > Chlorite
A ₁₂	20-40	Smectite > Kaolinite > Mixed layer > Chlorite
B ₂₁	40-60	Smectite > Mixed layer > Kaolinite > Chlorite
IIC ₁	60-80	Smectite > Kaolinite > Mixed layer
P ₄ : Piedmont plain, Kajali, Tal. Veraval, Dist. Junagadh. MSL 11 m		
Ap	0-50	Smectite > Kaolinite > Mixed layer
B ₂₁	50-120	Smectite > Kaolinite > Mixed layer > Chlorite
IIC ₁	120-150	Smectite > Mixed layer > Kaolinite > Chlorite
IIC ₂	150-200	Smectite > Vermiculite > Mixed layer > Chlorite
IIIC ₃	200-240	Smectite > Vermiculite > Mixed layer > Chlorite
T₄ : Rayadi toposequence		
P ₁₃ : Hill slope, Dean, Tal. Khambha, Dist. Amreli. MSL 160 m		
A ₁₁	0-15	Smectite > Illite > Mixed layer > Chlorite
AC	15-28	Smectite > Illite > Mixed layer
P ₁₄ : Upper piedmont, Dean, Tal. Khambha, Dist. Amreli. MSL 149 m		
Ap	0-17	Smectite > Chlorite > Mixed layer
A ₁₂	17-33	Smectite > Chlorite > Mixed layer
AC	33-40	Smectite > Chlorite > Mixed layer
P ₁₅ : Lower piedmont, Chotara, Tal. Rajula, Dist. Amreli. MSL 74 m		
Ap	0-18	Smectite > Mixed layer > Chlorite
B ₂₁	18-45	Smectite > Mixed layer > Chlorite
IIC ₁	46-65	Smectite > Chlorite > Mixed layer
IIC ₂	65-85	Smectite > Chlorite > Mixed layer
P ₁₆ : Coastal plain, Kadiyali, Tal. Jafrabad, Dist. Amreli. MSL 5 m		
Ap	0-18	Smectite > Chlorite > Illite > Mixed layer
B _{21ck}	18-38	Smectite > Chlorite > Mixed layer
B _{22ck}	38-50	Smectite > Chlorite > Mixed layer
B _{23ck}	50-70	Smectite > Chlorite > Illite > Mixed layer

BC _{ck}	70-100	Smectite > Chlorite > Illite > Mixed layer

Table 4.20. Relative abundance of dominant and associated minerals in sand fractions of selected horizons and pedons from different land slopes.

Horizon	Depth (cm)	Dominant minerals	Associate minerals
1	2	3	4
LS-1 : Hill slope			
P ₁ : Hill slope, Sasan (Gir), Tal. Talala, Dist. Junagadh. MSL 162 m Hiran toposequence (T ₁)			
A ₁	0-17	Pl > V > Q	Ol > Au > Hm > Go > Amph
A ₁₂	17-35	Pl > V > Q	Au > Ol > Hm > Go > Amp
AC	35-43	Pl > Au > Q	Ol > V > Hm > Go > Ap
P ₁₃ : Dedan, Tal. Khambha, Dist. Amreli. MSL 160 m Rayadi toposequence (T ₄)			
A ₁₁	0-15	Pl > Q > V	Au > Go > Ol > Hm > Ap
AC	15-28	Pl > Q > V	Ol > Au > Hm > Go > Ap
LS-2 : Upper piedmont			
P ₂ : Borvav (Gir), Tal. Talala, Dist. Junagadh. MSL 125 m Hiran toposequence (T ₁)			
Ap	0-20	Pl > Q > Ol	V > Au > Go > Hm
A ₁₂	20-30	Pl > V > Q	Ol > Go > C > Au > Hm
AC	30-45	Pl > V > Ol	Au > Go > Hm
P ₅ : Jamwala (Gir), Tal. Una, Dist. Junagadh. MSL 90 m Shingoda toposequence (T ₂)			
Ap	0-25	Q > Pl > C	V > Au > Hm > Go > Ol
P ₉ : Fatsar, Tal. Una, Dist. Junagadh. MSL 120 m Machhundri toposequence (T ₃)			
Ap	0-20	Q > Pl > V	Hm > Ol > Go > Au > C
P ₁₄ : Dedan, Tal. Khambha, Dist. Amreli. MSL 149 m Rayadi toposequence (T ₄)			
Ap	0-17	Pl > Q > V	Au > Ol > Go > Hm
A ₁₂	17-33	Pl > Q > V	Au > Go > Hm > Ap
AC	33-40	Pl > Q > V	Au > Go > Hm > Ap
LS-3 : Lower piedmont			
P ₃ : Maljinjava, Tal. Talala, Dist. Junagadh. MSL 70 m Hiran toposequence (T ₁)			
Ap	0-20	Q > Pl > C	V > Hm > Go > Au > Ap
A ₁₂	20-40	Q > Pl > C	V > Go > Hm > Ap > Au
B ₂₁	40-60	Q > Pl > C	V > Go > Ol > Au
IIC ₁	60-80	Q > C > V	Pl > Ol > Go > Au
P ₆ : Kareda, Tal. Kodinar, Dist. Junagadh. MSL 63 m Shingoda toposequence (T ₂)			
Ap	0-20	Pl > Q > C	V > Au > Hm > Go > Ol
P ₁₀ : Judavadali, Tal. Una, Dist. Junagadh. MSL 80 m Machhundri toposequence (T ₃)			

Ap	0-18	Q > Pl > C	V > Go > Hm

Table 4.20 Contd...

1	2	3	4
P ₁₅ : Chotara, Tal. Rajula, Dist. Amreli. MSL 74 m Rayadi toposequence (T ₄)			
Ap	0-18	Pl > Q > V	Au > Go > Hm > Ap
B ₂₁	18-45	Q > Pl > Au	Go > Hm > Ap
IIC ₁	46-65	Q > Pl > Hm	Au > Go > Ap
IIC ₂	65-85	Q > Pl > Hm	Go
LS-4 : Piedmont plain			
P ₄ : Kajali, Tal. Veraval, Dist. Junagadh. MSL 11 m Hiran toposequence (T ₁)			
Ap	0-50	Q > Pl > Au	C > V > Hm > Ol > Ap
B ₂₁	50-120	Q > Pl > C	V > Au > Go > Hm > Ol
IIC ₁	120-150	Pl > Q > C	V > Go > Hm > Ol > Au > Ap
IIC ₂	150-200	Pl > C > V	Q > Au > Go > Ap
IIC ₃	200-240	Pl > C > V	Q > Au > Hm > Go > Ol
P ₇ : Devali, Tal. Kodinar, Dist. Junagadh. MSL 12 m Shingoda toposequence (T ₂)			
Ap	0-27	Pl > Q > V	C > Au > Hm > Go > Ol
P ₁₁ : Delawada, Tal. Una, Dist. Junagadh. MSL 24 m Machhundri toposequence (T ₃)			
Ap	0-20	Pl > Q > V	Go > Hm > Ol > Au
LS-5 : Coastal plain			
P ₈ : Chauhani Khan, Tal. Kodinar, Dist. Amreli. MSL 4 m Shingoda toposequence (T ₂)			
Ap	0-25	Pl > Q > V	Au > Go > Ol > Hm > Ap > Amph
P ₁₂ : Rampara, Tal. Una, Dist. Junagadh. MSL 8 m Machhundri toposequence (T ₃)			
Ap	0-20	Pl > Q > V	C > Hm > Ol > Au
P ₁₆ : Kadiyali, Tal. Jafrabad, Dist. Amreli. MSL 5 m Rayadi toposequence (T ₄)			
Ap	0-18	Q > C > Pl	Hm > Go
B _{21ck}	18-38	Q > C > Pl	Hm > Go > V
B _{22ck}	38-50	Q > C > Pl	Hm > Go > V
B _{23ck}	50-70	Pl > C > Q	Hm > Go > V
BC _{ck}	70-100	Q > C > Pl	V > Go > Hm

Pl – Plagioclase, Au – Augite, V – Vermiculite, Q – Quartz, Go – Goethite,
C – Calcite, Hm – Hematite, Ap – Apatite, Ol – Olivine, Amph – Amphibole

Table 4.21. Relative abundance of dominant and associated minerals in silt fractions of selected horizons and pedons from different land slopes.

Horizon	Depth (cm)	Dominant minerals	Associate minerals
1	2	3	4
LS-1 : Hill slope			
P ₁ : Hill slope, Sasan (Gir), Tal. Talala, Dist. Junagadh. MSL 162 m Hiran toposequence (T ₁)			
A ₁	0-17	Pl > Au > V	Q > Go > Ap > Ol > Hm
A ₁₂	17-35	Pl > Au > V	Q > Go > Ol > Hm
AC	35-43	Pl > V > Q	Go > Hm > Au > Ol
P ₁₃ : Dedan, Tal. Khambha, Dist. Amreli. MSL 160 m Rayadi toposequence (T ₄)			
A ₁₁	0-15	Pl > Q > V	Au > Hm > Ap > Go
AC	15-28	Pl > Q > V	Au > Hm > Go > Ap
LS-2 : Upper piedmont			
P ₂ : Borvav (Gir), Tal. Talala, Dist. Junagadh. MSL 125 m Hiran toposequence (T ₁)			
Ap	0-20	Pl > Q > V	Go > Au > Hm > Ol
A ₁₂	20-30	Pl > Q > V	Go > Au > Hm > Ol
AC	30-45	Pl > V > Go	Amph > Hm > Au > Ol
P ₅ : Jamwala (Gir), Tal. Una, Dist. Junagadh. MSL 90 m Shingoda toposequence (T ₂)			
Ap	0-25	Q > Pl > V	Au > Go > Hm > Ol > Ap
P ₉ : Fatsar, Tal. Una, Dist. Junagadh. MSL 120 m Machhundri toposequence (T ₃)			
Ap	0-20	Q > V > C	Pl > Ol > Au > Go > Ap
P ₁₄ : Dedan, Tal. Khambha, Dist. Amreli. MSL 149 m Rayadi toposequence (T ₄)			
Ap	0-17	Pl > Q > V	Au > Ol > Go > Hm > Ap
A ₁₂	17-33	Pl > Q . Au	V > Hm > Go > Ap
AC	33-40	Q > Pl > Au	V > Ol > Go > Hm
LS-3 : Lower piedmont			
P ₃ : Maljinjava, Tal. Talala, Dist. Junagadh. MSL 70 m Hiran toposequence (T ₁)			
Ap	0-20	Q > Pl > V	Go > Au > Hm > Ap
A ₁₂	20-40	Q > Pl > V	Go > Au > Hm > Ap
B ₂₁	40-60	Q > Pl > V	Go > C > Au > Ol > Ap
IIC ₁	60-80	Q > Pl > V	Go > C > Au > Ol > Ap
P ₆ : Kareda, Tal. Kodinar, Dist. Junagadh. MSL 63 m Shingoda toposequence (T ₂)			
Ap	0-20	Q > Pl > V	Au > Hm > Ol > Ap > Go
P ₁₀ : Judavadali, Tal. Una, Dist. Junagadh. MSL 80 m Machhundri toposequence (T ₃)			
Ap	0-18	Q > V > C	Pl > Ol > Au > Go > Hm > Ap

Table 4.21 Contd...

1	2	3	4
P ₁₅ : Chotara, Tal. Rajula, Dist. Amreli. MSL 74 m Rayadi toposequence (T ₄)			
Ap	0-18	Pl > Q > V	Au > Go > Hm > Ap
B ₂₁	18-45	Q > Pl > Au	V > Hm > Go > Ap
IIC ₁	46-65	Q > Pl > Au	V > Hm > Go > Ap
IIC ₂	65-85	Q > Pl > C	Au > Hm > Go > Ap
LS-4 : Piedmont plain			
P ₄ : Kajali, Tal. Veraval, Dist. Junagadh. MSL 11 m Hiran toposequence (T ₁)			
Ap	0-50	Q > Pl > V	Au > Go > Hm > Ol > Ap
B ₂₁	50-120	Q > Pl > V	Au > Go > Hm > Ol > Ap
IIC ₁	120-150	Pl > Q > V	Au > Go > Hm > Ol > Ap
IIC ₂	150-200	Q > Pl > C	V > Ol > Au > Go > Ap
IIC ₃	200-240	Q > Pl > V	Au > Ol > Hm > Go > Ap
P ₇ : Devali, Tal. Kodinar, Dist. Junagadh. MSL 12 m Shingoda toposequence (T ₂)			
Ap	0-27	Q > Pl > V	Au > Hm > Ol > Go
P ₁₁ : Delawada, Tal. Una, Dist. Junagadh. MSL 24 m Machhundri toposequence (T ₃)			
Ap	0-20	Q > Pl > V	Au > Ol > Go > Ap
LS-5 : Coastal plain			
P ₈ : Chauhani Khan, Tal. Kodinar, Dist. Amreli. MSL 4 m Shingoda toposequence (T ₂)			
Ap	0-25	Pl > Q > V	Au > Ol > Hm > Go > Ap
P ₁₂ : Rampara, Tal. Una, Dist. Junagadh. MSL 8 m Machhundri toposequence (T ₃)			
Ap	0-20	Pl > Q > V	Au > Ol > Hm > Ap > Go
P ₁₆ : Kadiyali, Tal. Jafrabad, Dist. Amreli. MSL 5 m Rayadi toposequence (T ₄)			
Ap	0-18	Q > Pl > C	Au > V > Hm > Go > Ap
B _{21ck}	18-38	Q > Pl > C	Au > V > Hm > Go > Ap
B _{22ck}	38-50	Q > Pl > C	Au > V > Hm > Go
B _{23ck}	50-70	Q > C > Pl	V > Au > Go > Hm > Ap
B _{Cck}	70-100	Q > C > Pl	Hm > Au > Go > Ap

Pl – Plagioclase, Au – Augite, V – Vermiculite, Q – Quartz, Go – Goethite,
C – Calcite, Hm – Hematite, Ap – Apatite, Ol – Olivine, Amph – Amphibole

Table 4.22. Relative abundance of dominant minerals in clay fraction of selected horizons and pedons from different land slopes.

Horizon	Depth (cm)	Sequence of clay minerals
1	2	3
LS-1 : Hill slope		
P ₁ : Hill slope, Sasan (Gir), Tal. Talala, Dist. Junagadh. MSL 162 m Hiran toposequence (T ₁)		
A ₁	0-17	Smectite > Kaolinite > Mixed layer
A ₁₂	17-35	Smectite > Kaolinite > Mixed layer
AC	35-43	Smectite > Vermiculite > Mixed layer > Kaolinite
P ₁₃ : Dedan, Tal. Khambha, Dist. Amreli. MSL 160 m Rayadi toposequence (T ₄)		
A ₁₁	0-15	Smectite > Illite > Mixed layer > Chlorite
AC	15-28	Smectite > Illite > Mixed layer
LS-2 : Upper piedmont		
P ₂ : Borvav (Gir), Tal. Talala, Dist. Junagadh. MSL 125 m Hiran toposequence (T ₁)		
Ap	0-20	Smectite > Vermiculite > Mixed layer > Kaolinite
A ₁₂	20-30	Smectite > Vermiculite > Mixed layer > Kaolinite
AC	30-45	Smectite > Vermiculite > Mixed layer > Kaolinite > Chlorite
P ₅ : Jamwala (Gir), Tal. Una, Dist. Junagadh. MSL 90 m Shingoda toposequence (T ₂)		
Ap	0-25	Smectite > Chlorite > Mixed layer > Kaolinite
P ₉ : Fatsar, Tal. Una, Dist. Junagadh. MSL 120 m Machhundri toposequence (T ₃)		
Ap	0-20	Smectite > Chlorite > Mixed layer > Illite
P ₁₄ : Dedan, Tal. Khambha, Dist. Amreli. MSL 149 m Rayadi toposequence (T ₄)		
Ap	0-17	Smectite > Chlorite > Mixed layer
A ₁₂	17-33	Smectite > Chlorite > Mixed layer
AC	33-40	Smectite > Chlorite > Mixed layer
LS-3 : Lower piedmont		
P ₃ : Maljinjava, Tal. Talala, Dist. Junagadh. MSL 70 m Hiran toposequence (T ₁)		
Ap	0-20	Smectite > Kaolinite > Mixed layer > Chlorite
A ₁₂	20-40	Smectite > Kaolinite > Mixed layer > Chlorite
B ₂₁	40-60	Smectite > Mixed layer > Kaolinite > Chlorite
IIC ₁	60-80	Smectite > Kaolinite > Mixed layer
P ₆ : Kareda, Tal. Kodinar, Dist. Junagadh. MSL 63 m Shingoda toposequence (T ₂)		
Ap	0-20	Smectite > Vermiculite > Chlorite > Mixed layer
P ₁₀ : Judavadali, Tal. Una, Dist. Junagadh. MSL 80 m Machhundri toposequence (T ₃)		
Ap	0-18	Smectite > Beidellite > Chlorite > Mixed layer

Table 4.22 Contd...

1	2	3
P ₁₅ : Chotara, Tal. Rajula, Dist. Amreli. MSL 74 m Rayadi toposequence (T ₄)		
Ap	0-18	Smectite > Mixed layer > Chlorite
B ₂₁	18-45	Smectite > Mixed layer > Chlorite
IIC ₁	46-65	Smectite > Chlorite > Mixed layer
IIC ₂	65-85	Smectite > Chlorite > Mixed layer
LS-4 : Piedmont plain		
P ₄ : Kajali, Tal. Veraval, Dist. Junagadh. MSL 11 m Hiran toposequence (T ₁)		
Ap	0-50	Smectite > Kaolinite > Mixed layer
B ₂₁	50-120	Smectite > Kaolinite > Mixed layer > Chlorite
IIC ₁	120-150	Smectite > Mixed layer > Kaolinite > Chlorite
IIC ₂	150-200	Smectite > Vermiculite > Mixed layer > Chlorite
IIC ₃	200-240	Smectite > Vermiculite > Mixed layer > Chlorite
P ₇ : Devali, Tal. Kodinar, Dist. Junagadh. MSL 12 m Shingoda toposequence (T ₂)		
Ap	0-27	Smectite>Vermiculite>Chlorite>Mixed layer>Kaolinite
P ₁₁ : Delawada, Tal. Una, Dist. Junagadh. MSL 24 m Machhundri toposequence (T ₃)		
Ap	0-20	Smectite > Chlorite > Mixed layer
LS-5 : Coastal plain		
P ₈ : Chauhani Khan, Tal. Kodinar, Dist. Amreli. MSL 4 m Shingoda toposequence (T ₂)		
Ap	0-25	Smectite>Beidellite>Chlorite>Mixed layer>Vermiculite
P ₁₂ : Rampara, Tal. Una, Dist. Junagadh. MSL 8 m Machhundri toposequence (T ₃)		
Ap	0-20	Smectite > Chlorite > Illite > Mixed layer
P ₁₆ : Kadiyali, Tal. Jafrabad, Dist. Amreli. MSL 5 m Rayadi toposequence (T ₄)		
Ap	0-18	Smectite > Chlorite > Illite > Mixed layer
B _{21ck}	18-38	Smectite > Chlorite > Mixed layer
B _{22ck}	38-50	Smectite > Chlorite > Mixed layer
B _{23ck}	50-70	Smectite > Chlorite > Illite > Mixed layer
BC _{ck}	70-100	Smectite > Chlorite > Illite > Mixed layer

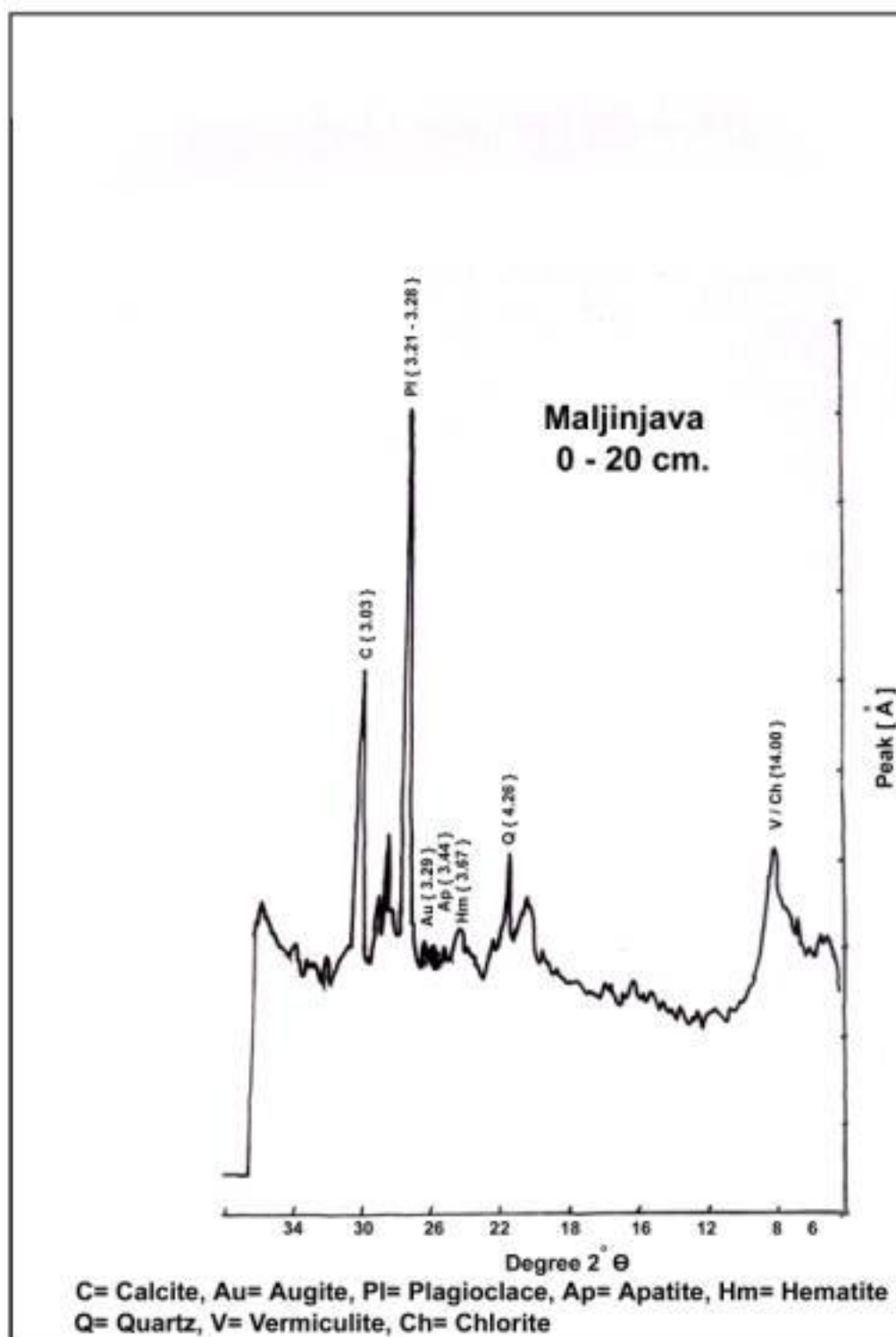


Fig 4.1 X-ray diffractogram of sand size minerals in surface horizon of lower piedmont [P₃T₁].

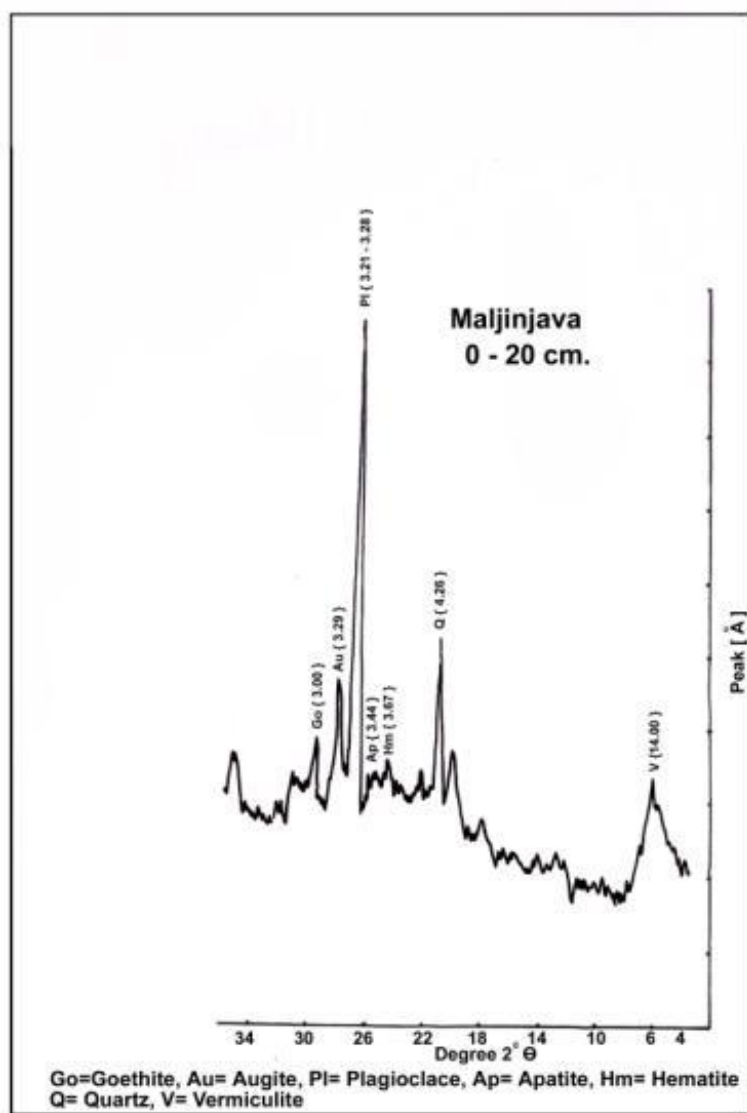


Fig 4.2 X-ray diffractogram of silt size minerals in surface horizon of lower piedmont [P₃T₁].

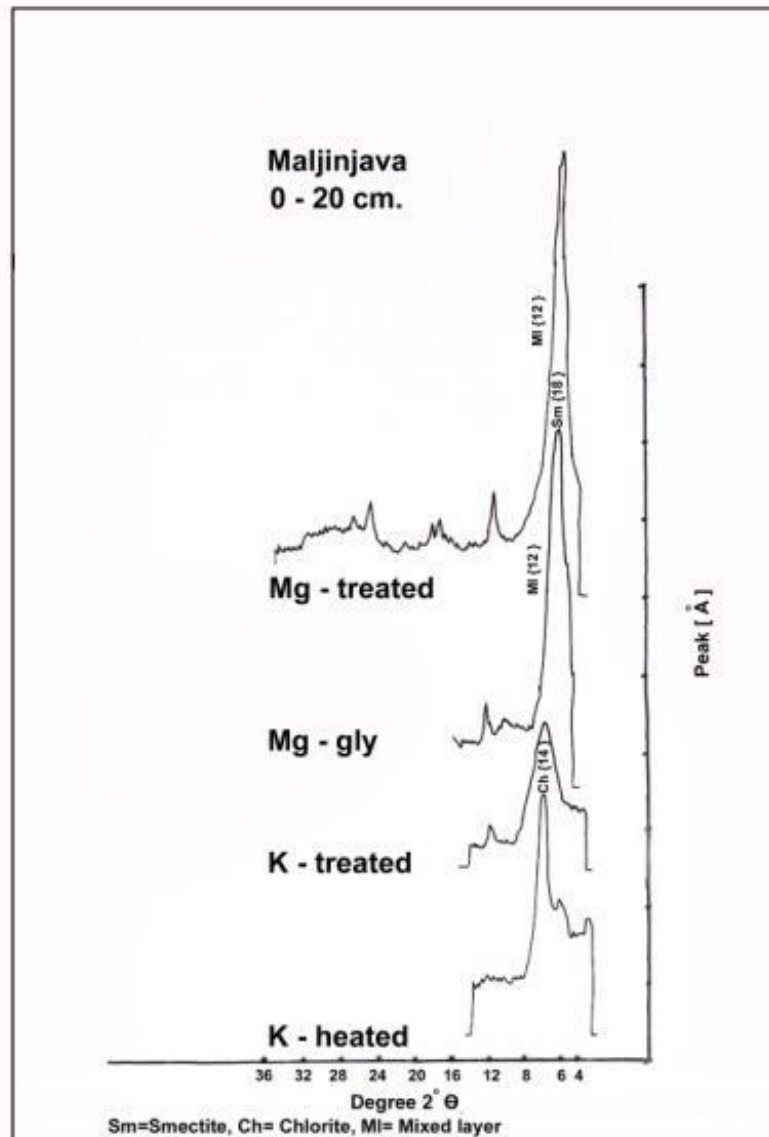


Fig 4.3 X-ray diffractogram of clay size minerals in surface horizon of lower piedmont [P₃T₁].

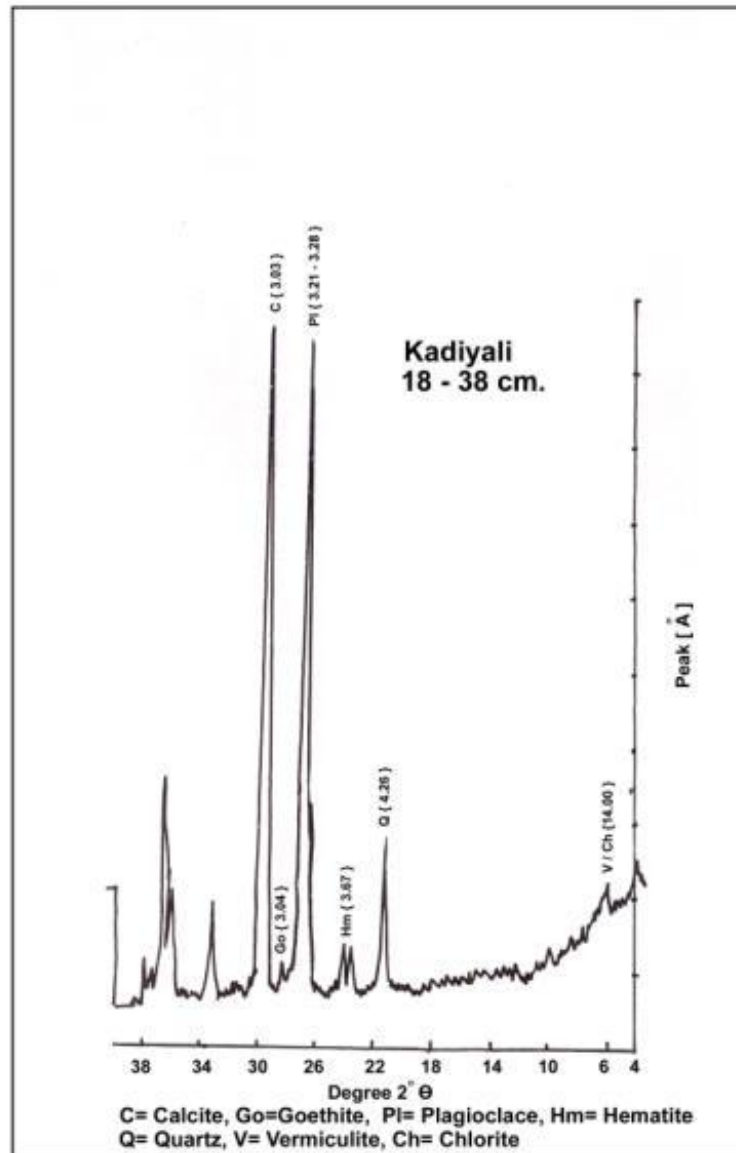


Fig 4.4 X-ray diffractogram of sand size minerals in sub - surface horizon of costal plain [P₁₆T₄].

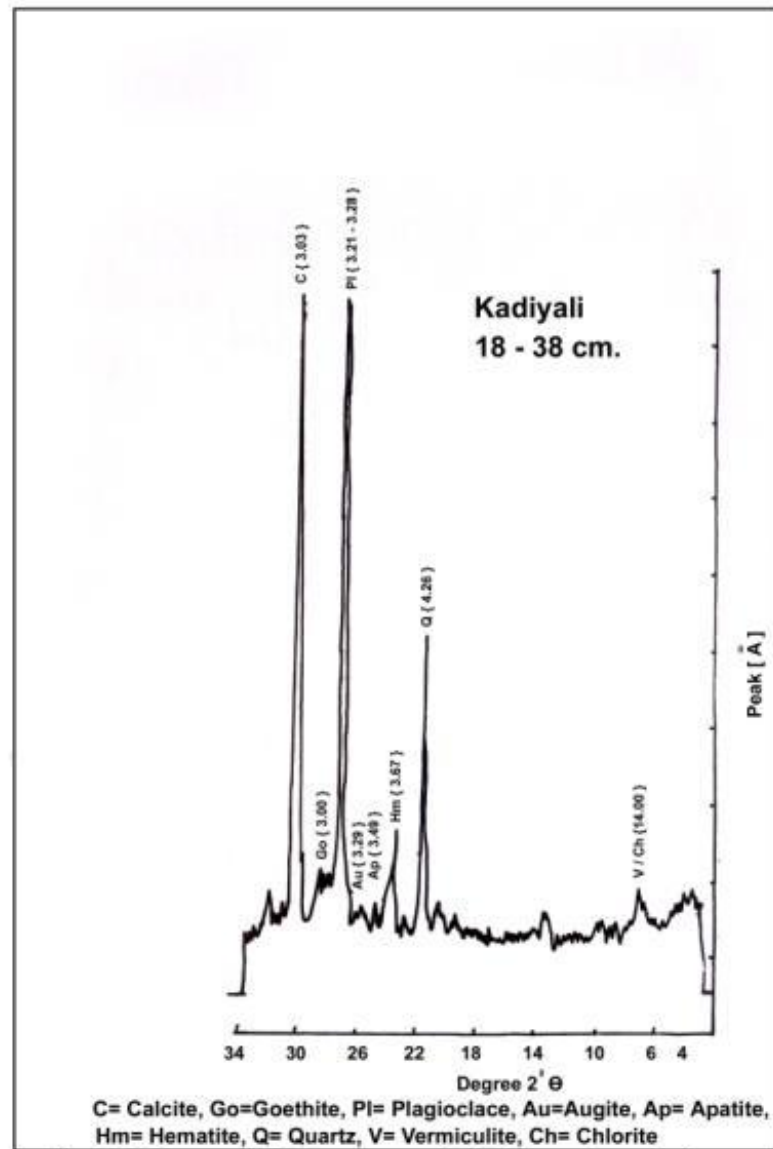


Fig 4.5 X-ray diffractogram of silt size minerals in sub - surface horizon of coastal plain [P₁₆T₄].

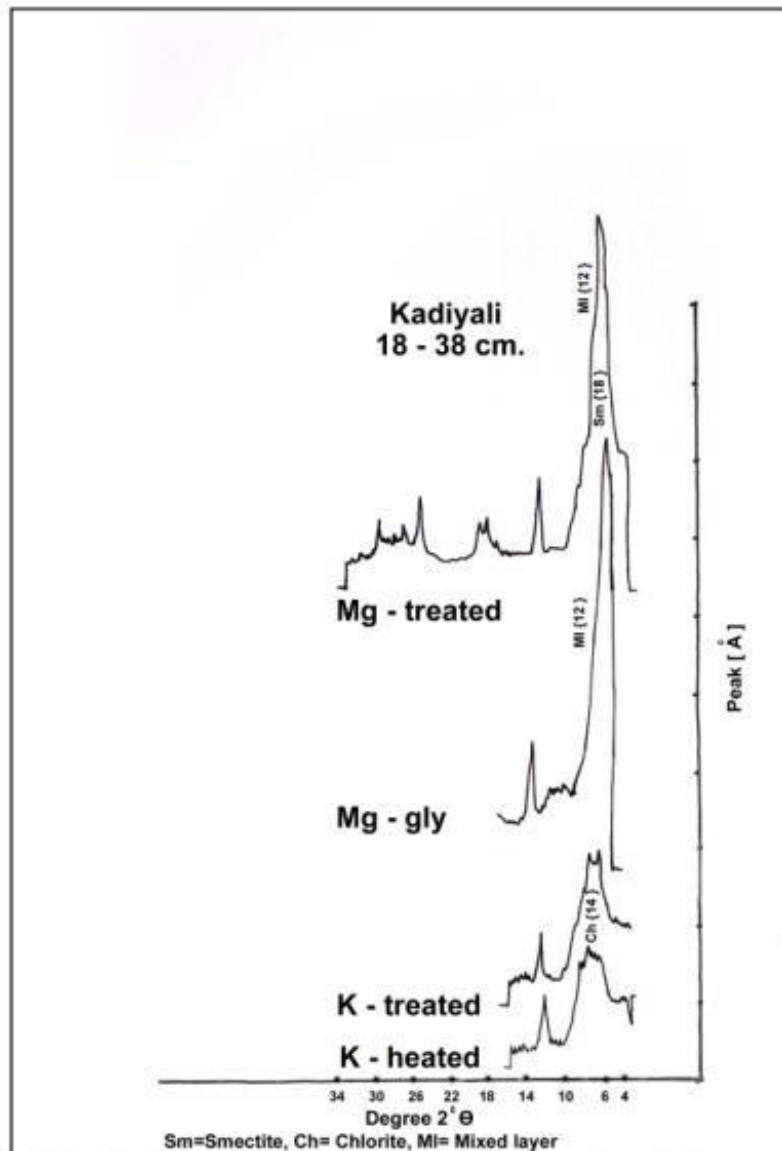


Fig 4.6 X-ray diffractogram of clay size minerals in sub - surface horizon of costal plain [P₁₆T₄].

Silt Mineralogy

The result of XRD pattern of silt fractions of the representative pedons of the Hiran toposequence (T_1) presented in Table 4.18. The results reveals that the dominant silt minerals identified in the solum of the pedon- P_1 of hill slope and P_2 of upper piedmont were in order of plagioclase > augite > vermiculite and plagioclase > quartz > vermiculite, respectively. The dominance of plagioclase was due to basaltic parent materials in these soils. While the presence of augite in the soils of hill slope indicated presence of basic rocks in the provenance (Tiwary and Mishra, 1993). The other common associated minerals identified were goethite, apatite, olivine and hematite. Amphibole was present only in AC horizon of pedon- P_2 (Borvav) in upper piedmont.

The X-ray diffractograms indicated the sequence of quartz > plagioclase > vermiculite was existed throughout the profile in the pedon- P_3 (Maljinjawa) (Fig.4.2) in lower piedmont and pedon- P_4 (Kajali) in piedmont plain except in IIC_1 and IIC_2 horizons of P_4 . The dominant of quartz in silt fraction may be due to the transportation from hill slope and upper piedmont and of sediments to lower piedmont through surface runoff. The other common associated minerals identified in lower piedmont and piedmont plain were hematite, goethite, augite, apatite, calcite and olivine. Goethite and apatite minerals were present throughout the profile in pedon- P_3 (Maljinjawa) in lower piedmont (Fig. 4.2) while the olivine and apatite minerals were also present throughout the profiles in piedmont plain area of Kajali (Pedon- P_4). Olivine, hematite and goethite supply the iron while apatite ($Ca_3(PO_4)_2$) supply the phosphorus in these soils. Apatite is the primary source of phosphorus in soils and may decompose readily under the influence of carbolic acid due to biological weathering in the presence of milliolitie lime stone near the sea cost of south Saurashtra region. However, this phosphorus which release from apatite become immobile in these soils as it readily combines with clays and $CaCO_3$, forming immobile constituents (Sehgal, 1986).

In general, goethite ($\text{FeO}(\text{OH}) \cdot n\text{H}_2\text{O}$) and hematite (Fe_2O_3) are the important soil forming oxides minerals identified as associated minerals in sand and silt fractions in all the pedons across the land slopes of Hiran toposequence (T_1). The hematite occurs as coating on the sand grains and act as a cementing agent in the soils. It swells up on absorbing water to form goethite (Sehgal, 1986). Amphibole mineral was present in sand and silt fractions in hill slope and upper piedmont of Hiran toposequence. Amphibole and olivine are ferromagnesian minerals which are long term supplier of Ca, Mg and Fe for plant nutrition (Sehgal, 1986).

The plagioclase has been identified as a dominated minerals in sand and silt fractions in hill slope and upper piedmont while the quartz was the dominated mineral in lower piedmont area. Quartz and plagioclase minerals dominated in sand and silt fractions of soils of piedmont plain area. Quartz is strongly resistant to physical and chemical weathering as the structure is densely packed, electrically neutral and prevents any form of substitution. With time, quartz accumulates in soils as the other susceptible minerals decompose to form clay and decrease in their respective amounts.

Clay Mineralogy

The X-ray diffraction of Mg saturated and glycolated clays from selected horizons invariably show reflections at $16.5 \text{ \AA}^0$, $14 \text{ \AA}^0$, $10 \text{ \AA}^0$ and $7 \text{ \AA}^0$. (Fig. 4.3)

The reflection at a d-spacing of $14 \text{ \AA}^0$ for Mg-saturated air dried samples which expanded to $16.5 \text{ \AA}^0$ on solvation with ethylene glycol suggested the presence of smectite. A $10 \text{ \AA}^0$ peak which, remained unaffected by glycolation, K-saturation and heating confirms the presence of illite. The part of reflection at $14 \text{ \AA}^0$ which did not expand on glycolation, but collapsed to $10 \text{ \AA}^0$ on K-saturation and heating (400°C) showed the presence of vermiculite. Part of $14 \text{ \AA}^0$ which resisted collapse on heating is due to chlorite. Broad reflection

between 10 and 14 Å⁰ indicated the presence of mixed layer minerals. Kaolinite was indicated by the peaks at 7.2 Å⁰ and 3.5 Å⁰ d-spacing in the Mg-saturated clay after dissolution of 14 Å⁰ mineral in the clay fraction. Plagioclase and calcite were indicated by 3.18 Å⁰ and 3.03 Å⁰ reflections, respectively. (Fig. 4.3)

Qualitative estimates obtained from XRD patterns of clay fractions of the soils of Hiran toposequence (T₁) situated in Junagadh district of southern Saurashtra (Table 4.19) indicates that smectite predominated in the solum of pedon-P₁ (Sasan) of hill slope followed by kaolinite and mixed layer. Smectite being the first weathering product of basalt would have contributed smectite (Singh, 1999). It is presumed that in the initial stage of soil formation, weathering materials from the hills charged with smectite were deposited in the micro-basins. Smectite remained in its natural state under concave shape land configuration, where pedo-environment and surroundings are in equilibrium. The same is subjected to degradation at the site of other land forms such as semi hyperbolic and linear shape land configurations, where the seasonal contrast is affected (Singh, 1999).

The dominant clay minerals were identified in the order of smectite > vermiculite > mixed layer and kaolinite throughout the profile in pedon-P₂ (Borvav) of upper piedmont while chlorite present predominantly only in AC horizon of pedon-P₂.

The smectite was the predominant mineral in clay fraction in surface (Fig. 4.3) and subsurface in pedon-P₃ (Maljinjawa) of lower piedmont and P₄ (Kajali) of piedmont plain followed by kaolinite and mixed layer. However, no proper sequence in dominance of minerals was observed and variation in mineralogical make up with depth was not systematic in lower piedmont and piedmont plain. Chlorite was present in solum of the pedon-P₃ and through out profile except at surface in P₄.

In general, it can be concluded that the smectite was the dominant mineral in clay fraction from hill slope to piedmont plain area of Hiran

toposequence of southern Saurashtra. The dominance of smectite in these soils might be due to the climate of studied region is semi-arid (Bhattacharyya *et al.*, 1993), the summers are dry, the alternate wet and dry conditions along with drainage restrictions controlled by topography and microclimate, results in formation and stability of smectite. (Wildman *et al.*, 1968 and Mahere *et al.*, 2001), the smectite is the first weathering product of basalt (Pal and Deshpande, 1987) and appear to be largely inherited by the soils from the parent material (Jassal *et al.*, 2000). The relative influence of topography could however have resulted in erratic trends of other minerals distribution in respective pedons and the soil developed over quartz-gabbro, dolerite and lime stone are also predominantly montmorillonitic / smectite clays (Prasad *et al.*, 1977).

4.2.1.2 Rayadi Toposequence

The XRD patterns of sand, silt and clay fractions of pedon P₃ to P₁₆ of Rayadi toposequence are depicted in Table 4.17 to 4.19 and Fig. 4.4 to 4.6.

Sand Mineralogy

Qualitative estimates obtained from the XRD patterns of sand fractions of the soils of the Rayadi toposequence (T₄) from Amreli district are presented in Table 4.17. The results reveals that the dominant sand minerals observed in decreasing order of plagioclase > quartz > vermiculite throughout the profile in pedon-P₁₃ (Dedan) of hill slope and P₁₄ (Dedan) of upper piedmont. The dominance of plagioclase may be due to the basaltic parent material (Tiwary and Mishra, 1993). The other associated minerals present throughout the profile in hill slope and upper piedmont were augite, goethite and hematite. The other associated minerals present in different horizons were apatite and olivine. The amphibole was not identified in hill slope and upper piedmont.

A critical observation of the data depicted in Table 4.17 reveal that the dominant sand minerals identified in the lower piedmont were in sequence of quartz > plagioclase in pedon-P₁₅ (Chotara) except at the surface while the sequence was quartz > calcite in pedon-P₁₆ (Kadiyali) of coastal plain except in B₂₃ horizon. In general, it can be concluded that the dominant sand minerals observed in was the order of plagioclase > quartz > vermiculite in hill slope and upper piedmont area of Rayadi toposequence. The sand minerals in order of abundance identified were quartz > plagioclase in lower piedmont and quartz > calcite in coastal plain area of Rayadi toposequence situated in Amreli district. The other common associated minerals identified in the solum of the pedons P₁₅ and P₁₆ of upper piedmont and coastal plain were hematite and goethite. The remaining associated minerals observed in the different horizons of the pedon-P₁₅ and P₁₆ (Fig. 4.4) were vermiculite, augite and apatite. The dominance of quartz in lower piedmont and coastal plain may be attributed to its greater resistance to weathering and its subsequent transportation from hill slopes and upper piedmont towards the coastal plain by water erosion. The dominance of calcite with quartz were also reported by Singh (1999) in plains area. The occurrences of milliolitic lime stone chips in coastal plain of Saurashtra region which show the presence of single step growth and equant tabular growth of calcite cement which indicate their precipitation by mild CaCO₃ solution of low Mg nature in fresh water condition (Patel and Bhatt, 1995).

Silt Mineralogy

The XRD pattern of silt fraction of the representative pedons of Rayadi toposequence (T₄) situated in Amreli district (Table 4.17) indicates that plagioclase was the dominant mineral followed by quartz in silt fraction in solum of pedon-P₁₃ (Dedan) of hill slope and P₁₄ (Dedan) of upper piedmont area. The other common associated silt minerals observed throughout profile in hill slope and upper piedmont were vermiculite, augite, hematite and goethite. The apatite was absent only in AC horizon of pedon-P₁₄. The presence of

augite in hill slope and upper piedmont indicated the presence of basic rocks. The results are in concurrence with those of Tiwary and Mishra (1993).

The X-ray diffraction results insinuated that the quartz was the dominated silt mineral in the pedon-P₁₅ (Chotara) of lower piedmont and P₁₆ (Kadiyali) of coastal plain (Fig. 4.5) followed by plagioclase. The next dominant minerals identified were augite in lower piedmont (Pedon-P₁₅) and calcite in coastal plain (Pedon-P₁₆ & Fig. 4.5). The other associated minerals identified throughout profile in lower piedmont and coastal plain were augite, goethite and hematite. The remaining minerals present in different horizons were apatite and vermiculite. The olivine was absent in silt fraction in lower piedmont and coastal plains. Apatite supply the phosphorus in these soils while goethite and hematite supply the iron.

In general, goethite and hematite minerals identified as an associated mineral in sand and silt fractions in all the pedons from hill slope towards the sea cost in Rayadi toposequence in Amreli district. Both these minerals supply Fe in these soils. The phosphorus supplying apatite was present in all the pedons of Rayadi toposequence.

The plagioclase was the dominant mineral in hill slope and upper piedmont followed by quartz whereas the quartz dominated in the sand and silt fractions in lower piedmont and coastal plain area of Rayadi toposequence situated in Amreli district.

Clay Mineralogy

Qualitative estimate obtained from XRD patterns of clay fractions of soils of Rayadi toposequence (T₄) situated in Amreli district of southern Saurashtra (Table 4.19) indictes that the smectite was the dominant mineral in the clay fraction in the solum of the pedon-P₁₃ (Dedan) of hill slope and P₁₄ (Dedan) of upper piedmont followed by illite and mixed layer and chlorite and mixed layer, respectively. This may be due to the smectite is inherently present in basalt (Singh, 1999). The chlorite was absent at the AC horizon of hill slope

only. The dominance of chlorite after smectite in upper piedmont may be due to the mechanical break down from metamorphic rocks from hill slope, which gave rise to clay sized chlorites (Barua, 1989).

A critical observation of the data depicted in Table 4.19 unveils that the dominant clay minerals observed in the order of smectite followed by mixed layer and chlorite at surface and subsurface of pedon-P₁₅ (Chotara) of lower piedmont while in P₁₆ (Kadiyali) of coastal plain, it was in sequence of smectite> chlorite throughout the profile (Fig. 4.6). The other associated minerals identified were illite and mixed layer.

In general, it can be concluded that the smectite was the dominant mineral in the pedons from the hill slope to the coastal plain of Rayadi toposequence (T₄). The reasons for the dominance of smectite in clay fraction were also discussed in this text and by Wildman *et al.* (1968), Pal and Deshpande (1987), Bhattacharyya *et al.* (1993), Jassal *et al.* (2000) and Mahere *et al.* (2001). Chlorite and mixed layer also identified throughout the profiles from hill slope to the sea coast. Illite mineral observed in pedon-P₁₅ of hill slope and P₁₆ at the surface, B₂₃ and BC horizons of coastal plain.

4.2.2 Mineralogical Composition of Different Land Slopes Across the Toposequences

The X-ray diffraction pattern of sand, silt and clay fractions of the pedons from different land slopes across the toposequences of the southern Saurashtra are depicted in Table 4.20 to 4.22 and Fig. 4.1 to 4.6.

Sand Mineralogy :

The XRD pattern of sand fraction of selected horizons and pedons from the various land slopes are presented in Table 4.20.

Hill slope : Qualitative data obtained from XRD pattern of sand fractions of the pedon-P₁ (Sasan) of Hiran toposequence and P₁₃ (Dedan) of Rayadi toposequence (T₄) of the southern Saurashtra indicates that the dominant sand minerals identified were in the sequence of the plagioclase > vermiculite > quartz. The dominance of plagioclase may be due to the basaltic parent material as plagioclase is a constituent mineral in basalt (Tiwary and Mishra, 1993). The associated minerals assemblage identified in the sand fractions as: olivine, augite, hematite, goethite, amphibole, apatite and calcite.

Upper Piedmont : The X-ray diffraction studies reveals that the soils from upper piedmont area of southern Saurashtra (Table 4.20) have dominant of plagioclase in pedon-P₂ (Borvav) of Hiran toposequence (T₁) and P₁₄ (Dedan) of Rayadi toposequence (T₁). While the quartz was the dominant mineral at the surface of P₅ (Jamwala) of Hiran toposequence (T₁) and P₉ (Fatsar) of Machhundri toposequence (T₃). Thus, the dominant sand minerals observed were in the order of plagioclase and quartz > vermiculite where as chlorite, olivine, hematite and augite were categorized as associated minerals. A critical examination of the data indicated that calcite was third in dominant after plagioclase at the surface of pedon-P₅ (Jamwala) of Shingoda toposequence (T₂), instead of vermiculite as observed in P₉ (Fatsar) and P₁₄ (Dedan).

Lower Piedmont : A glance at Table 4.20 implies that plagioclase was the dominant mineral followed by quartz in the surface in pedon-P₆ (Kareda) of Shingoda toposequence (T₂) and P₁₅ (Chotara) of Rayadi toposequence (T₄). The next dominant associated minerals were calcite and vermiculite at the surface of pedon-P₆ and P₁₅, respectively. The quartz was also dominant mineral followed by plagioclase in the pedon-P₃ (Maljinjawa) (Fig. 4.1) and at the surface of P₁₀ (Judavadali). Thus, the plagioclase and quartz were dominant minerals followed by calcite and vermiculite in lower piedmont. The associated minerals observed were olivine, augite, hematite, goethite and apatite.

Piedmont Plain : The plagioclase was the dominant mineral in Ap horizon of pedon-P₇ (Devali) of Shingoda toposequence (T₂) and P₁₁ (Delawada) of Machhundri toposequence (T₃) followed by quartz and vermiculite. While the quartz was the dominated in the Ap and B₂₁ horizons of pedon-P₄ (Kajali) of Hiran toposequence (T₁). Whereas, the plagioclase was dominant in lower horizons viz., IIC, IIC₂, and IIC₃ of the same pedon-P₄. In general, the dominant sand minerals observed were in the sequence of plagioclase > quartz > vermiculite.

The occurrence of similar types of minerals was due to the similarity in the nature of parent rocks (Tiwary *et al.*, 1987), which were mainly basalt and dolerite. These rocks are black and are primarily composed of plagioclase (Tiwary and Mishra, 1993). The associated minerals identified were augite, calcite, goethite and hematite.

Coastal Plain : The plagioclase was the dominant mineral followed by quartz and vermiculite in the Ap horizon of pedon-P₈ (Chauhani Khan) of Shingoda toposequence (T₂) and P₁₂ (Rampara) of Machhundri toposequence (T₃) while the quartz was also dominated mineral followed by calcite and plagioclase in the pedon-P₁₆ (Kadiyali) of Rayadi toposequence (T₄) (Fig. 4.4). The abrupt high dominance of calcite with quartz indicated different geological material below B horizon in plains (Singh, 1999). The occurrences of milliolitic lime stone chips in coastal plain of Saurashtra region which show the presence of single step growth and equant tabular growth of calcite cement, indicate their precipitation by mild CaCO₃ solution of low-Mg nature in fresh water condition (Patel and Bhatt, 1995).

In general, the dominant sand minerals identified were in the order of plagioclase > quartz > vermiculite and calcite whereas associated minerals were augite, goethite and hematite in coastal plain.

By and large, quartz is the highly resistant mineral in these soils. The weathering resistant of sand size minerals are plagioclase > augite > olivine >

calcite (Sehgal, 1986). Looking to the overall data, it seems that variation in mineralogical make up with depth was not systematic.

Silt Mineralogy

The X-ray diffraction (XRD) pattern of silt fraction of selected horizons and pedons from the various land slopes are briefly summarized in Table 4.21.

Hill Slope : The content of plagioclase was dominated in the pedon-P₁ (Sasan) of Hiran toposequence (T₁) and P₁₃ (Dedan) of Rayadi toposequence (T₄) due to the presence of basaltic parent materials. Augite and quartz were the next prominent minerals followed by vermiculite in pedon-P₁ and P₁₃, respectively. The presence of augite mineral in the soils of hill slope indicated the presence of basic rocks in the provenance (Tiwary and Mishra, 1973). The associated minerals identified were goethite, hematite, apatite and olivine. The calcite and amphibole were absent in the soils of hill slope.

Upper Piedmont : The mineralogy of silt fraction in the solums of pedon-P₂ (Borvav) of Hiran toposequence (T₁) and P₁₄ (Dedan) of Rayadi toposequence (T₄) indicates that the plagioclase was dominant mineral followed by quartz. The next prominent mineral was vermiculite in Ap and A₁₂ horizons of P₂ while vermiculite in Ap and augite in A₁₂ horizon in P₁₄. Quartz was the dominated mineral in Ap horizon of pedon-P₅ (Jamwala) of Shingoda toposequence (T₂) and P₉ (Fatsar) of Machhundri toposequence (T₃) followed by plagioclase in pedon-P₅ and vermiculite in pedon-P₉.

In general, the dominant silt minerals identified in order of plagioclase > quartz > vermiculite. The other associated minerals observed were augite, goethite, hematite, olivine and apatite.

Lower Piedmont : The quartz was the dominant mineral in pedon-P₃ (Maljinjawa) of Hiran toposequence (T₁) (Fig. 4.2), lower horizons of P₁₅ (Chotara) of Rayadi toposequence (T₄) and Ap horizon of pedon-P₆ (Kareda) of

Shingoda toposequence (T₂) and P₁₀ (Judavadali) of Machhundri toposequence (T₃) followed by plagioclase in pedon-P₃, Ap horizon of P₆ and subsurface horizons of P₁₅ and vermiculite in Ap horizon of P₁₀. The next prominent mineral was vermiculite in P₃ and Ap horizon of P₆ and P₁₅ while the calcite was the next prominent mineral of the P₁₀.

In general, the dominant silt minerals observed were in the sequence of quartz > plagioclase > vermiculite whereas, other associated minerals identified were augite, calcite, goethite, hematite, apatite and olivine.

Piedmont Plain : The quartz was dominant mineral followed by plagioclase in pedon-P₄ (Kajali) of Hiran toposequence (T₁), Ap horizons of P₇ (Devali) of Shingoda toposequence (T₂) and P₁₁ (Delawada) of Machhundri toposequence (T₃) except in IIC₁ of horizon P₄. The next prominent mineral was vermiculite in P₄ and Ap horizon of P₇ and P₁₁.

In general, the dominant silt minerals observed in the order of quartz > plagioclase > vermiculite whereas other associated minerals identified were augite, calcite, goethite, hemtite, apatite and olivine.

Coastal Plain : The dominant silt minerals followed the sequence of plagioclase > quartz > vermiculite in Ap horizon of pedon-P₈ (Chauhani Khan) of Shingoda toposequence (T₂) and P₁₂ (Rampara) of Machhundri toposequence (T₃). The quartz was the dominant followed by plagioclase and calcite in Ap, B₂₁ and B₂₂ (Fig. 4.5) horizons of pedon P₁₆ (Kadiyali) of Rayadi toposequence (T₄). In general, the dominant silt minerals of coastal plain were in order of plagioclase and quartz > vermiculite and chlorite whereas associated minerals identified were augite, calcite, goethite, hematite, apatite and olivine.

Clay Mineralogy

The XRD pattern of clay fraction of selected horizons and pedons from the various land slopes are presented in Table 4.22.

Hill Slope : Qualitative data obtained from XRD patterns of clay fractions showed the predominant occurrence of smectite mineral in the pedon-P₁ (Sasan) of Hiran toposequence (T₁) and P₁₃ (Dedan) of Rayadi toposequence (T₄) of hill slope. Smectite, being the first weathering product of basaltic parent material would have contributed smectite. It is presumed that in the initial stage of soil formation, weathering material from the hills charged with smectite was deposited in the micro-basins. Smectite remained in their natural state under concave shape land configuration, where pedo-environment and surroundings are in equilibrium. The same is subjected to degradation at the sites of other land form such as semi hyperbolic and linear shape land configurations, where the seasonal contrast is affected (Singh, 1999).

The dominant clay mineral sequences observed in the solum of pedon-P₁ (Sasan) and P₁₃ (Dedan) were smectite > kaolinite > mixed layer and smectite > illite > mixed layer > chlorite, respectively. It seems that the higher rainfall having in hill slope area have the occurrence of kaolinite as a dominant mineral whereas lower rainfall area in hill slope have the illite as dominant next to smectite.

In general, the dominant clay minerals observed were in the order of smectite > kaolinite and illite > mixed layer in the hill slope. The chlorite, illite and beidellite were absent in pedon-P₁ while kaolinite and vermiculite were absent in P₁₃.

Upper Piedmont : The smectite was the dominant mineral in all the pedons i.e. P₂ (Borvav) of Hiran toposequence (T₁), P₅ (Jamwala) of Shingoda toposequence (T₂), P₉ (Fatsar) of Machhundri toposequence (T₃) and P₁₄ (Dedan) of Rayadi toposequence (T₄). The dominant clay minerals observed were in the sequence of smectite > vermiculite > mixed layer in pedon-P₂ and smectite > chlorite > mixed layer in P₁₄ and at the surface of P₅ and P₉.

In general, the dominant clay minerals were in the order of smectite > chlorite > mixed layer whereas associated minerals identified were kaolinite, illite, vermiculite and beidellite in upper piedmont.

It is interesting to note that the chlorite was present next to smectite in clay fraction in soils of upper piedmont which gave rise to clay-sized chlorites simply by mechanical break down from the metamorphic rocks of the hill slopes (Barua, 1989).

Lower Piedmont : The smectite was the dominant mineral in clay fraction in all the pedons i.e. P₃ (Maljinjawa) of Hiran toposequence (T₁) (Fig. 4.3), P₆ (Kareda) of Shingoda toposequence (T₂), P₁₀ (Jundavadali) of Machhundri toposequence (T₃) and P₁₅ (Chotara) of Rayadi toposequence (T₄). However, no proper sequence in dominance of minerals was observed and variation in mineralogical make up with depth was not systematic. The associated minerals identified were kaolinite, chlorite, vermiculite, beidellite, mixed layer and illite.

Piedmont Plain : The smectite was the dominant mineral in clay fraction identified in all the pedons i.e. P₄ (Kajali) of Hiran toposequence (T₁), P₇ (Devali) of Shingoda toposequence (T₂) and P₁₁ (Delawada) of Machhundri toposequence (T₃). However, irregular sequences in dominance of minerals were observed in piedmont plain area. The associated minerals observed in clay fraction were kaolinite, chlorite, vermiculite and mixed layer.

Coastal Pain : The dominant clay minerals identified were in the order of smectite > chlorite in pedon-P₁₂ (Rampara) of Machhundri toposequence (T₃) and P₁₆ (Kadiyali) of Rayadi toposequence (T₄) (Fig. 4.6), while in P₈ (Chauhani Khan) of Shingoda toposequence (T₂), it was in sequence of smectite > beidellite. The associated minerals identified were vermiculite, kaolinite, mixed layer, illite and beidellite.

Looking at the overall all perusal of the data of the southern Saurashtra region, it can be concluded that the smectite mineral dominates in the clay fractions of all the land slopes across the toposequences of southern Saurashtra. The dominance of smectite in the soils of the different land slopes might be due to the following reasons :

- i) The present day climate of region is semi-arid having the precipitation of around 550 mm per annum. (Bhattacharyya *et al.*, 1993), summer are dry and low leaching condition due to insufficient rainfall.
- ii) The alternate wet and dry condition along with drainage restrictions controlled by topography and micro-climate results in the formation and stability of smectite. The results are also supported by Wildmen *et al.* (1968) and Mahere *et al.* (2001).
- iii) Soil clays from profile developed over syenite and that over basalt in flat valley bottom have some illite associated with predominantly montmorillonitic clay (smectite). Soil developed over quartz-gabbro, dolerite and lime stone are predominantly montmorillonitic (smectie) with smaller amounts of kaolinite (Prasad *et al.*, 1977).
- iv) The smectite is the first weathering product of basalt (Pal and Deshpande, 1987) and appear to be largely inherited by the soils from the parent material. (Jassal *et al.*, 2000). The relative influence of topography could however have resulted in erratic trends of other minerals distribution in respective pedons.

4.3 SOIL PHYSICAL CHARACTERISTICS

Maintenance of favourable physical environment in soil is a prerequisite in soil management for the better plant growth in sustainable agriculture. The soil physical condition consisting of different parameters like, soil separate, particle density, bulk density, pore space, expansion, MWHC, saturated hydraulic conductivity, infiltration rate, available water capacity and water retention characteristic determined and are describe in following sub heads :

4.3.1 Mechanical composition and other physical characteristics

4.3.1.1 Hiran toposequence (T_1)

4.3.1.2 Shingoda toposequence (T_2)

4.3.1.3 Machhundri toposequence (T_3)

4.3.1.4 Rayadi toposequence (T_4)

4.3.1.5 Land slopes

4.3.2 Hydrological characteristics

4.3.2.1 Hiran toposequence (T_1)

4.3.2.2 Shingoda toposequence (T_2)

4.3.2.3 Machhundri toposequence (T_3)

4.3.2.4 Rayadi toposequence (T_4)

4.3.2.5 Land slopes

4.3.1 Mechanical Composition and other Physical Characteristics

The data concerning the mechanical composition and other physical characteristics of the pedon of different toposequences across the land slopes are presented in Table 4.23 to 4.27 and graphically exhibited in Fig. 4.7 to 4.10 and are discussed as under.

4.3.1.1 Hiran toposequence (T_1)

Pedon 1 Sasan (Gir) from Hill Slope : The data on mechanical composition and other physical characteristic of pedon-1 at hill slope shows (Table 4.23) that total sand, silt and clay content were 37.90, 32.90 and 29.20 percent at the surface (A_1) and 32.50, 35.80 and 31.70 per cent at sub surface (A_{12}) horizon,

while in the AC horizons were 56.30, 29.40 and 14.30 per cent, respectively. The clay content slightly increased from A₁ to A₁₂ horizon where accumulation of clay take place (Fig. 4.7), which may be due to eluviation process. This is in accordance with the finding of Singh *et al.* (1999). Savalia *et al.* (2000) also observed slight eluviation of clay in Paralithic Troparthen soils of Uben irrigation command area of Saurashtra region of Gujarat. Normally, coarse sand and fine sand were high in AC horizon. The texture of the soil was silty clay loam in surface and sub surface, while in parent material (AC horizon) it was found silty loam.

The values of particle density decreased and bulk density increased with depth (Fig. 4.8) from 2.47 to 2.40 and 1.26 to 1.32 Mg m⁻³, respectively. The pore space was decreased with depth from 49.0 to 45.0 per cent. The expansion of soil lies between 11.28 and 12.25 per cent in A₁ and A₁₂ horizon, respectively, while it was low (8.32 per cent) in AC horizon. The higher expansion of soils because of dominant of smectite minerals present in clay fraction.

Pedon 2 (Borvav) from Upper Piedmont : Appraisal of data on mechanical composition and other physical properties in Table 4.23 indicates that the content of total sand was gradually increase from 24.30 per cent in surface to 57.70 per cent in parent material at AC horizon. The distribution of coarse sand was followed the similar pattern as that of total sand. On the other hand, fine sand decreased from the surface horizon (Ap) to sub surface A₁₂ horizon and thereafter increased in AC horizon. The content of silt and clay were decreased with depth gradually from 35.60 and 40.10 per cent in the surface horizon to 21.80 and 20.50 per cent in the lower most horizons, respectively. The drastic decrease in clay content was noted with increasing soil depth (Fig. 4.7). The comparable results also were obtained by Savlia *et al.* (2000) in Vertic Calciustepts soils of Uben irrigation command area of middle Saurashtra region. The silty clay and silty clay loam texture were detected in surface and sub surface horizon, while the loam was noted in AC horizon. The particle

density ranged between 2.42 and 2.48 Mg m⁻³. However, particle density does not exhibited any specific trend. The bulk density ranged between 1.28 to 1.40 Mg m⁻³ and the values of increase along with depth of profile examine (Fig. 4.8). The pore space ranged from 42.90 to 47.10 per cent, which show the decreasing trend with an increase in depth of soil profile studied. The values for expansion of soil ranged between 13.19 to 18.10 per cent. However, expansion of soil could not registered any specific trend along the depth.

Pedon 3 (Maljinjava) from the Lower Piedmont : The data on mechanical composition and other physical properties are furnished in Table 4.23. The results reveal that pedon-3 have total sand fraction ranged from 20.10 to 21.50 per cent. The vertical distribution of total sand fraction was irregular, which might be due to the difference in the movement of clay within the profile and position of the transect (Sharma, 1995). Fine sand constituted higher proportion of the total sand and varied from 10.90 to 12.00 per cent. Coarse sand, on the other hand ranged from 8.10 to 10.60 per cent. The vertical distribution of fine sand and coarse sand was irregular. The content of silt fraction increased gradually from 35.30 per cent in the surface horizon to 49.50 per cent in the lower most horizon. On the other hand, reverse trend was observed in case of clay content and it was decreased from 43.50 per cent in the surface horizon to 35.00 per cent in the IIC₁ horizon (Fig. 4.7). The silty clay texture identified throughout the solum of this pedon whereas the IIC₁ horizon possessed silty clay loam texture.

The particle density and bulk density varied from 2.40 to 2.57 and 1.33 to 1.48 Mg m⁻³, respectively. The particle density increased with increase in depth in the solum of the profile whereas the bulk density increased along with depth throughout profile (Fig. 4.8). The pore space ranged from 38.30 to 47.00 per cent, which show the decreasing trend with an increase in depth of the profile studied. The expansion of soil varied between 15.16 to 21.30 per cent. However, the expansion of soil was regularly increase from surface to B₂₁ horizon and thereafter it was decrease at IIC₁ horizon.

Pedon 4 (Kajali) from the Piedmont Plain : Glimpses of Table 4.23 show the highest proportion of silt followed by clay and sand in bulk of soil. The total sand content ranged from 19.60 to 34.60 per cent. The vertical depth distribution for total sand was irregular. Almost similar trend of vertical distributions were observed for coarse sand and fine sand fraction. The vertical distribution of silt content gradually decreased with increasing soil depth. The clay fraction, on the other hand, gradually increased from 35.60 per cent in the surface horizon to maximum 41.00 per cent in IIC₂ (150-200 cm) horizon and thereafter, it was slight decreased in IIIC₃ horizon to 39.40 per cent (Fig. 4.7). The increase of clay content from Ap to IIC₂ horizon might be due to differences in original sediments (Sidhu *et al.*, 1976). Slight increase in clay in deeper horizon might be due to translocation of clay along the percolating water. The dispersion during monsoon rains might have favoured the translocation of clay in the medium textured soil (Barua, 1989). The texture varied from silty clay loam to clay loam.

The particle density, bulk density and pore space was ranged from 2.40 to 2.50 Mg m⁻³, 1.32 to 1.55 Mg m⁻³ and 36.70 to 45.00 per cent, respectively. The particle density gradually increased from 2.40 Mg m⁻³ in the surface horizon to the 2.50 Mg m⁻³ in IIC₂ horizon, whereas opposite trend was noticed in pore space, where it gradually decreased from 45.00 per cent in surface horizon to 36.70 per cent in lower most horizon. On the other hand, the bulk density increased with increasing soil depth (Fig. 4.8). The expansion of soil was recorded in higher range and varied from 13.19 to 23.40 per cent.

4.3.1.2 Shingoda Toposequence (T₂)

Pedon 5 (Jamwala) from the Upper Piedmont : The data provided in Table 4.24 signify that the total sand fraction varied from 29.20 to 34.90 per cent. The coarse and fine sand content ranged from 14.60 to 17.50 and 11.70 to 20.50 per cent, respectively. The content of the fine sand increased with increasing depth, but in case of coarse and total sand, the vertical distribution

was found irregular. The content of silt and clay varied from 37.00 to 39.50 and 28.00 to 31.30 per cent, respectively. The silt content was decreased with increasing depth throughout the profile, while the vertical distribution of clay fraction was irregular (Fig. 4.7). The silty clay loam texture was identified throughout the profile.

The content of particle and bulk density lies from 2.40 to 2.43 and 1.31 to 1.40 Mg m⁻³, respectively. The vertical distribution of particle and bulk density (Fig. 4.8) found systematic and increased with increasing soil depth. The pore space and expansion of soil ranged from 42.30 to 45.40 and 10.40 to 17.40 per cent, respectively. The pore space and expansion decreased with increasing depth.

Pedon 6 (Kareda) from the Lower Piedmont : The data bestowed in Table 4.24) of the pedon P₆ expound that total sand content ranged from 46.60 to 52.50 per cent. The content of coarse sand gradually increased from 25.70 per cent in the surface horizon to 38.70 per cent in the lower most horizons. On the other hand, reverse trend was observed in case of fine sand content, where it was decreased from 26.80 per cent in the surface horizon to 7.90 per cent in AC horizon. The silt content ranged from 29.00 to 39.20 per cent. The lowest clay percent was recorded in this pedon and it was ranged from 14.20 to 17.80 per cent (Fig. 4.7). This might be due to the micro elevation differences in this area. A part of this land have upland like status compared to surrounding plain. This was peculiar feature of the lower piedmont. The texture of the pedon was found silty loam throughout the profile.

The particle density ranged from 2.45 to 2.51 Mg m⁻³, whereas the bulk density ranged from 1.54 to 1.60 Mg m⁻³. The uniform particle density was observed throughout the solum in this pedon. However, there was no much variation in the bulk density values of surface and sub surface (1.54 to 1.57 Mg m⁻³) and of with parent material at AC horizon (1.60 Mg m⁻³) because of similar kind of land use (Coloumbe *et al.*, 1996). The bulk density increased with increasing depth of soil (Fig. 4.8). The high value of bulk density (> 1.4

Mg m⁻³) may offer some kind of mechanical impedance to the roots at the lower depth (Grossman *et al.*, 1985 and Singh, 1999). The distribution of clay registered decreasing trend for more than 10 per cent in the sub surface horizon of pedon P₆ indicated its fluvial nature. Similar result was reported by Sharma (1994). The pore space varied from 34.70 to 38.60 per cent indicating the poor-air moisture regime. The result is in conformity with the work of Pal (1976) and Sharma (1995) who reported that the total porosity less than 40 per cent in profile indicates poor air-moisture regime. The depth distribution of pore space decreased with increasing depth, lower magnitude of particle density variation suggests that significant variation was not evident in mineralogical make up of soils (Singh, 1999). The values for expansion of soil ranged between 4.87 to 12.71 per cent. However, the vertical distribution of expansion of soil was irregular.

Pedon 7 (Devali) from the Piedmont Plain : A glimpse of Table 4.24 explicates that the values for total sand content varied from 24.80 to 63.40 per cent. The vertical distribution of total sand was not systematic. The wide variation in depth distribution was observed in coarse sand where it was recorded minimum i.e. 13.00 per cent in surface than subsequently increased 56.00 per cent in lower most horizon. The fine sand content varied from 7.40 to 15.30 per cent. The vertical distribution of fine sand was irregular. The silt and clay content varied from 17.10 to 39.10 and 10.20 to 36.10 per cent, respectively. The clay content in B₂₁ horizon was higher than Ap and IIIC₃, horizons might be suggestive of eluviation and/or in situ weathering of primary minerals to form clay (Fig. 4.7). The results are in concurrence with those obtained by the finding of Paramasivam (1992). The depth distribution of silt and clay (Fig. 4.7) were irregular. The high variation in texture was observed in this pedon. The silty clay loam was found in surface and sub surface while the clay loam, loam and silty loam were observed in IIC₁, IIC₂ and IIIC₃ horizons of this pedon, respectively.

The value for particle and bulk density varied from 2.37 to 2.46 and 1.33 to 1.50 Mg m⁻³, respectively. The particle density showed decreasing pattern with increasing depth, while in case of bulk density, the depth distribution showed opposite trend (Fig. 4.8) to that of particle density. The value of pore space varied from 37.50 to 45.90 per cent, whereas in expansion of soil, it ranged from 6.66 to 17.60 per cent. The decreasing trend of pore space was observed with increasing depth. In case of expansion of soil, the vertical distribution was irregular.

Pedon 8 (Chauhani Khan) from the Coastal Plain : The scrutiny of Table 4.24 implies that the total sand content ranged between 19.60 and 39.50 per cent. The proportion of fine sand (16.90 to 36.10 per cent) was higher than coarse sand (2.00 to 12.80 per cent). The values for silt content varied from 35.50 to 50.90 per cent and clay content from 22.20 to 38.00 per cent (Fig. 4.7). The proportion of silt fraction was higher followed by clay and sand. Further, it can also be inferred from the results that coarse sand, fine sand, total sand, silt and clay content (Fig. 4.7) could not register any specific trend of distribution along with depth of studied pedon. However, increase of clay content in B₂₁, B₂₂ and IIC₁ horizons, of this pedon is primarily due to (1) differences in original sediment (Sidhu *et al.*, 1976), (2) these clay might be due to dispersion caused by high sodium ion and were translocation by leaching water, (3) translocation clay by monsoon rains in medium textured soils (Barua, 1989). The variation in soil texture was observed within the profile. The silty loam texture was observed in Ap and B₂₁ horizons. The silty clay loam texture was found in B₂₂ and IIC₁ horizon, whereas silty loam in IIC₂ horizon.

The particle and bulk density varied from 2.49 to 2.60 and 1.35 to 1.50 Mg M⁻³, respectively. The particle density increased from 2.49 Mg m⁻³ in sub surface to 2.60 Mg m⁻³ at 'C' horizon. The bulk density increased with increasing soil depth (Fig. 4.8). The values for pore space and expansion of soil varied from 42.30 to 46.00 and 11.52 to 16.65 per cent, respectively. The

pore space decreased with increase depth. However, distribution of expansion of soil with depth was found to be irregular.

4.3.1.3 Machhundri Toposequence (T₃)

Pedon 9 (Fatsar) from the Upper Piedmont : A close look at the Table 4.25 of pedon P₉ shows that total sand, silt and clay ranged from 43.20 to 61.52, 11.28 to 17.76 and 27.20 to 39.20 per cent, respectively. The vertical depth distribution of total sand, silt and clay (Fig. 4.7) was observed uniform in the solum of the pedon. The texture of pedon was clayey in surface and sub surface horizons while it was clay loam in AC horizon.

The particle and bulk density varied from 2.45 to 2.50 and 1.39 to 1.48 Mg m⁻³, respectively. The vertical distribution of particle and bulk density (Fig. 4.8) increased with increasing soil depth. The bulk density in AC horizon was observed > 1.45 Mg m⁻³ (Fig. 4.8), which may due to the high proportion of coarse sand at AC horizon, a fact also corroborated by the findings of Grossman *et al.* (1985) and Singh (1999). The pore space and expansion of soil ranged from 40.80 to 43.30 and 12.24 to 15.68 per cent, respectively. The vertical depth distribution of pore space was regular and it decreased with an increase in the depth, while in case of expansion of soil, it was irregular with depth in the studied pedon.

Pedon 10 (Judavadali) from the Lower Piedmont : A glance at Table 4.25 of pedon P₁₀ show that the content of total sand considerably increased from 25.28 in surface to 49.44 per cent in BC horizon. The proportion of fine sand (Weighted mean 18.01 per cent) was higher than that of coarse sand (Weighted mean 15.46 per cent) (Table 4.27). The content of silt and clay varied from 27.86 to 39.28 and 21.00 to 37.60 per cent, respectively. The vertical distribution of silt fraction was irregular. However, the clay content decreased with increasing soil depth (Fig. 4.7). The uniform silty clay loam texture was observed throughout profile.

The particle and bulk density varied from 2.45 to 2.48 and 1.32 to 1.42 Mg m^{-3} , respectively. The vertical distribution of particle density was irregular. The bulk density gradually and linearly increased with increasing depth throughout the profile (Fig. 4.8). The pore space and expansion of soil varied from 42.70 to 46.10 and 12.85 to 14.53 per cent, respectively. The vertical distribution of pore space decreased with increasing depth. While expansion of soil with depth was found to be irregular.

Pedon 11 (Delawada) from the Piedmont Plain : An appraisal of data in Table 4.25 of pedon P₁₁ unveils that the total sand, silt and clay content varied from 11.67 to 45.53, 22.69 to 48.44 and 26.78 to 39.89 per cent, respectively. The downward movement of clay was observed from surface layer to the lower depth of profile could be the probable reason for the increase in the clay content with depth (Fig. 4.7). Similar results with respect to distribution of clay within the profile were reported by several workers (Desai, 1942; Agarwal *et al.*, 1957; Biswas *et al.*, 1966, and Savalia *et al.*, 2000). The fine sand proportion (8.55 to 36.47 per cent) was higher than coarse sand (3.12 to 10.67 per cent) in total sand fraction. The vertical distribution of total sand, silt and clay (Fig. 4.7) was found irregular. The clay loam texture was found in surface horizon, whereas silty clay loam texture was observed throughout the sub surface horizons.

The particle and bulk density varied from 2.48 to 2.55 and 1.30 to 1.45 Mg m^{-3} , respectively. The vertical distribution of particle density was not systematic, but the bulk density was slightly increasing with increasing depth throughout the pedon (Fig. 4.8). The pore space and expansion of soil varied from 42.00 to 48.00 and 10.40 to 16.85 per cent, respectively. The pore space was slightly decreased with increasing depth. However, depth distribution of expansion of soil was irregular.

Pedon 12 (Rampara) from the Coastal Plain : A perusal of data presented in Table 4.25 of pedon P₁₂ show that the total sand, silt and clay content varied from 22.00 to 44.22, 34.38 to 49.50 and 21.40 to 30.06 per cent, respectively.

The vertical distribution of total sand, silt and clay (Fig. 4.7) was not systematic. The proportion of coarse sand (9.50 to 31.96 per cent) was higher than fine sand (5.93 to 13.29 per cent) in the total sand fraction. The relative proportion of silt fraction was higher followed by total sand and clay. The distribution of clay registered a decrease or increase more than 10 per cent in the sub surface horizons of Pedon P₁₂ indicating its fluvial nature (Sharma, 1994). The silty clay loam texture was observed in surface and sub surface horizons while the silty loam was found below B₂₁ horizon to the IIC₃ horizon of the studied pedon.

The particle density, bulk density and pore space varied from 2.38 to 2.42 Mg m⁻³, 1.40 to 1.60 Mg m⁻³ and 33.90 to 41.20 per cent, respectively. The vertical distribution of particle density and expansion were found irregular. However, the bulk density slightly increased (Fig. 4.8) and pore space was slightly decreased with increasing depth. The expansion of soil was varied from 7.45 to 14.32 per cent.

4.3.1.4 Rayadi Toposequence

Pedon 13 (Dedan) from the Hill Slope : A peak at Table 4.26 of pedon P₁₃ illuminates that the content of total sand, silt and clay were 35.86, 28.94 and 35.20 per cent in surface horizon whereas 60.51, 10.13 and 29.36 per cent in AC horizon, respectively. The relative proportion of coarse sand was much higher (26.90 to 48.32 per cent) than that of fine sand (9.96 to 12.19 per cent) in total sand fraction. The silty clay loam texture was found in surface horizon whereas clay loam texture was observed in AC horizon.

The particle density was found 2.53 and 2.50 Mg m⁻³ in surface and AC horizon, respectively. The bulk density (Fig. 4.8) and pore space found 1.34 Mg m⁻³ and 47.00 per cent at surface horizon and 1.40 Mg m⁻³ and 44.00 per cent in AC horizon, respectively. The expansion of soil was higher (11.63 per cent) in surface horizon than AC horizon (9.35 per cent).

Pedon 14 (Dedan) from the Upper Piedmont : The data furnished in Table 4.26 of pedon P₁₄ indicates that the total sand, silt and clay content varied from 20.27 to 33.07, 31.13 to 38.13 and 35.80 to 44.00 per cent, respectively. The total sand content increased with increasing soil depth. The relative proportion of coarse sand (11.80 to 25.26 per cent) was higher than fine sand (7.33 to 8.48 per cent) in total sand fraction. The depth distribution of silt fraction showed opposite trend to that of total sand. However, the clay content increased (i.e. eluviation of clay) from the surface (41.60 per cent) horizon to the A₁₂ horizon (44.00 per cent). Thereafter, it was decreased upto 35.80 per cent in AC horizon (Fig. 4.7). The silty clay texture was found in surface and sub surface horizons whereas silty clay loam texture was observed in AC horizon.

The particle and bulk density varied from 2.48 to 2.53 and 1.38 to 1.45 Mg m⁻³, respectively. The vertical distribution of particle and bulk density (Fig. 4.8) was increased with increasing depth. The high value of bulk density i.e. >1.4 Mg m⁻³ was observed at AC horizon (1.45 Mg m⁻³) which might be offer some kinds of mechanical impedance to the roots at the lower most horizon (Grossman *et al.*, 1985 and Singh, 1999). The pore space and expansion of soil varied from 42.70 to 44.40, 18.91 to 21.56 per cent, respectively. The pore space decreased with increasing soil depth. However, the depth distribution of expansion of soil was irregular.

Pedon 15 (Chotara) from the Lower Piedmont : The data given in Table 4.26 of pedon P₁₅ point out that the total sand, silt and clay varied from 17.78 to 23.86, 28.42 to 31.94 and 44.20 to 53.80 per cent, respectively. The proportion of coarse sand was higher (11.04 to 14.91 per cent than fine sand (6.66 to 8.95 per cent) in total sand fraction. The relative proportion of clay fraction was higher than silt fraction followed by sand fraction. The content of sand fraction was decreased gradually from 23.86 per cent in surface horizon to 17.78 per cent in lower most horizons. On the other hand, reverse trend was observed in case of clay content (Fig. 4.7) where it was increased from 44.20 per cent at surface horizon to the 53.80 in IIC₂ horizon. The increased clay content with

depth in profile may be ascribe to the down ward movement of fine clay particles. This is in line with the reports of Chakravarty and Barua (1983), Kulkarni *et al.* (1986) and Paramasivam (1992). The silt content decrease with increasing depth. The silty clay texture was observed throughout the profile under study.

The particle density, bulk density and pore space were varied from 2.40 to 2.45 Mg m⁻³, 1.35 to 1.47 Mg m⁻³ and 39.50 to 43.80 per cent, respectively.

The particle density was increased from 2.40 Mg m⁻³ at surface horizon to 2.45 per cent in IIC₁ horizon. Thereafter, it was decreased up to 2.43 Mg m⁻³ in lower most horizon. The bulk density value > 1.4 Mg m⁻³ was observed in IIC₁ (1.43 Mg m⁻³) and in IIC₂ horizon (1.47 Mg m⁻³) which may be offer some kinds of mechanical impedance (clay pan) to the roots at the lower depths (Grossman *et al.*, 1985 and Singh, 1999). The pore space and expansion of soil varied from 39.50 to 43.80 and 20.52 to 25.10 per cent, respectively. The pore space was decreased from surface horizon (43.80 per cent) to lower most horizons (39.50 per cent). The expansion of soil was the highest in all the horizons as compared to the rest of the pedons due to high clay content (44.20 to 53.80 per cent) (Table 4.26) and dominant of smectite in clay fraction throughout the profile under study (Table 4.19).

Pedon 16 (Kadiyali) from the Coastal Plain : The data bestowed in Table 4.26 expound that the total sand, silt and clay content varied from 19.74 to 48.92, 28.80 to 49.61 and 20.20 to 31.40 per cent, respectively. The relative proportion of fine sand (13.07 to 41.86 per cent) was higher than coarse sand (6.14 to 24.35 per cent) in total sand fraction. The relative proportion of silt fraction (weighted mean 39.07 per cent) was considerably higher than sand (weighted mean 35.66 per cent) followed by silt (weighted mean 25.27 per cent) fraction (Table 4.27). The vertical distribution of total sand, silt and clay (Fig. 4.7) was found irregular. The highly variation in texture was observed within the profile under study. The silty loam texture was observed in Ap, B₂₃

and BC horizons, while the silty clay loam was identified in B₂₁ and B₂₂ horizons of studied pedon.

The particle density, bulk density and pore space varied from 2.38 to 2.42 Mg m⁻³, 1.40 to 1.52 Mg m⁻³ and 37.20 to 41.70 per cent, respectively. The vertical distribution of particle density was irregular. However, the bulk density increased from 1.40 Mg m⁻³ in the surface horizon to 1.52 Mg m⁻³ to the lowest most horizon (Fig. 4.8). The bulk density of > 1.4 Mg m⁻³ below surface horizon may offer some kind of mechanical impedance (clay pan) to the root growth in lower depth (Grossman *et al.*, 1985 and Singh, 1999). The lower values of pore space in B₂₂, B₂₃ and BC horizons might be due to presence of soft powdery lime (CaCO₃ 46.50 to 65.00 per cent) (Table 4.36) that fills the voids created by lime concretions (Singh, 1999). The expansion of soil varied from 12.00 to 17.87 per cent. The expansion of soil decreased from 17.87 per cent in the surface horizon to the 12.00 per cent in parent material in BC horizon.

4.3.1.5 Land Slopes

The weighted mean data of mechanical composition and some other physical characteristics of pedons from five land slopes across the different toposequences of southern Saurashtra are presented in Table 4.27.

(A) Hill slope (LS-1): The total sand, silt and clay content varied from 39.07 to 47.30, 20.21 to 33.46 and 27.47 to 32.49 per cent with the mean value of 43.18, 26.84 and 29.98 per cent, respectively (Table 4.27). The relative proportion of total sand fraction was higher followed by clay and silt, while in case of total sand fraction, coarse sand (28.90 per cent) was double than fine sand (14.28 per cent). The particle density, bulk density and pore space varied between 2.44 to 2.52 Mg m⁻³, 1.28 to 1.37 Mg m⁻³ and 45.60 to 47.75 per cent with the mean value of 2.48 Mg m⁻³, 1.33 Mg m⁻³ and 46.68 per cent, respectively. The bulk density value was higher (1.37 Mg m⁻³) in pedon P₁₃

(Dedan) at eastern area than P₁ (Sasan) at western area (1.28 Mg m⁻³). The expansion of soil varied from 10.57 to 11.14 per cent with mean value of 10.86 per cent. This might be due to high clay content dominant with smectite clay minerals present in the soils.

(B) Upper piedmont (LS-2) : The total sand, silt and clay content varied from 22.46 to 47.40, 16.26 to 37.74 and 29.48 to 41.55 per cent with the mean value of 34.94, 30.00 and 35.06 per cent, respectively (Table 4.27), indicating about equal relative proportion of total sand (34.94 per cent) and clay fraction (35.00 per cent) followed by silt in soil separate. The relative proportion of coarse sand (21.09 per cent) was higher than fine sand (13.84 per cent) in total sand fraction. The highest clay content (41.55 per cent) was observed in pedon-P₁₄ (Dedan) of Rayadi toposequence (T₄) followed by P₉ (Fatsar) of Machhundri toposequence (36.34 per cent) and P₂ (Borvav) of Hiran toposequence (32.88 per cent) indicating when traverse from west to east in upper piedmont, the proportion of fineness of soil particles increased. The particle density, bulk density and pore space ranged between 2.41 to 2.50 Mg m⁻³, 1.32 to 1.42 Mg m⁻³ and 42.45 and 45.37 per cent with the mean value of 2.46 Mg m⁻³, 1.38 Mg m⁻³ and 44.03 per cent, respectively (Table 4.27). The highest particle density (2.50 Mg m⁻³) was observed in pedon-P₁₄ (Dedan) of Rayadi toposequence, while minimum (2.41 Mg m⁻³) was in P₅ (Jamawala) of Shingoda toposequence. The maximum bulk density (1.42 Mg m⁻³) was observed in P₉ (Fatsar) of Machhundri toposequence followed by P₁₃ (Dedan) of Rayadi toposequence (1.40 Mg m⁻³). The minimum bulk density (1.32 Mg m⁻³) was observed in pedon-P₅ (Jamawala) of Shingoda toposequence and P₂ (Borvav) of Hiran toposequence. The highest pore space was observed in P₂ (Borvav) of Hiran toposequence followed by P₅ (Jamawala) of Shingoda toposequence and P₄ (Kajali) of Hiran toposequence. The minimum pore space was recorded in P₉ (Fatsar) of Machhundri toposequence. The expansion of soil varied widely and ranged from 14.24 to 20.48 per cent with a mean value of 16.46 per cent indicating the soils of Upper piedmont were highly expansible. This might be due to high clay content (35.06 per cent) and

dominance of expandable smectite type of clay minerals (Table 4.22). The maximum expansion of soil (20.48 per cent) was observed in pedon-P₁₄ (Dedan) of Rayadi toposequence followed by P₂ (Borvay) of Hiran toposequence and P₅ (Jamawala) of Shingoda toposequence. The minimum expansion of soil was observed in P₉ (Fatsar) of Machhundri toposequence.

(C) Lower piedmont (LS-3) : The total sand, silt and clay content ranged from 20.56 to 50.77, 29.99 to 38.87 and 16.40 to 49.45 per cent with the mean value of 31.45, 34.10 and 34.45 per cent, respectively (Table 4.27) indicating about equal proportion of silt and clay fraction in lower piedmont area. The proportion of coarse sand was considerably higher (17.24 per cent) than fine sand (14.21 per cent) in total sand fraction. The content of total sand varied widely. The highest total sand (50.77 per cent) was observed in pedon-P₆ (Kareda) of Shingoda toposequence and lowest (20.56 per cent) in P₁₅ (Chotara) of Rayadi toposequence. The highest clay content (49.45 per cent) was recorded in P₁₅ (Chotara) of Rayadi toposequence followed by P₃ (Maljinjava) of Hiran toposequence and P₁₀ (Judavadali) of Machhundri toposequence. The particle density, bulk density and pore space varied from 2.43 to 2.50 Mg m⁻³, 1.36 to 1.57 Mg m⁻³ and 36.93 to 44.77 per cent, with the mean value of 2.47 Mg m⁻³, 1.44 Mg m⁻³ and 41.76 per cent, respectively. The maximum bulk density (1.57 Mg m⁻³) was recorded in pedon-P₆ (Kareda) of Shingoda toposequence followed by P₃ (Maljinjava) of Hiran toposequence as well as P₁₅ (Chotara) of Rayadi toposequence and P₁₀ (Judavadali) of Machhundri toposequence. The highest pore space (44.77 per cent) was observed in P₁₀ and lowest (36.93 per cent) in P₆. The expansion of soil ranged between 8.96 and 23.76 per cent with a mean value of 16.10 per cent. The expansion of soil was observed highest (23.76 per cent) in pedon-P₁₅ (Chotara) of Rayadi toposequence followed by P₃ (Maljinjava) of Hiran toposequence and P₁₀ (Judavadali) of Machhundri toposequence. The lowest expansion of soil (8.96 per cent) was observed in P₆ (Kareda) of Shingoda toposequence.

(D) Piedmont plain (LS-4) : The total sand, silt and clay content ranged from 22.68 to 51.87, 22.68 to 39.22 and 25.45 to 38.10 per cent with the mean value of 33.73, 33.68 and 32.59 per cent, respectively indicating about equal proportion of total sand, silt and clay fraction in piedmont plain area. The coarse sand was slight higher (17.86 per cent) than fine sand (15.82 per cent) in total sand fraction. The highest total sand, silt and clay content were observed in pedon-P₇ (Devali) of Shingoda toposequence, P₄ (Kajali) of Hiran toposequence and P₁₁ (Delawada) of Machhundri toposequence, respectively. While, the lowest total sand, content was observed in pedon-P₄ (Kajali) and the lowest silt and clay content in pedon-P₇ (Devali) of Shingoda toposequence. The particle density, bulk density and pore space ranged from 2.41 to 2.51 Mg m⁻³, 1.40 to 1.44 Mg m⁻³ and 40.79 to 44.05 per cent with the mean value of 2.46 Mg m⁻³, 1.42 Mg m⁻³ and 42.06 per cent, respectively. There were no wide variation in particle density, bulk density and pore space within the pedon in piedmont plain area. However, wide variation observed in case of expansion of soil, where it was ranged from minimum 10.74 per cent in pedon-P₇ (Devali) of Shingoda toposequence to the maximum of 18.60 per cent in P₄ (Kajali) of Hiran toposequence.

(E) Coastal plain (LS-5) : The total sand, silt and clay content varied from 25.02 to 35.66, 39.07 to 43.98 and 24.65 to 31.0 per cent with the mean value of 30.97, 42.06 and 26.97 per cent, respectively (Table 4.27) indicating higher proportion of silt fraction followed by total sand and minimum of clay. The relative proportion of fine sand (18.32 per cent) was one and half times higher than coarse sand (12.60 per cent) in total sand fraction. The highest total sand content was observed in pedon-P₁₆ (Kadiyali) of Rayadi toposequence followed by P₁₂ (Rampara) of Machhundri toposequence and P₈ (Chauhani Khan) of Shingoda toposequence. The highest silt content was observed in pedon-P₈ (Chauhani Khan) followed by P₁₂ (Rampara) and P₁₆ (Kadiyali) and the highest clay content was recorded in P₈ (Chauhani Khan) followed by P₁₆ (Kadiyali) and P₁₂ (Rampara). The particle density, bulk density and pore space ranged from 2.40 to 2.55 Mg m⁻³, 1.44 to 1.53 Mg m⁻³ and 36.44 to 43.56 per cent with

the mean value of 2.45 Mg m^{-3} , 1.48 Mg m^{-3} and 39.57 per cent, respectively. The highest particle density was observed in pedon-P₈ (Chauhani Khan) followed by P₁₂ (Rampara) as well as P₁₆ (Kadiyali) whereas that of bulk density was observed (1.53 Mg m^{-3}) in P₁₂ (Rampara) followed by P₁₆ (Kadiyali) and P₈ (Chauhani Khan). However, there was no wide variation in pore space within the pedons in the coastal plain area. The expansion of soil varied between 10.28 to 14.49 per cent with a mean value of 12.12 per cent. The highest expansion of soil was observed in pedon-P₁₆ (Kadiyali) followed by P₈ (Chauhani Khan) and P₁₂ (Rampara).

Overall in Southern Saurashtra Region

In general, it can be inferred from the weighted mean data of mechanical composition and other soil physical characteristics from different land slopes across the toposequences of southern Saurashtra (Table 4.27) that the total sand, silt and clay content were varied from 20.56 to 51.87, 16.26 to 43.98 and 16.40 to 49.45 per cent with the mean value of 35.27, 32.44 and 32.29 per cent in the soils of southern Saurashtra, respectively. The distribution of total sand content was found to be in the decreasing order of : Hill slope > Upper piedmont > Piedmont plain > Lower piedmont > Coastal plain (Fig. 4.9). The similar trend was observed in the distribution of coarse sand fraction in the soils of different land slopes of southern Saurashtra. However, the distribution of fine sand from hill slope to coastal plain was not found consistent.

As far as silt content is concerned, it was found to be in the following increasing sequence : Hill slope < Upper piedmont < Lower piedmont < Piedmont plain < Coastal plain (Fig. 4.9) indicating the ingration of silt fraction (fine fraction) of the soil particles from higher topography to the lower topography as silt particles are highly vulnerable to water erosion (Sharma and Dev, 1985a, Sharma and Roychowdhury, 1988; Prasad *et al.*, 1989; Singh *et al.*, 1991; Nizeyimina and Bicki, 1992; Ramana Murthy and Sharma, 1992; Sharma, 1994 and Sharma, 1995).

Looking to the clay content, it was found to be in the following decreasing order : Upper piedmont > Lower piedmont > Piedmont plain > Hill slope > Coastal plain (Fig. 4.9) indicating no definite trend in distribution of clay fraction from hill slope to coastal plain might be due to the clay is not affected by weathering factor.

The particle density ranged from 2.40 to 2.55 Mg m^{-3} with a mean value of 2.46 Mg m^{-3} . However, there was no variation in particle density values in different land slopes of southern Saurashtra. The bulk density and pore space varied between 1.28 to 1.57 Mg m^{-3} and 36.44 to 47.75 per cent with the mean value of 1.41 Mg m^{-3} and 42.59 per cent, respectively. The bulk density values observed in the following increasing order : Hill slope < Upper piedmont < Coastal plain < Piedmont plain < Lower piedmont (Fig. 4.10). The higher bulk density observed from lower piedmont to the coastal plain might be attributed to the presence of some heavy minerals and compaction of all the micropeds (Paramasivam, 1992). The high values of bulk density i.e. > 1.4 Mg m^{-3} observed in most of the pedons from lower piedmont to the coastal plain area may cause the mechanical impedance to the roots at the lower depth (Grossman *et al.*, 1985 and Singh, 1999), which might not be favourable for the orchards, forestry and horticultural crops, but favourable only for shallow rooted field crops. The soils of hill slope and upper piedmont area have low value of bulk density i.e. 1.33 and 1.38 Mg m^{-3} , respectively indicating easy penetration of roots to the lower depth and are more favourable for horticultural crops, orchards, forestry and deep rooted crops. The pore space and expansion of soil ranged from 36.44 to 47.75 and 8.96 to 23.76 per cent, with the mean of 42.59 and 14.52 per cent, respectively. The packing patterns of soil fragments determined the total porosity of the soils. The pore space and expansion of soil were observed in the decreasing sequences of Hill slope > Upper piedmont > Coastal plain > Piedmont plain > Lower piedmont and Upper piedmont > Lower piedmont > Piedmont plain > Coastal plain > Hill slope, respectively. The pedon-P₁₂ of Rampara in Machhundri toposequence and P₁₆ of Kadiyali in Rayadi toposequence in the coastal plain area and pedon P₆ (Kareda) of

Shingoda toposequence have < 40.00 per cent pore space in the profiles indicating poor air-moisture regime. These findings are akin to those of Pal (1976) who suggested that the total porosity less than 40 per cent in the profile indicating the poor air-moisture regime.

4.3.2 Hydrological Characteristics

The hydrological properties of soil are important in the management of irrigated agriculture. The hydrologic properties of soils like saturated hydraulic conductivity, infiltration rate, MWHC, field capacity, PWP, available water capacity, PAWC, moisture retention characteristic and profile water storage capacity are the basic information required in planning of an effective system of soil and water management particularly under semi arid regions. All the above mentioned hydrological characteristics are presented and discussed here in this chapter as follows :

4.3.2.1 Hiran toposequence

The data pertaining to hydrological characteristics of the pedons P_1 to P_4 of Hiran toposequence are presented in Table 4.28 and moisture retention characteristics curves of the pedon P_1 to P_4 (weighted mean) are graphically exhibited in Fig. 4.14.

Pedon 1 Sasan (Gir) from the Hill slope : A close look at Table 4.28 shows that the maximum water holding capacity varied from 35.88 to 50.18 per cent with maximum of 50.18 per cent in A_{12} horizon due to high clay content (31.70 per cent) in this horizon (Table 4.28 & Fig. 4.11). The saturated hydraulic conductivity of the pedon decreased with increasing depth (Fig. 4.12) having the slow rate at surface (0.38 cm hr^{-1}) to very slow (0.09 cm hr^{-1}) at parent material (AC horizon). This might be due to the dominant proportion of smectite clay at surface as compared to sub surface horizon and have much more micro pores causing poor water transmission properties. The infiltration rate was moderately slow (1.23 cm hr^{-1} and Fig.4.13).

The moisture retention at field capacity (0.03 MPa) and wilting point (1.5 MPa) varied from 0.37 to 0.46 and 0.17 to 0.21 $\text{m}^3 \text{m}^{-3}$, respectively (Table 4.28). The variation was restricted to low tension (0.03 and 0.05 MPa) as the structure and pore geometry of the soils play an import role in retention, whereas at higher tension (0.10 to 1.5 MPa) there was a little variations possibly due to moisture retention on surface of the clays. Higher field capacity values associated with clay showed a corresponding increase in water retention at 1.5 MPa. These findings are in vicinity of those reported by Antony (1986), Challa and Gaikwad (1987), Tiwary *et al.* (1989) and Parmasivam (1992). The moisture retention characteristics curve of the pedon P₁ (weighted mean) are illustrated graphically in Fig. 4.14. Further, it can also be inferred from the data (Table 4.28) that the values of moisture retention at different bars were recorded higher in A₁₂ horizon as compared to A₁ and AC horizon. Similar, results were also recorded by Sharma (2000). The amount of available watent content varied between 0.18 to 0.25 $\text{m}^3 \text{m}^{-3}$. The available water content was more in sub surface layer compared to surface layer (Fig. 4.15). The moisture held between the field capacity (0.033 MPa) and permanent wilting point (PWP) (1.5 MPa) may not be actually available to crops though it is considered available. Hence, plant available water capacity (PAWC) was calculated to draw an inference for water retention behaviour of the soil under study. The maximum water holding capacity (v/v), plant available water capacity and moisture retention (Fig. 4.16) varied from 47.36 to 64.23 per cent, 1.44 to 4.50 cm ha^{-1} and 3.79 to 11.56 cm ha^{-1} , respectively. The MWHC (v/v), PAWC and moisture retention values were recorded higher in subsurface as compared to surface horizon. Suitable management practices can be adopted to minimize the risk of crop failure in the rainfed agriculture with the knowledge of water storage capacity of soil in addition to rainfall characteristics. The total plant available water capacity (Total PAWC) of the profile was recorded 0.099 m ha^{-1} (39 per cent) out of 0.255 m ha^{-1} of total water storage capacity of pedon P₁

(Table 4.28 & Fig. 4.17) indicating very little plant available water capacity and low water storage capacity. This is due to shallow depth in hill slope area as well as loss of water due to runoff. The PAWC/WSC ratio was found 0.388.

Podon 2 (Borvav) from the Upper piedmont : The data of Table 4.28 show that maximum water holding capacity ranged from 34.50 to 48.83 per cent. The vertical distribution of maximum water holding capacity was irregular (Fig. 4.11). The saturated hydraulic conductivity varied from 0.08 to 0.18 cm hr⁻¹ (Table 4.28) with a weighted mean of 0.14 cm hr⁻¹ (Table 4.32) indicating the soils are slow in hydraulic conductivity. The rate of hydraulic conductivity decreased with increasing (Fig. 4.12). The reduction in hydraulic conductivity irrespective of a reducing clay content with depth may be attributed to the found that the soils on the surface is better aggregated (B.D. 1.35) as compared to the soils in the lower horizons (B.D. > 1.4). These findings are corroborated by those reported by Paramsivam (1992). The infiltration rate was 0.78 cm hr⁻¹ (Fig. 4.13) indicating the moderately slow infiltration rate. This may be due to the dominant proportion of smectite clay (Table 4.28) and have much more micropores causing poor water transmission properties. The low infiltration rate was also recorded in the soils of Hiran-II command area in southern Saurashtra (0.25 to 0.87 cm hr⁻¹) (NWR & WSD, 1999).

The moisture held at 0.03 MPa and 1.5 MPa varied between 0.41 to 0.44 and 0.19 to 0.22 m³ m⁻³, respectively (Table 4.28). The moisture retention characteristic curve of pedon P₂ (weighted mean) are graphically exhibited in Fig. 4.14. It appears that most of the water (50 to 60 %) retained by the soil is depleted upto 0.50 MPa tension. The similar results were reported by Kaushal *et al.* (1986). Above 0.50 MPa tension the water released with each increment of tension was very slow and in narrow range at different depth. The low content of water was found at 1.5 MPa.

A close look at Table 4.28 shows that available water content (AWC) and volumetric moisture percentage of MWHC (v/v) were found between 0.20 m³ m⁻³ to 0.23 and 48.30 to 65.92 per cent, respectively. The vertical

distribution of available water capacity with depth (Fig. 4.15) showed a similar trend as with the volumetric moisture percentage at MWHC (v/v). The available water content and MWHC (v/v) observed higher in subsurface horizon as compared to surface horizon. The plant available water capacity and moisture retention ranged from 2.30 to 4.40 and 6.59 to 11.83 cm ha⁻¹, (Fig. 4.16), respectively. The plant available water capacity and moisture retention were higher in surface horizon than subsurface horizon. The vertical distribution of plant available water capacity with depth showed a similar pattern as with the moisture retention. The total PAWC of the profile recorded 0.097 m ha⁻¹ (38.0 per cent) out of 0.257 m ha⁻¹ of total water storage capacity of pedon P₂ (Table 4.28 & Fig. 4.17) indicating very low PAWC, which might be due to the shallow depth of soil in upper piedmont area. These findings are parallel to those of Singh (1999), Walia *et al.* (1999) and Sharma (2000) who reported that water storage capacity of soil influenced by soil depth. The PAWC/WSC ratio was recorded 0.377.

Pedon 3 (Maljinjava) from the Lower piedmont : An appraisal of data on hydrological characteristics are depicted in Table 4.28 unveils that the maximum water holding capacity (MWHC) i.e. between 40.00 to 56.00 per cent and it was maximum at the surface (56.00 per cent) thereafter, it was gradually decreased with increasing soil depth upto the IIC₁ horizon. Similarly, the MWHC was found to be decrease with depth in the profile (Fig. 4.11), which may be attributed to the decrease level of clay content (Table 4.28). Similar result was also observed by Shukla and Roychaudhury (1966), Sharma (1994) and Sharma (1995). It is inferred from the data that the MWHC was observed in higher range (40.00 to 56.06 per cent) (Fig. 4.11), which may be attributed to the higher range of clay content (35.00 to 43.50 per cent) (Table 4.23) in studied pedon. The saturated hydraulic conductivity gradually increased from 0.03 cm hr⁻¹ in the surface horizon to 0.16 cm hr⁻¹ in the lower most horizon (Fig. 4.12) with the weighted mean of 0.08 cm hr⁻¹ (Table 4.28) indicating very low hydraulic conductivity. It might be due to the increase in bulk density (1.33 to 1.48 Mg m⁻³) with increasing the soil depth. The

infiltration rate was recorded 0.63 cm hr^{-1} (Fig. 4.13) indicating the soil associated with this pedon were moderately slow in infiltration rate. It might be due to the soil having high clay content (35 to 43.50 per cent) (Table 4.23). The results are in concurrence with those obtained by Savalia *et al.* (2000). The moisture content at 0.03 and 1.5 MPa ranging from 0.46 to 0.49 and 0.19 to $0.23 \text{ m}^3 \text{ m}^{-3}$, respectively (Table 4.28). The moisture retention was highest in B₂₁ horizon up to 0.10 MPa tension might be due to more CaCO₃ content (22 per cent) (Table 4.33) in B₂₁ horizon as compared to other horizons. Similar, results were also evidenced by Prasad *et al.* (1998). The moisture retention characteristics curve of pedon P₃ (weighted mean) also depicted graphically in Fig. 4.14 shows that with increase in tension, the soil water content decreased at more or less similar rate upto 0.50 MPa. It appear that most of water retained by the soil is depleted upto 0.5 MPa tension. The available water capacity (Fig. 4.15) and MWHC (v/v) ranged from 0.25 to $0.27 \text{ m}^3 \text{ m}^{-3}$ and 59.20 to 74.78 per cent, respectively (Table 4.26). The vertical distribution of available water content with depth (Fig. 4.15) showed a similar trend as with the MWHC (v/v). The plant available water capacity and moisture retention (Fig. 4.16) ranged from 5.00 to 5.40 and 11.83 to 14.96 cm ha^{-1} , respectively (Table 4.28). The vertical distribution of plant available water capacity with depth showed a similar trend as with the available water content, MWHC (v/v) and moisture retention. The total PAWC of the profile was observed 0.210 m ha^{-1} out of 0.537 m ha^{-1} (39 per cent) of total water storage capacity of the pedon P₃ (Table 4.28 & Fig. 4.17). Paramshivam (1992) also reported the 18.58 to 22.35 cm available water holding power of different pedons of Koduveri soil series of lower Bhavani project command area of Tamil Nadu. The fraction of PAWC/WSC was identified 0.391. (Table 4.28).

Pedon 4 (Kajali) from the Piedmont plain : A perusal of data on hydrological characteristics are given in Table 4.28 stipulate that the maximum water holding capacity lie from 40.10 to 48.20 per cent. However, it can also be inferred from the data that maximum water holding capacity could not registered any specific trend of distribution along depth of the studied pedon

(Fig. 4.11). The saturated hydraulic conductivity of this pedon varied from 0.02 to 0.03 cm hr⁻¹ (Fig. 4.12) indicating very slow hydraulic conductivity. This might be due to the high exchangeable sodium which induces high dispersion of the clay in these soils and which lead to clogging of most of the micropores, thus causing compaction in the subsurface horizon (Paramsivam, 1992).

The infiltration rate recorded in this pedon was 0.54 cm hr⁻¹ (Fig. 4.13) indicating that the soils of this pedon were moderately slow in infiltration rate. This might be due to the surface sealing of pores. The non-capillary pores may become capillary in size and smaller capillary pores might be sealed which may affect the rate of movement of water and decrease the infiltration (Ghildyal and Tripathi, 1987). The amount of water held at 0.03 and 1.5 MPa varied from 0.50 to 0.59 and 0.21 to 0.24 m³ m⁻³, respectively (Table 4.28). Perusal of data revealed that at the surface layer water retained was low as compared to subsurface layers between 0.03 to 0.5 MPa tensions. The vertical distribution of moisture content at 0.03 MPa with depth showed a similar pattern as with the clay content. The moisture retention characteristics curve of pedon P₄ (weighted mean) is shown graphically in Fig. 4.14. The available water capacity (Fig. 4.15) and MWHC (v/v) vary from 0.29 to 0.35 m³ m⁻³ and 57.82 to 71.52 per cent, respectively. The available water content and MWHC (v/v) increased with depth in the solum of the pedon. The PAWC and moisture retention ranged from 9.90 to 22.40 and 19.45 to 44.93 cm ha⁻¹, respectively (Table 4.28). The vertical distribution of PAWC and moisture retention (Fig. 4.16) showed an irregular trend. The total PAWC of the profile was 0.767 m ha⁻¹ (about 50 per cent) out of 1.539 m ha⁻¹ of total water storage capacity of pedon (Table 4.28 & Fig. 4.17) indicating very high plant available water capacity and water storage capacity of the profile. This might be due to smectite type of clay and high clay coupled with higher exchangeable sodium. Thus, it also corroborated by the finding of Paramsivam (1992). The wide

PAWC/WSC ratio of 0.498 may be due to very deep soil (200 cm) which have more storage capacity.

4.3.2.2 Shingoda toposequence (T₂)

The data on hydrological characteristics of the pedons P₅ to P₈ of Shingoda toposequence are depicted in Table 4.29, while the moisture retention characteristics curve (weighted mean) of the pedons P₅ to P₈ are depicted in Fig. 4.14.

Pedon 5 (Jamwala) from the Upper piedmont : A perusal of the data in Table 4.29 shown the hydrological characteristics of the pedon P₅ reveal that the maximum water holding capacity ranged from 40.40 to 45.20 percent, whereas the saturated hydraulic conductivity ranged from 0.08 to 0.17 cm hr⁻¹, respectively. The maximum water holding capacity (Fig. 4.11) and saturated hydraulic conductivity (4.12) decreased gradually from 45.20 per cent and 0.17 cm hr⁻¹ in surface horizon to 40.40 per cent and 0.08 cm hr⁻¹ in BC horizon, respectively. The weighted mean of saturated hydraulic conductivity was recorded 0.12 cm hr⁻¹ (Table 4.32), indicating very slow saturated hydraulic conductivity. The lower value of saturated hydraulic conductivity in this pedon might be ascribed to higher smectite dominant clay, which swells on wetting (Diwakar and Singh, 1992). The infiltration rate of the pedon was 0.80 cm hr⁻¹ (Fig. 4.13) indicating moderately slow infiltration rate. Such moderately slow infiltration rate (1.43 cm hr⁻¹) reported were also earlier by Savalia *et al.* (2000) in medium black soils of Uben irrigation command area in north Saurashtra

region. Narmada Water Resources and Water Supply Deptt., Gujarat State (NWR & WSD, 2000) has also reported the infiltration rate to range from 1.04 to 1.37 cm hr⁻¹ in the medium black soils of Shingoda Irrigation command area in southern Saurashtra.

The moisture held at 0.03 MPa varies from 0.40 to 0.43 m³ m⁻³ whereas moisture content at 0.05 and 1.5 MPa were constant i.e. 0.34 and 0.22 m³ m⁻³, respectively, through out profile (Table 4.29). The curvilinear part of the moisture retention curve (Fig. 4.14) reveals that loosely bound water was retained up to 0.10 MPa, while strongly adsorbed water was represented by almost parallel line to X-axis beyond this suction in question. The loosely bound water between 0.30 to 0.1 Mpa is accumulated in structural pores (Singh *et al.*, 2001). The amount of available water content and MWHC (v/v) found between 0.18 to 0.21 m³ m⁻³ and 55.35 to 58.95 per cent, respectively (Table 4.29). The available water content decreased with increasing depth (Fig. 4.15). However, such type of trend was irregular in case of MWHC (v/v). The PAWC and moisture retention varied from 1.80 to 5.70 and 5.65 to 16.61 cm ha⁻¹, respectively (Table 4.29). The vertical distributions of PAWC and moisture retention (Fig. 4.16) were not found in systematic manner. The PAWC and moisture retention were higher in subsurface than surface horizon. The total PAWC of the profile recorded was 0.128 m ha⁻¹ (35 per cent) out of 0.370 m ha⁻¹ of total water storage capacity of pedon P₅ (Table 4.29 & Fig. 4.17) indicating low PAWC. Thus might be due shallow depth of the pedon in upper piedmont area (Singh, 1999; Walia *et al.*, 1999 and Sharma, 2000). The PAWC/WSC ratio observed was 0.346 (Table 4.29).

Pedon 6 (Kareda) from the Lower piedmont : The data in Table 4.29 indicated the hydrological characteristics of the pedon P₆ that the maximum water holding capacity ranged from 31.80 to 34.00 per cent (Fig. 4.11), whereas saturated hydraulic conductivity ranged from 0.11 to 0.17 cm hr⁻¹ (Fig. 4.12). The lower water holding capacity of this pedon might be due to the high bulk density (1.54 to 1.60 Mg m⁻³) as recorded during the

present study (Table 4.24). The weighted mean of saturated hydraulic conductivity recorded 0.14 cm hr^{-1} (Table 4.32) indicating a very slow saturated hydraulic conductivity. This might be due to the increase in bulk density (1.54 to 1.50 Mg m^{-3}) with increasing soil depth. The infiltration rate was found 1.12 cm hr^{-1} (Fig. 4.13) indicating moderately slow infiltration rate of these soils. Similar results were also reported by Savalia *et al.* (2000) who reported 1.43 cm hr^{-1} infiltration rate in calcareous black soils of Uben command area in north Saurashtra region. This fact also corroborated by the findings of NWR and WSD (2000) in the same soils of Shingoda command area in southern Saurashtra.

The moisture retention at 0.03 and 1.5 MPa ranged from 0.26 to 0.32 and 0.10 to $0.11 \text{ m}^3 \text{ m}^{-3}$, respectively (Table 4.29). The moisture retention characteristics curve of the pedon P_6 (weighted mean) are displayed graphically in Fig. 4.14. It is inferred from the that very low amount of water was loosely found between 0.03 to 0.1 MPa , whereas very low amount of strongly adsorbed water retained above 0.5 MPa tension. This might be due to the soils have low clay content associated with the pedon P_6 were situated at micro-elevations, i.e. in between the area of upper and lower piedmont and shallow depth. The available water content and MWHC (v/v) varied from 0.16 to $0.21 \text{ m}^3 \text{ m}^{-3}$ and 49.89 to 52.36 per cent, respectively (Table 4.29). The available water content decreased with increasing depth (Fig. 4.15). The vertical distribution of MWHC (v/v) was found irregular. The PAWC and moisture retention vary from 3.20 to 4.20 and 9.98 to 10.47 cm ha^{-1} , respectively (Table 4.29). The PAWC and moisture retention (Fig. 4.16) were somewhat higher in surface horizon. However, more or less uniform distribution of moisture retention was observed in pedon P_6 . The PAWC was found 0.114 m ha^{-1} (37 per cent) out of 0.309 m ha^{-1} of total water storage capacity of the pedon P_6 (Fig. 4.17) having PAWC/WSC ratio 0.369 (Table 4.29).

Pedon 7 (Devali) from the Piedmont plain : The data on hydrological characteristics of pedon P₇ are presented in Table 4.29. The maximum water holding capacity varied from 25.70 per cent at the IIC₃ horizon to the maximum i.e. 56.10 per cent at the surface. Thus inferred from the data that the maximum water holding capacity showed decreasing trend with increasing depth (Fig. 4.11). The maximum water holding capacity was higher in surface and subsurface as compared to lower horizons due to the high clay content (35.30 to 36.10 %) (Table 4.24) in surface and subsurface horizons as compared to lower depths. The saturated hydraulic conductivity of this pedon increased with increasing soil depth having very slow rate (0.11 cm hr⁻¹) at the surface to the slow rate (0.25 cm hr⁻¹) in parent material at IIC₃ horizon (Fig. 4.12). The very slow rate of saturated hydraulic conductivity was observed in surface (0.11 cm hr⁻¹) and sub surface (0.12 cm hr⁻¹) due to high clay content (35.30 to 36.10 per cent) (Table 4.24). The infiltration rate was observed 0.78 cm hr⁻¹ (Fig. 4.13) indicating moderately slow infiltration rate.

The moisture retention at 0.03 MPa ranged from 0.27 to 0.48 m³ m⁻³, whereas at 1.5 MPa it was found constant value i.e. 0.21 m³ m⁻³ up to the IIC₁ horizon, but there after it was decreased (Table 4.29). Further, it can also be inferred from data that the moisture retention value was recorded higher in subsurface horizon (B₂₁) at 0.03 MPa while reverse trend was observed at 0.05 MPa (Table 4.29). The moisture retention characteristics curve of the pedon P₇ (weighted mean) furnished graphically in Fig. 4.14. The available water content and MWHC (v/v) were ranged from 0.13 to 0.27 m³ m⁻³ and 38.51 to 74.67 per cent, respectively (Table 4.29). The vertical distribution of available water content (Fig. 4.15) and MWHC (v/v) found irregular. The PAWC and moisture retention varied from 2.16 to 7.02 and 5.61 to 20.16 cm ha⁻¹, respectively (Table 4.29). The vertical distribution of PAWC and moisture retention (Fig. 4.16) with depth was found irregular. The data PAWC of the profile was identified 0.238 m ha⁻¹ (38 per cent) out of 0.622 m ha⁻¹ of total water storage capacity of pedon P₇ (Fig. 4.17) having PAWC/PWC ratio of 0.383 (Table 4.29).

Pedon 8 (Chauhani Khan) from the Coastal plain : The data concerning on hydrological characteristics are furnished in Table 4.29 shows that the maximum water holding capacity varied from 35.00 to 53.34 per cent. The vertical distribution of maximum water holding capacity was systematic and it was increased gradually with an increasing the depth (Fig 4.11). The saturated hydraulic conductivity of the soil was observed 0.01 cm hr^{-1} throughout the profile (Fig. 4.12) indicating very slow in hydraulic conductivity. The reasons for the same are described earlier in this text as per the pedon P_4 of Hiran toposequence. The infiltration rate of soil was observed 0.60 cm hr^{-1} indicating moderately slow infiltration rate of soil. The reasons for slow infiltration rate are described earlier in this text as per the pedon P_4 (Kajali) of Hiran toposequence.

The moisture held at 0.03 and 1.5 MPa tensions varied between 0.46 to 0.56 and 0.21 to $0.23 \text{ m}^3 \text{ m}^{-3}$, respectively (Table 4.29). The moisture retention at 0.03 and 0.05 MPa was increased with increasing depth upto IIC_1 horizon thereafter at IIC_2 horizon, it was slightly decreased. The trend was similar as that of clay content. The moisture retention was increased with increasing depth at 0.10 MPa. The moisture retention characteristics curve of the pedon P_8 (weighted mean) arranged graphically in Fig. 4.14. The available water content and MWHC (v/v) ranged from 0.25 to $0.33 \text{ m}^3 \text{ m}^{-3}$ and 47.28 to 80.07 per cent, respectively (Table 4.29). The available water capacity increased with increasing depth upto IIC_1 horizon thereafter it was decreased at IIC_2 horizon (Fig 4.15). This trend was similar as that of clay content. The MWHC (v/v) was increased with an increasing the depth up to the lower most horizon. The PWAC and moisture retention ranged from 2.70 to 16.50 and 6.11 to 35.87 cm ha^{-1} , respectively (Table 4.29). The vertical distribution of PAWC and moisture retention (Fig. 4.16) with depth was found irregular. The PAWC and moisture retention were observed very high in IIC_1 horizon due to higher amount of clay (33 to 38 per cent) (Table 4.24) and high exchangeable Ca^{2+} , Mg^{2+} and Na^+ (Table 4.34). The total PAWC was found of 0.425 m ha^{-1} (44 per cent) out of 0.965 m ha^{-1} of total water storage capacity of pedon P_8 (Fig.

4.17) having PWAC/WSC ratio of 0.440 (Table 4.29) indicating wide ratio for the same which might be due to more depth of soil, high exchangeable sodium percentage and other cations.

4.3.2.3 Machhundri Toposequence (T₃)

The data on hydrological characteristics of pedons P₉ to P₁₂ of Machhundri toposequence are depicted in Table 4.30, while the moisture retention characteristic curve (weighted mean) of pedons P₉ to P₁₂ are shown in Fig. 4.14.

Pedon 9 (Fatsar) from the Upper piedmont : The data on hydrological characteristics of Table 4.30 reveal that the maximum water holding capacity and saturated hydraulic conductivity ranged from 41.0 to 41.26 per cent and 0.05 to 0.08 cm hr⁻¹, respectively. The maximum water holding capacity was observed uniform throughout the profile (Fig. 4.11), while saturated hydraulic conductivity with depth was found to be irregular (Fig. 4.12). The weighted mean of saturated hydraulic conductivity was 0.07 cm hr⁻¹ (Table 4.32), indicating a very slow saturated hydraulic conductivity of this pedon. This may possibly be due to higher clay contents (27.20 to 39.20 per cent) (Table 4.25). Similar, result was also reported by Kosmos and Moustakes (1990). The infiltration rate was identified 0.72 cm hr⁻¹ (Fig. 4.13) indicating moderately slow infiltration rate. Comparable results were recorded by Savalia *et al.* (2000). NWR & WSD (1998) also reported slow to moderately slow (0.12 to 1.52 cm hr⁻¹) infiltration rate in the medium black soils of Machhundri Irrigation Command area situated in southern Saurashtra region.

The moisture retained at 0.03 and 1.5 MPa varied between 0.44 to 0.49 and 0.21 to 0.23 m³ m⁻³, respectively (Table 4.30). In light of data presented, it is seem that between 0.03 to 0.1 MPa higher amount of water is retained in the subsurface layer as compared to surface layer and within this range the lowest amount of water was retained at AC horizon, thereafter

as increased the tension from 0.5 to 1.0 MPa, the lowest amount of water retained in surface horizon (Table 4.30). The moisture retention characteristics curve of the pedon P₉ (weighted mean) graphically exhibited in Fig. 4.14. The available water capacity (Fig. 4.15) and MWHC (v/v) ranged from 0.23 to 0.26 m³ m⁻³ and 57.35 to 60.68 per cent, respectively (Table 4.30). The vertical distribution of AWC with depth was found irregular. However, the MWHC (v/v) increased with an increasing depth. The PAWC and moisture retention (Fig. 4.16) values ranged from 1.82 to 5.00 and 4.13 to 11.47 cm ha⁻¹, respectively (Table 4.30). The surface layer contents have higher PAWC as compared to subsurface horizons. The total PAWC of the profile was 0.087 m ha⁻¹ (42 per cent) out of 0.205 m ha⁻¹ of total water storage capacity (Fig. 4.17) indicating very low PAWC and WSC might be due to shallow depth (30 cm) of the pedon at the upper piedmont area. The PAWC/WSC ratio was found 0.424 (Table 4.30).

Peon 10 (Judavadali) from the Lower piedmont : The data pertaining on hydrological characteristics of pedon P₁₀ are depicted in Table 4.30 explicates that the maximum water holding capacity and saturated hydraulic conductivity ranged between 38.20 to 41.46 per cent (Fig. 4.11) and 0.04 to 0.22 cm hr⁻¹, (Fig. 4.12) respectively having very slow saturated hydraulic conductivity (0.04 to 0.05 cm hr⁻¹) observed in solum of the pedon. However, in BC horizon, it was found slow (0.22 cm hr⁻¹). The infiltration rate was found (0.64 cm hr⁻¹) moderately slow (Fig. 4.13). Such type of result had been reported by Savalia *et al.* (2000) and NWR & WSD (1998).

The data regarding the moisture held at 0.03 and 1.5 MPa ranged from 0.37 to 0.43 and 0.18 to 0.20 m³ m⁻³, respectively (Table 4.30). The Curvilnear part of moisture retention curve (Fig. 4.14) revealed that the loosely bound water was retained up to 0.1 MPa, while strongly adsorbed water was represented by almost parallel line to X-axis beyond this suction in question. The loosely bound water between 0.03 to 0.1 MPa is accumulated in structural pores (Singh *et al.*, 2001). The AWC and MWHC (v/v) varied from 0.19 to

0.23 m³ m⁻³ (Fig. 4.15) and 54.24 to 58.85 per cent, respectively (Table 4.30). The PAWC and moisture retention ranged between 1.90 to 4.14 and 5.42 to 9.85 cm ha⁻¹, (Fig. 4.16) respectively (Table 4.30). The PAWC and moisture retention decreased with increasing depth, following the same trend as that of the clay (Table 4.25). The total PAWC of the profile was observed to be 0.122 m ha⁻¹ (49 per cent) out of 0.248 m ha⁻¹ of total water storage capacity (Table 4.30 & Fig. 4.17) having PAWC/WSC ratio of 0.492, indicating very high PAWC and wide PAWC/WSC ratio of the soils associated with this pedon. This might be due to the higher amount of smectitic clays as a result of the dominance of micropores (Paramsivam, 1992).

Pedon 11 (Delawada) from the Piedmont plain : An appraisal of data of the hydrological characteristics of pedon P₁₁ are presented in Table 4.30 reveals that the maximum water holding capacity and saturate hydraulic conductivity varied from 40.00 to 47.20 per cent (Fig. 4.11) and 0.01 to 0.07 cm hr⁻¹, (Fig. 4.12) respectively. The distribution of maximum water holding capacity with depth was irregular (Fig. 4.11). However, the saturated hydraulic conductivity decreased from the surface horizon (0.07 cm hr⁻¹) to the IIC₂ horizon (0.01 cm hr⁻¹). Thereafter, it increased at IIC₃ horizon (0.06 cm hr⁻¹). The saturated hydraulic conductivity was very slow and decreased with the depth (Fig. 4.12). The decrease in hydraulic conductivity was the function of increasing clay content and high ESP (9.78 to 13.70 per cent) (Table 4.30), which causes the plugging of pores by dispersal of clay. This is also corroborated by the findings of Ghazy *et al.* (1988). Mathen and Mahendran (1993) and Khan and Afzal (1993). The infiltration rate was 0.48 cm hr⁻¹ (Fig. 4.13) and is considered to be moderately slow infiltration rate. The moisture retention characteristics curve of the pedon P₁₁ (weighted mean) are exhibited graphically in Fig. 4.14. The AWC and MWHC (v/v) ranged from 0.25 to 0.29 m³ m⁻³ and 54.00 to 61.36 per cent, respectively. The moisture retention at 0.05 to 0.5 MPa increased with increasing the depth upto IIC₂ horizon thereafter it slightly decreased in substratum at IIC₃ horizon. The PAWC and moisture retention ranged from 4.05 to 13.75 and 8.10 to 32.91 cm ha⁻¹, respectively

(Table 4.30) indicating wide variation within the profile. The highest PAWC and moisture retention were found in parent material at IIC₃ horizon which might be due to highest amount of clay content (39.39 per cent) observed in this horizon (Table 4.30). The PAWC was slightly lower at sub surface horizon as compared to surface horizon thereafter it was increased with increasing depth upto IIC₃ horizon. However, the vertical distribution of moisture retention was observed irregular (Fig. 4.16). The PAWC of the pedon was 0.366 m ha⁻¹ (48 per cent) out of 0.764 m ha⁻¹ of total water storage capacity (Fig. 4.17) having PAWC/WSC ratio of 0.479 (Table 4.30).

Pedon 12 (Rampara) from the Coastal plain : A perusal of data on hydrological characteristics of pedon P₁₂ are presented in Table 4.30 stipulate that the maximum water holding capacity and saturated hydraulic conductivity varied between 36.65 to 44.48 per cent (Fig. 4.11) and 0.01 to 0.26 cm hr⁻¹, (Fig. 4.12) respectively. The depth distribution of saturated hydraulic conductivity was irregular (Fig. 4.12). The saturated hydraulic conductivity was found very slow (0.1 cm hr⁻¹ weighted mean). The infiltration rate was recorded 0.41 cm hr⁻¹ (Fig. 4.13) indicating slow infiltration rate. The reasons for the very slow hydraulic conductivity and moderately slow infiltration rate as discussed earlier in this text of the pedon P₄ of Hiran toposequence.

The moisture held at 0.03 and 1.5 MPa varied between 0.38 to 0.52 and 0.16 to 0.23 m³ m⁻³, respectively (Table 4.30). With increase in tension, the moisture retention power was decreased at more or less similar rate up to 0.5 MPa. It is appears that most of the water retained by the soil was depleted upto 0.5 MPa tension (Khan *et al.*, 1997). Above 0.5 MPa tension, the water was released with each increment of tension was very slow having narrow range at different depths. The variation of water retention characteristics of the pedon P₁₂ is depicted in Fig. 4.14. The AWC and MWHC (v/v) ranged from 0.22 to 0.29 m³ m⁻³ and 58.64 to 68.02 per cent, respectively (Table 4.30). The available water content was gradually increased with increasing the depth upto 115 cm depth thereafter it was decreased in lower most IIC₃ horizon (Fig.

4.15). The vertical distribution of MWHC (v/v) with depth was not in systematic manner. The PAWC and moisture retention (Table 4.16) varied from 4.60 to 7.25 and 12.32 to 17.01 cm ha⁻¹, respectively (Table 4.30). The vertical distribution of PAWC and moisture retention (Fig 4.16) with depth was found irregular. The total PAWC of the profile was observed 0.371 m ha⁻¹ (41 per cent) out of 0.912 m ha⁻¹ of total water storage capacity (Fig. 4.17) having the PAWC/WSC ratio of 0.407 indicating very high water storage capacity which might be due to enough soil depth (143 cm) in coastal plain.

4.3.2.4 Rayadi Toposequence (T₄)

The data pertaining on hydrological characteristics of the pedons P₁₃ to P₁₆ of Rayadi toposequence are presented in Table 4.31, while the variation in water retention characteristics of pedons P₁₃ to P₁₆ are displayed graphically in Fig. 4.14.

Pedon 13 (Dedan) from the Hill slope : The maximum water holding capacity and saturated hydraulic conductivity varied from 42.37 to 50.51 per cent (Fig. 4.11) and 0.24 to 0.35 cm hr⁻¹ (Fig. 4.12), respectively (Table 4.31). The saturated hydraulic conductivity was higher (0.35 cm hr⁻¹) in A₁₁ horizon than at AC horizon (0.24 cm hr⁻¹). The weighted mean of saturated hydraulic conductivity of 0.30 cm hr⁻¹ (Table 4.32) indicating the slow rate of saturated hydraulic conductivity. This might due to the dominant smectite clay which have more total pores volume with the micro pores causing poor water transmission. The infiltration rate observed 1.19 cm hr⁻¹ (Fig. 4.13) indicating moderately slow infiltration rate.

The moisture held at 0.03 was found 0.34 to 0.37 m³ m⁻³ whereas at 0.10, 0.5, 1.0 and 1.5 MPa tensions, the constant values of 0.19, 0.16, 0.14 and 0.13 m³ m⁻³, respectively, throughout the profile (Table 4.31). The moisture retention values at 0.03 and 0.05 MPa were higher in surface horizon as compared to AC horizon. The moisture retention characteristics curve of pedon

P₁₃ (weighted mean) illustrated graphically in Fig. 4.14. The AWC and MWHC (v/v) varied between 0.21 to 0.24 m³ m⁻³ (Fig. 4.15) and 59.32 to 67.68 per cent, respectively (Table 4.31). In the light of data presented, it could be inferred that higher amount of moisture retained in surface layer as compared to substratum which perhaps might be due to high clay content and organic matter in upper layer as compared to sub stratum. The PAWC and moisture retention ranged from 2.73 to 3.60 and 7.71 to 10.15 cm ha⁻¹, respectively. The PAWC and moisture retention (Fig. 4.16) values were higher in surface horizon as compared to AC horizon. The total PAWC of profile was found 0.063 m ha⁻¹ (35 per cent) out of 0.179 m ha⁻¹ of total water storage capacity of profile (Fig. 4.17) having of PAWC/WSC ratio of 0.352 (Table 4.31), indicating very low PAW and WSC due to shallow depth (28 cm) of the pedon in hill slope area.

Pedon 14 (Dedan) from the Upper piedmont : The maximum water holding capacity and saturated hydraulic conductivity ranged between 51.66 to 54.70 per cent (Fig. 4.11) and 0.04 to 0.09 cm hr⁻¹ (Fig. 4.12), respectively (Table 4.31). The MWHC was increased up to A₁₂ horizon thereafter it was decreased at AC horizon (Fig. 4.11). This type of trend was also observed in that of clay content in this pedon. Sharma (1994) were also reported that the maximum water holding capacity of the soil was generally related to the texture of the soil, which increased with an increased in clay content. The weighted mean of saturated hydraulic conductivity of 0.06 cm hr⁻¹ indicating very slow rate of saturated hydraulic conductivity. This might be due to the high clay content and dominance of expandable smectite clay minerals dominant in this soil (Mathen and Mahendran, 1993 and Diwakar and Singh, 1992). The infiltration rate was observed 0.73 cm hr⁻¹ (Fig. 4.13) indicating moderately slow infiltration rate.

The moisture retained at 0.03 and 1.5 MPa tension varied between 0.40 to 0.51 and 0.18 to 0.22 m³ m⁻³, respectively (Table 4.31). The moisture retention was higher at 0.03 MPa in subsurface as compared to surface soil

while opposite trend was observed at 0.05 to 1.5 MPa tensions where moisture retention was higher in surface horizon as compared to subsurface. The moisture retention characteristics curve of pedon P₁₄ (weighted mean) are shown graphically in Fig. 4.14. The AWC and MWHC (v/v) ranged from 0.22 to 0.30 m³ m⁻³ and 72.17 to 76.58 per cent, respectively. The vertical distribution of AWC (Fig. 4.15) and MWHC (v/v) with depth was found to be irregular. The PAWC and moisture retention varied from 1.54 to 4.80 and 5.24 to 12.27 cm ha⁻¹ (Fig. 4.16), respectively (Table 4.31). The PAWC and moisture retention (Fig. 4.16) values decreased with increasing the depth. The total PAWC of the profile was 0.109 m ha⁻¹ (37 per cent) out of 0.298 m ha⁻¹ of total water storage capacity (Fig. 4.17) having PAWC/WSC ratio of 0.366 (Table 4.31) indicating low PAWC and WSC which might be due to shallow soil depth in upper piedmont area.

Peon 15 (Chotara) from the Lower piedmont : The maximum water holding capacity and saturated hydraulic conductivity ranged from 48.35 to 55.69 per cent (Fig. 4.11) and 0.01 to 0.09 cm hr⁻¹ (Fig. 4.12), respectively. The high MWHC might be due to the high clay content (35.80 to 44.00 per cent) observed in this pedon. The saturated hydraulic conductivity was very slow which might be due to the impact of high total clay content, dominance smectite clay and high ESP (8.54 to 12.87, Table 4.36), which may have resulted in plugging the pores. So and Cook (1993) have also reported an adverse impact of dispersed clay and silt on hydraulic conductivity. These findings are similar to those reported by Diwakar and Singh (1992), Khan and Afzal (1993) and Mathen and Mahendran (1993). The infiltration rate of soil was found to be 0.43 cm hr⁻¹ (Fig. 4.13) indicating slow infiltration rate. Gupta (2002) also reported the terminal infiltration rates of black clay soil region of peninsular India to range from 0.20 to over 29.00 mm hr⁻¹.

The moisture held at 0.03 and 1.5 MPa were in higher range and varied from 0.50 to 0.57 and 0.19 to 0.23 m³ m⁻³, respectively (Table 4.31). This might be due to high amount of clay (44.20 to 53.80 per cent, Table 4.26)

and organic carbon (0.45 to 0.75 per cent, Table 4.36). The results are in concurrence with those obtained by finding of Prasad *et al.* (1998). The moisture retention was increased at 0.03 to 0.10 MPa tensions with increasing depth upto IIC₁ horizon of the studied pedon. The moisture retention characteristics curve of pedon P₁₅ (weighted mean) envisaged graphically in Fig. 4.14. The AWC and MWHC (v/v) ranged from 0.31 to 0.34 m³ m⁻³ and 70.50 to 77.97 per cent, respectively (Table 4.31) indicating high available water capacity and MWHC (v/v) which might be due to high clay and organic matter content in the soils of the studied pedon. The vertical distribution of AWC (Fig. 4.15) and MWHC (v/v) with depth was found irregular. The PAWC and moisture retention ranged from 5.58 to 9.18 and 12.69 to 21.05 cm ha⁻¹ (Fig. 4.16), respectively (Table 4.31), indicating higher range of PAWC and moisture retention within the profile under study. This might be due to high clay and organic matter content. The vertical distribution of PAWC and moisture retention (Fig. 4.16) with depth was not found systematic. The total PAWC of the profile recorded 0.278 m ha⁻¹ (44 per cent) out of 0.626 m ha⁻¹ of total water storage capacity (Fig. 4.17) having PAWC/WSC ratio of 0.444, indicating very high amount of total PAWC and WSC and wide PAWC/WSC ratio might be due to dominance of smectite type clay, higher total clay and organic matter content with enough soil depth.

Pedon 16 (Kadiyali) from the Coastal plain : The maximum water holding capacity ranged from 26.98 to 50.67 per cent (Table 4.31). The vertical distribution of MWHC was irregular (Fig. 4.11). It is interesting to note that saturated hydraulic conductivity of these soils found almost absent it might be due to the dominance of smectite type of clay, high exchangeable sodium (ESP) (9.70 to 14.56, Table 4.36) and high SAR in saturation extract (9.69 to 29.25, Table 4.41) which decomposed the organic matter and dispersed the clay results in completely clogging of pores which stop the water transmission in these soils. These findings are in agreement with those of Diwakar and Singh (1992), Khan and Afzal (1993) and Mathen and Mahendran (1993). The infiltration rate was observe 0.09 cm hr⁻¹ (Fig. 4.13) indicating very slow

infiltration rate due to the surface sealing of smaller capillary pores (Ghildyal and Tripathi, 1987).

The moisture held at 0.03 and 1.5 MPa was ranged between 0.33 to 0.41 and 0.16 to 0.19 $\text{m}^3 \text{m}^{-3}$, respectively (Table 4.31). The moisture retention at 0.03 to 1.5 MPa was higher in subsurface as compared to surface horizon. The moisture retention at 0.05 to 1.0 MPa tensions was increasing with an increased soil depth up to B₂₂ horizon. The moisture retention characteristics curve of pedon P₁₆ (weighted mean) illustrated graphically in Fig. 4.14. The AWC and MWHC (v/v) ranged from 0.15 to 0.22 $\text{m}^3 \text{m}^{-3}$ and 41.01 to 70.94 per cent, respectively (Table 4.31). The vertical distribution of AWC (Fig. 4.15) and MWHC (v/v) found irregular with depth. The PAWC and moisture retention ranged from 2.40 to 4.50 and 4.97 to 12.77 cm ha^{-1} , respectively (Table 4.31). The vertical distribution of PAWC and moisture retention (Fig. 4.16) were not in systematic manner with depth. The total PAWC of profile was identified 0.185 (36 per cent) out of 0.511 m ha^{-1} of total water storage capacity of profile (Fig.4.17) with PAWC/WSC ratio of 0.362 (Table 4.31) indicating high PAWC, WSC and wide PAWC/WSC ratio was might be due to high clay and organic matter content and sufficient depth of soils in the coastal area.

4.3.2.5 Land Slopes

The weighted mean data of hydrological characteristics of some pedons from different five land slopes across the four toposequences of southern Saurashtra are depicted in Table 4.32.

(A) Hill Slope : The maximum water holding capacity ranged between 46.33 and 46.73 per cent with a mean value of 46.53 per cent (Table 4.32). It was observed about uniform within the pedons in hill slopes. The saturated hydraulic conductivity and infiltration rate varied from 0.22 to 0.30 and 1.19 to 1.23 cm hr^{-1} with the mean of 0.26 and 1.21 cm hr^{-1} , respectively (Table 4.32 &

Fig. 4.18) indicating slow rate of hydraulic conductivity and moderately slow infiltration rate in hill slopes area.

The moisture held at 0.03 and 1.5 MPa varied from 0.36 to 0.42 and 0.13 to 0.19 $\text{m}^3 \text{m}^{-3}$ with the mean of 0.39 and 0.16 $\text{m}^3 \text{m}^{-3}$, respectively (Table 4.32). The moisture retention values at 0.03 to 1.5 MPa tension were higher in pedon P₁ (Sasan) of Hiran toposequence than pedon P₁₃ (Dedan) of Rayadi toposequence might be due to high organic carbon content in former soils (Prasad *et al.*, 1998). The AWC was found 0.23 $\text{m}^3 \text{m}^{-3}$ in pedons P₁ and P₁₃ (Fig. 4.19). The MWHC (v/v) ranged from 59.20 to 63.80 per cent with the mean of 61.50 per cent. The total PAWC and total water storage capacity of the profile ranged from 0.063 to 0.099 and 0.179 to 0.255 m ha^{-1} (Fig. 4.19) with the mean of 0.081 and 0.217 m ha^{-1} , respectively (Table 4.32). The PAWC/WSC ratio was found 0.370 indicating 37 per cent water is available for plant out of total water storage capacity of the hill slope area (Fig. 4.19).

(B) Upper piedmont : The maximum water holding capacity was ranged from 42.52 to 53.15 per cent with a mean value of 46.43 per cent (Table 4.32). The highest MWHC was observed in pedon P₄ (Kajali) of Hiran toposequence followed by P₉ (Fatsar) of Machhundri toposequence and P₂ (Borvav) of Hiran toposequence. Whereas, the lowest MWHC was observed in P₅ (Jamwala) in Shingoda toposequence. The saturated hydraulic conductivity and infiltration rate varied from 0.06 to 0.14 and 0.72 to 0.80 cm hr^{-1} with the mean value of 0.10 and 0.76 cm hr^{-1} , respectively (Fig. 4.18) indicating very slow rate of saturated hydraulic conductivity and moderately slow infiltration rate. The highest saturated hydraulic conductivity (0.14 cm hr^{-1}) recorded in pedon P₂ (Borvav) of Hiran toposequence followed by P₅ (Jamwala) of Shingoda toposequence and P₉ (Fatsar) of Machhundri toposequence. It seems that the saturated hydraulic conductivity was decreased with increased distance from west to east in upper piedmont. The highest infiltration rate (0.80 cm hr^{-1}) was found in pedon P₅ (Jamwala) followed by P₂ (Borvav) and P₄ (Kajali).

The moisture held at 0.03 and 1.5 MPa ranged from 0.42 to 0.48 and 0.21 to 0.22 $\text{m}^3 \text{m}^{-3}$ with the mean of 0.45 and 0.21 $\text{m}^3 \text{m}^{-3}$, respectively (Table 4.32). The highest moisture retention (0.48 $\text{m}^3 \text{m}^{-3}$) at field capacity (0.03 MPa) was observed in pedon P₁₄ of Hiran toposequence followed by P₉ (Fatsar) of Machhundri toposequence. These parameters were also followed the trend from west to east direction as was noted in case of saturated hydraulic conductivity. The AWC and MWHC (v/v) ranged from 0.20 to 0.27 $\text{m}^3 \text{m}^{-3}$ and 56.45 to 74.41 per cent with the weighted mean of 0.24 $\text{m}^3 \text{m}^{-3}$ and 61.70 per cent, respectively. The available water content of different pedons in upper piedmont area was in decreasing order of P₁₄T₄ > P₉T₃ > P₂T₁ > P₅T₂ (Table 4.32). The total PAWC and water storage capacity (WSC) ranged from 0.087 to 0.128 and 0.205 to 0.370 m ha^{-1} (Fig. 4.19) with the mean values of 0.105 and 0.283 m ha^{-1} , respectively. The total PAWC and total WSC observed in decreasing sequence of P₅T₂ > P₁₄T₄ > P₂T₁ > P₉T₃. The PAWC/WSC ratio ranged between 0.346 to 0.424 with the mean value of 0.378 indicating 38 per cent water available for plant out of total water storage capacity of the upper piedmont area (Table 4.32 and Fig. 4.19).

(C) Lower piedmont : The maximum water holding capacity ranged from 32.77 to 52.17 per cent with a mean of 43.29 per cent (Table 4.32). The highest MWHC (52.17 per cent) was recorded in pedon P₁₅ (Chotara) of Rayadi toposequence followed by P₅ (Jamwala) of Shingoda toposequence and P₁₀ (Judavadali) of Machhundri toposequence. The lowest MWHC (32.77 per cent) was observed in P₆ (Kareda) of upper piedmont may be due to the high bulk density of soil. The saturated hydraulic conductivity and infiltration rate ranged from 0.02 to 0.14 and 0.43 to 1.12 cm hr^{-1} with the mean of 0.08 and 0.71 cm hr^{-1} indicating very slow rate of saturated hydraulic conductivity and moderately slow infiltration rate in lower piedmont area (Table 4.32 & Fig. 4.18). The very slow rate of saturated hydraulic conductivity was might be due to the high bulk density (1.44 mg m^{-3}) of the soils of lower piedmont area. The highest saturated hydraulic conductivity (0.14 cm hr^{-1}) of soil was recorded in pedon P₆ (Kareda) of Shingoda toposequence followed by P₅ (Jamwala) of

Shingoda toposequence as well as P₁₀ (Judavadali) of Machhundri toposequence. The lowest (0.02 cm hr⁻¹) saturated hydraulic conductivity was observed in pedon P₁₅ (Chotara) of Rayadi toposequence (Table 4.32) might be due to the high clay content combined with dominant of smectite clay minerals and high ESP which resulted in clogging of micropores (Khan and Afzal, 1993 and So and Cock, 1993). The highest infiltration rate was recorded in pedon P₆ (Kareda) of Shingoda toposequence followed by P₁₀ (Judavadali) of Machhundri toposequence and P₅ (Jamwala) of Shingoda toposequence. The lowest infiltration rate (0.43 cm hr⁻¹) was observed in pedon P₁₅ (Chotara) of Rayadi toposequence may be due to the high clay content and high exchangeable sodium in this soil.

The moisture was held at 0.03 and 1.5 MPa ranged from 0.30 to 0.53 and 0.11 to 0.21 m³ m⁻³ with the mean of 0.43 and 0.18 m³ m⁻³, respectively. The highest moisture (0.53 m³ m⁻³) held at field capacity (0.03 MPa) was observed in pedon P₁₅ (Chotara) of Rayadi toposequence followed by P₃ (Maljinjava) of Hiran toposequence and P₁₀ (Judavadali) of Machhundri toposequence (Table 4.32). It appears that most of the water retained by the soil is depleted up to 0.50 MPa tension. Above 0.5 MPa tension the water release with each increment of tension was very slow in different pedons in lower piedmont area under study. The AWC and MWHC (v/v) ranged from 0.19 to 0.33 m³ m⁻³ (Fig. 4.19) and 51.50 to 73.65 per cent with the mean of 0.25 m³ m⁻³ and 61.82 per cent, respectively (Table 4.32). The AWC and MWHC (v/v) of different pedons in lower piedmont area were in decreasing sequence of P₁₅T₄ > P₃T₁ > P₁₀T₃ > P₆T₂ (Table 4.32). The total PAWC and total water storage capacity (WSC) ranged from 0.114 to 0.278 and 0.248 to 0.626 m ha⁻¹ with the mean of 0.181 and 0.430 m ha⁻¹ (Fig. 4.19), respectively (Table 4.32). The PAWC/WSC ratio ranged from 0.369 to 0.492 with the mean of 0.424 indicating 42 per cent water available for plant out of total water storage capacity of the lower piedmont area (Fig. 4.19).

(D) Piedmont plain : The maximum water holding capacity ranged from 41.91 to 44.58 per cent with a mean of 43.05 per cent (Table 4.32). The highest MWHC (44.58 per cent) was observed in pedon P₄ (Kajali) of Hiran toposequence followed by P₇ (Devali) of Shingoda toposequence and P₁₁ (Delawada) of Machhundri toposequence. The value of MWHC was decreased as per distance increased from west to east in piedmont plain area. The saturated hydraulic conductivity and infiltration rate ranged from 0.02 to 0.16 and 0.48 to 0.78 cm hr⁻¹ with the mean of 0.07 and 0.60 cm hr⁻¹, respectively (Table 4.32 & Fig. 4.19) indicating very slow rate of saturated hydraulic conductivity and moderately slow infiltration rate in piedmont plain area. The very slow rate of saturated hydraulic conductivity observed in piedmont plain might be due to high clay content, dominant smectite minerals and high ESP which clogging the pores by dispersed organic matter and clay (Ghazy *et al.*, 1988; Khan and Afzal, 1993 and Mathen and Mahendran, 1993). The highest infiltration rate (0.78 cm hr⁻¹) was recorded in pedon P₇ (Devali) of Shingoda toposequence followed by P₄ (Kajali) of Hiran toposequence and P₁₁ (Delawada) of Machhundri toposequence (Table 4.32).

The moisture content at 0.03 and 1.5 MPa was ranged from 0.39 to 0.54 and 0.18 to 0.22 m³ m⁻³ with the mean of 0.46 and 0.20 m³ m⁻³, respectively (Table 4.32). The moisture retention values at 0.03 to 1.5 MPa tensions were highest in pedon P₄ (Kajali) of Hiran toposequence followed by P₁₁ (Delawada) of Machhundri toposequence and P₇ (Devali) of Shingoda toposequence (Table 4.32). The AWC and MWHC (v/v) ranged from 0.22 to 0.32 m³ m⁻³ and 58.74 to 64.13 per cent with the mean of 0.26 m³ m⁻³ (Fig. 4.19) and 61.02 per cent, respectively (Table 4.32). Further, a higher magnitude of AWC and MWHC (v/v) were recorded in pedon P₄ (Kajali) of Hiran toposequence followed by P₁₁ (Delawada) of Machhundri toposequence and the lowest magnitude was recorded in P₇ (Devali) of Shingoda toposequence. The total PAWC and water storage capacity values of different pedons under investigation registered a range between 0.238 to 0.767 and 0.622 to 1.539 m ha⁻¹ with the mean of 0.457 and 0.975 m ha⁻¹, respectively (Table 4.32 & Fig. 4.19) indication high PAWC

of the area due to sufficient soil depth. The PAWC/WSC ratio ranged from 0.383 to 0.498 with a mean of 0.453 indicating 45 per cent water available for plant out of total water storage capacity of the piedmont plain (Fig. 4.19).

(E) Coastal plain : The maximum water holding capacity was found between 34.96 to 46.02 per cent with a mean of 40.93 per cent (Table 4.32). The highest MWHC (46.02 per cent) was recorded in the pedon P₈ (Chauhani Khan) of Shingoda toposequence followed by P₁₂ (Rampara) of Machhundri toposequence and P₁₆ (Kadiyali) of Rayadi toposequence. The saturated hydraulic conductivity and infiltration rate were ranged from 0.00 to 0.10 and 0.09 to 0.60 cm hr⁻¹ with the mean of 0.04 and 0.37 cm hr⁻¹ (Table 4.32 & Fig. 4.18), respectively indicating very slow rate of saturated hydraulic conductivity and slow infiltration rate in coastal plain of southern Saurashtra. This might be due to the dominance of expandable smectite clay minerals, high clay content, high ESP and high SAR in saturation extract which dispersed the organic matter and clay results in clogging / sealing of pores which indifference the water transmission in these soils of coastal plain (Sharma, 1981; Ghildyal and Tripathi, 1987; Ghazy *et al.*, 1988; Paramshivam, 1992; Khan and Afzal, 1993 and Mathen and Mahendran, 1993). The highest saturated hydraulic conductivity (0.10 cm hr⁻¹) was noted in pedon P₁₂ (Rampara) of Machhundri toposequence followed by P₈ (Chauhani Khan) of Shingoda toposequence. The highest infiltration rate was recorded in pedon P₈ (Chauhani Khan) of Shingoda toposequence followed by P₁₂ (Rampara) of Machhundri toposequence and P₁₆ (Kadiyali) of Rayadi toposequence (Table 4.32).

The data pertaining to moisture held at 0.03 and 1.5 MPa constitutes around 0.36 to 0.51 and 0.18 to 0.22 m³ m⁻³ with the mean of 0.44 and 0.20 m³ m⁻³, respectively (Table 4.32). Kaswala *et al.* (1999) also reported the moisture tension at 0.03 and 1.5 MPa ranging from 0.340 to 0.565 and 0.177 to 0.283 m³ m⁻³ in the some coastal soils of south Gujarat. The moisture retention values at 0.03 to 0.50 MPa tensions was registered a higher value in P₈ (Chauhani Khan) of Shingoda toposequence and the lowest value in P₁₆ (Kadiyali) of Rayadi

toposequence. The AWC and MWHC (v/v) values in coastal area ranged between 0.19 to 0.29 $\text{m}^3 \text{m}^{-3}$ and 49.95 to 65.85 per cent with the mean of 0.24 $\text{m}^3 \text{m}^{-3}$ and 59.87 per cent, respectively (Table 4.32). The highest AWC and MWHC (v/v) were recorded in pedon P_8 (Chauhani Khan) of Shingoda toposequence and the least value of these parameters were recorded for the P_{16} (Kadiyali) of Rayadi toposequence. The PAWC and WSC ranged from 0.185 to 0.425 and 0.511 to 0.965 m ha^{-1} with the mean of 0.327 and 0.796 m ha^{-1} (Fig. 4.19), respectively. The PAWC and WSC of different pedons were the highest in pedon P_8 (Chauhani Khan) followed by P_{12} (Rampara). The PAWC/WSC ranged from 0.362 to 0.440 with a mean of 0.403 indicating 40 per cent water is available for plant out of total water storage capacity of the coastal area (Table 4.32 and Fig. 4.19).

Overall Hydrological Characteristics of Southern Saurashtra

In general, the maximum water holding capacity of the soils in southern Saurashtra ranged from 32.77 to 53.15 per cent with the overall mean of 43.62 per cent (Table 4.32), and observed in the following sequence :

Hill slope > Upper Piedmont > Lower piedmont > Piedmont plain > Coastal Plain

The saturated hydraulic conductivity and infiltration rate ranged from 0.00 to 0.30 and 0.09 to 1.23 cm hr^{-1} with the overall mean of 0.10 and 0.70 cm hr^{-1} , respectively (Table 4.32) indicating very slow rate of saturated hydraulic conductivity and moderately slow infiltration rate in soils of southern Saurashtra which may be due to high clay content, dominant expandable smectite clay minerals, high bulk density from lower piedmont to coastal plain (1.42 to 1.47 Mg m^{-3}), high ESP and SAR in piedmont plain and coastal plain areas of southern Saurashtra. The saturated hydraulic conductivity and

infiltration rate of the soils of southern Saurashtra were recorded in the following decreasing order (Fig. 4.17):

Hill slope > Upper Piedmont > Lower piedmont > Piedmont plain > Coastal Plain

The moisture held at 0.03 and 1.5 MPa ranging from 0.30 to 0.54 and 0.11 to 0.22 $\text{m}^3 \text{m}^{-3}$ with the overall mean of 0.44 and 0.19 $\text{m}^3 \text{m}^{-3}$, respectively (Table 4.32). The moisture held at field capacity (0.03 MPa) was observed in following decreasing sequence of Piedmont plain > Upper piedmont > Coastal plain > Hill slope.

The AWC and MWHC (v/v) ranged between 0.19 to 0.33 $\text{m}^3 \text{m}^{-3}$ and 49.95 to 73.65 per cent with the overall mean of 0.25 $\text{m}^3 \text{m}^{-3}$ and 61.50 per cent, respectively (Table 4.32). The AWC was recorded in the decreasing order of Piedmont plain > Lower piedmont > Coastal plain and Upper piedmont > Hill slope.

There was no variation in MWHC (v/v) in different land slopes of the southern Saurashtra. The total PAWC and water storage capacity of the soils associated in different land slopes ranged from 0.063 to 0.767 and 0.179 to 1.539 m ha^{-1} with the mean of 0.229 and 0.537 m ha^{-1} , respectively (Table 4.32). The total PAWC and water storage capacity (Fig. 4.19) were found in the decreasing sequence of Piedmont plain > Coastal plain > Lower piedmont > Upper piedmont > Hill slope. The PAWC/WSC ratio ranged from 0.346 to 0.498 with the mean of 0.407 indicating the 41 per cent water is available for plant out of 0.537 m ha^{-1} of total water capacity of the soils of southern Saurashtra. (Table 4.32 and Fig. 4.19)

4.4 CHEMICAL CHARACTERISTICS

In order to understand the relationship between the soil and physiography, it is imperative to analyse various chemical properties in light of

micro topographical variation imposed by variation of land slope. The chemical characteristic of the soils of southern Saurashtra are discussed in the following subhead :

4.4.1 Different Chemical Characteristics

4.4.2 Composition of Saturation Extracts

4.4.1 Different Chemical Characteristics

The data pertaining to pH, EC, organic carbon, calcium carbonate, CEC, base saturation percent (BSP) and exchangeable sodium percentage (ESP) are discussed as per the following subhead:

4.4.1.1 Hiran toposequence.

4.4.1.2 Shingoda toposequence

4.4.1.3 Machhundri toposequence

4.4.1.4 Rayadi toposequence

4.4.1.5 Land slope

4.4.1.1 Hiran toposequence (T_1)

The data pertaining to different chemical characteristics of the pedons P_1 to P_4 of Hiran toposequence are presented in Table 4.33 and graphically exhibited in Fig. 4.20 to 4.25.

Pedon 1 (Sasan (Gir)) from the Hill slope : The data presented in Table 4.33 denote that the soil pH ranged between 7.48 to 7.90 (Table 4.33 and Fig. 4.20) with a weighted mean of 7.70 (Table 4.37) showing the slightly alkaline status which might be due to well drained nature of soils in associated with comparative high rainfall drained from basic trap rocks. A critical examination of the data indicates that soil pH was found relatively higher at surface as

compared to subsurface layer. This might be due to higher mineralization of lime forming the salts of bicarbonate at the surface horizon than the immediate subsurface horizon as evident by composition of saturation extract (Table 4.38). A fact also collaborated by the findings of Barua (1989).

The EC values of 1:2.5 soil:water ratio some what uniform in the entire profile and varied from 0.15 dSm^{-1} in AC horizon to 0.21 dSm^{-1} in A_{12} horizon (Fig. 4.21). Comparatively lower salt content in this pedon was probably due to the leached of salts from the higher elevations of Gir ranges of southern Saurashtra. Similar observation hve also been made by Barua (1989), while decreasing the impact of land form portion of salt content.

The organic carbon content varied from 0.42 to 1.25 with a weighted mean of 0.81 per cent (Table 4.37) indicating the soils were high in organic carbon content. This may be attributed to comparatively intense vegetation along the high rainfall (870 mm) in Gir forest region. The organic carbon content was higher at surface and decreases with the depth (Fig. 4.22) which might be due to the greater quantity of leaf fall/decay on surface as compared to sub surface horizon and maximum biological activities at the surface (Sharma, 1995).

The content of calcium carbonate varied between 7.50 to 13.00 percent. The surface layer contain considerably higher amount of calcium carbonate as compared to sub surface layer (Fig. 4.23). Similar result was also noted by Gundalia and Savalia (2000) for the Lithic Troorthent medium black soils of north Saurashtra. The CEC of the pedon P_1 ranged from 25.08 to 27.92 $\text{cmol}(\text{p}^+) \text{ kg}^{-1}$. Sharma and Bhaskar (2003) also reported the CEC of the soils of Rajkot district to be $34.5 \text{ cmol}(\text{p}^+) \text{ kg}^{-1}$ of soils over hummocks and ridges. The exchangeable Ca^{2+} , Mg^{2+} , Na^+ and K^+ ranged between 17.80 to 19.80, 1.65 to 5.15, 1.59 to 1.88 and 0.11 to 0.32 $\text{cmol}(\text{p}^+) \text{ kg}^{-1}$, respectively. The vertical distribution of exchangeable Ca^{2+} remained same, but the content of exchangeable Mg^{2+} increased with increasing soil depth. However, the content of exchangeable Na^+ and K^+ decreased in the sub surface layer. The distribution

of exchangeable cations were in the order of $\text{Ca}^{2+} > \text{Mg}^{2+} > \text{Na}^+ > \text{K}^+$. The base saturation per cent (BSP) value varied from 88.3 to 93.8. The value of BSP increased upto 35cm depth and then decreased in parent material at AC horizon. The distribution of base saturation followed the similar trend as that of clay content (Table 4.23). The findings of present investigation are in complete agreement with findings of Martini and Mosquera (1972), Rathore (1993) and Sharma (1995). High base saturation was mainly due to calcium followed by magnesium and less due to sodium and potassium, which is also supported by the work of Tiwary *et al.* (1989), Sharma (1994) and Sharma (1995). The value of ESP ranged between 5.69 to 7.50. The lower values of ESP might be due to the washing down of salts by rain (Paramasivam, 1992). The CEC/clay ratio ranged from 0.80 to 1.95. The vertical distribution of CEC/clay ratio was found irregular. The lower value of CEC/clay ratio in surface and subsurface horizons as compared to sub stratum (AC horizon) may be due to high organic matter content in the upper horizon.

Pedon 2 (Borvav) from the Upper piedmont : The pH and EC values ranged from 7.95 to 8.07 and 0.14 to 0.22 (Table 4.33) with the weighted mean of 8.08 and 0.19 dSm^{-1} (Table 4.37), respectively. The soils were moderately alkaline in reaction. NWR & WSD (1999) also reported the soil pH to vary from 7.4 to 8.4 indicating mildly alkaline to moderately alkaline soils in the Hiran-II command area of southern Saurashtra. The soil pH was higher in sub surface but decreased in AC horizon (Fig. 4.20). The EC decreased with increasing soil depth (Fig. 4.21).

The organic carbon and CaCO_3 ranged from 0.35 to 0.87 and 5.00 to 7.00 per cent with the weighted mean of 0.65 and 5.78 per cent (Table 4.37), respectively, indicating the soils were medium in organic carbon and slightly calcareous in nature. The organic carbon content considerably decreased with increasing soil depth (Fig. 4.22), while in case of CaCO_3 , the vertical distribution was found to be irregular (Fig. 4.23). Similar results were also observed by Pal *et al.* (2000) and Gundalia and Savalia (2000).

The CEC ranged between 23.92 to 25.39 $\text{cmol}(\text{p}^+) \text{ kg}^{-1}$. The vertical distribution of CEC was not found systematic. The exchangeable Ca^{2+} , Mg^{2+} , Na^+ and K^+ ranged from 14.60 to 15.85, 5.35 to 6.30, 1.41 to 1.97 and 0.02 to 0.04 $\text{cmol}(\text{p}^+) \text{ kg}^{-1}$, respectively. The exchangeable Ca^{2+} increased with increasing soil depth. The uniform distribution of exchangeable Mg^{2+} was observed in the solum of pedon P₂. However, exchangeable Na^+ was found higher in sub surface horizon followed by surface and AC horizon. The exchangeable K^+ was slightly higher in surface horizon than A₁₃ and AC horizons. The proportion of exchangeable cations were in the sequence of $\text{Ca}^{2+} > \text{Mg}^{2+} > \text{Na}^+ > \text{K}^+$. The BSP and ESP ranged from 90.00 to 95.00 and 5.61 to 7.76, respectively. The vertical distribution of BSP and ESP were found irregular. The comparatively lower value of ESP might be due to the washing down of salt by rain or irrigation water and indicates there is no any alkalinity hazard in near future. The reasons for high base saturation was discussed in the pedon-1. However, the distribution of base saturation was not followed the similar trend as that of clay content. These findings are in harmony with those of Martini and Mosquera (1972) and Rathore (1993). The CEC/clay ratio varied form 0.60 to 1.23 and it increased with increasing soil depth.

Pedon 3 (Malajinjawa) from the Lower piedmont : A perusal of data depicted in Table 4.33 reveal that soil pH and EC ranged from 7.87 to 8.11 and 0.25 to 0.36 dSm^{-1} with the weighted mean of 7.99 and 0.31 dSm^{-1} (Table 4.37), respectively. The soils were moderately alkaline in reaction. Further, the pH and EC exhibited into two distinct patterns. The value of pH (Fig. 4.20) and EC (Fig 4.21) decreased with an increase in soil depth from surface to subsurface horizon, thereafter an increase in the values of the pH and EC was observed up to IIC₁ horizon.

The organic carbon and CaCO_3 content varied between 0.59 to 0.75 and 12.50 to 22.00 per cent with the weighted mean of 0.70 and 17.63 per cent (Table 4.37), respectively, indicating the soils were medium in organic carbon content and highly calcareous in nature. The organic carbon content decreased from 0.75 per cent in the surface horizon to 0.59 per cent in B₂₁ horizon and thereafter increased upto 0.72 per cent in IIC₁ horizon (Table 4.33 & Fig. 4.22). The higher content of organic carbon in the surface horizon might be due to illuviation (Miller and Donahu, 1982) and maximum biological activities at surface (Sharma, 1995). The CaCO_3 content increased from 16.00 per cent in the surface horizon to 22.00 per cent in B₂₁ horizon and thereafter it was decrease upto 12.50 per cent in IIC₁ horizon (Fig. 4.23), which indicating mixed CaCO_3 origin i.e. pedogenic and lithogenic origin of lime. Similar, results were also observed by Savalia *et al.* (2000) in the soils of Vertic Calciustept of Uben irrigation command area of Saurashtra region.

The CEC ranged from 28.49 to 29.09 $\text{cmol (p}^+) \text{ kg}^{-1}$. The CEC in the medium black soils of Hiran-II command area of Saurashtra varied from 12.00 to 48.00 $\text{cmol (p}^+) \text{ kg}^{-1}$ (NWD & WSD, 1999). The CEC decreased with increasing soil depth. The exchangeable Ca^{2+} , Mg^{2+} , Na^+ and K^+ varied from 12.60 to 20.05, 5.45 to 11.05, 1.84 to 3.38 and 0.17 to 0.28 $\text{cmol (p}^+) \text{ kg}^{-1}$, respectively. The exchangeable Ca^{2+} and K^+ decreased with increasing soil depth. However, vertical distribution of exchangeable Mg^{2+} and K^+ was found irregular. The data on exchangeable cations of pedon P₃ reveal the order of dominant cations were being the same as $\text{Ca}^{2+} > \text{Mg}^{2+} > \text{Na}^{+2} > \text{K}^+$ that like that of pedon P₁ and P₂. The BSP and ESP ranged from 92.5 to 95.4 and 4.89 to 11.86. The distribution of BSP was irregular with depth, while ESP increased with increase in depth. The CEC/clay ratio varied from 0.67 to 0.81 and it was increased with increasing depth of soil.

Pedon 4 (Kajali) from the Piedmont plain : The pH and EC ranged between 7.84 to 8.35 and 0.55 to 1.32 (Table 4.33) with the weighted mean of 8.00 to 1.06 dSm^{-1} , (Table 4.37) respectively. The soils of this pedon found moderately alkaline in reaction. The salinity (EC) remained $< 1.0 \text{ dSm}^{-1}$, which is expected due to leaching of salts by rain. The pH of the surface horizon was distinctly higher than that of immediate subsurface horizons. This is due to higher accumulation of salts of bicarbonate of Na^+ at surface horizon than immediate subsurface horizon as indicated by composition of saturation extract (Table 4.38). The irregular distribution of pH value in pedon P₄ soils (Fig. 4.20) probably

indicates stratified nature of these soils. Suri (1976) reported that contradiction behaviour of the depth distribution of pH in soils may be due to quality of ground water and addition of salts alongwith alluvium. The vertical distribution of EC was found irregular (Fig. 4.21).

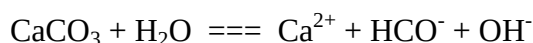
The organic carbon, CaCO_3 and CEC ranged from 0.12 to 0.69 per cent, 17.50 to 26.00 per cent and 24.78 to 30.20 $\text{cmol (p}^+) \text{ kg}^{-1}$ (Table 4.33) with weighted mean of 0.38 per cent, 22.83 per cent and 26.34 $\text{cmol (p}^+) \text{ kg}^{-1}$, (Table 4.37) respectively. The distribution of CaCO_3 followed the similar pattern as that of clay content in the solum of pedon P_4 . The soils were low in organic carbon and highly calcareous. The soils of pedon P_4 showed marked variation in organic carbon (Fig. 4.22) probably due to fluvial activity (Barua, 1989). The CaCO_3 content increased with increase in the depth indicating the lithogenic development of lime as soils were highly calcareous in nature. Gundalia and Savalia (2000) also reported the soils of Fluventic Ustochrept of the village Panchasar of Rajkot district possess the lithogenic development of lime. Similar observations were also reported by Sharma (1995). He found gradual increase of CaCO_3 in subsurface layer (Fig. 4.23) clearly indicate the effect of decalcification at the surface and its subsequent deposition in subsurface layers. An usual high CaCO_3 content (17.50 to 26.00 per cent) observed at the lowest elevation (MSL: 11m) of the piedmont plain might be the part of local alluvium deposition in view of terrain characteristics. These findings are in close vicinity of those of Sharma *et al.* (1996). Fairly uniform or uneven distribution of CaCO_3 could be due to its periodical accumulation through flowing water (Sharma *et al.*, 1999) from topographically high position. The exchangeable Ca^{2+} , Mg^{2+} , Na^+ and K^+ ranged from 11.95 to 18.20, 4.90 to 6.80, 3.59 to 4.69 and 0.50 to 1.17 $\text{cmol (p}^+) \text{ kg}^{-1}$, respectively. The vertical distribution of exchangeable cations was irregular. The exchangeable Ca^{2+} was the dominant base followed by Mg^{2+} . These two cations constitute the bulk of bases in the pedon P_4 . The distribution of exchangeable cation was in the order of $\text{Ca}^{2+} > \text{Mg}^{2+} > \text{Na}^+ > \text{K}^+$. The BSP, ESP and CEC/clay ranged from 89.0 to 95.9, 13.60 to 18.13 and 0.64 to 0.85, respectively. The vertical distribution of BSP, ESP and CEC/clay was irregular. The weighted mean of ESP was observed 14.90 (Table 4.37) indicating high ESP as compared to other pedons in Hiran toposequence. The ESP was in higher range in this pedon as compared to other pedons and it was high in IIC_3 horizon probably due to poor drainage, shallow ground water (Water table 5 m, Table 4.29) and greater quantity of Na-salts. The results are in accordance with the finding of Barua (1989). The relatively higher ESP of these soils points to need the possible potential alkalinity hazard in the near future. There is a to take adequate reclamation measures and drainage improvement in this area.

4.4.1.2 Shingoda Toposequence (T_2)

A perusal of data on different chemical characteristics from pedon P_5 to P_8 of Shingoda toposequence are presented in Table 4.34 and graphically exhibited in Fig. 4.20 to 4.25.

Pedon 5 (Jamwala) from the Upper piedmont : The pH, EC and organic carbon ranged from 8.05 to 8.19, 0.20 to 0.30 dSm⁻¹ and 0.47 to 0.84 per cent (Table 4.34) with the weighted mean of 8.13, 0.24 dSm⁻¹ and 0.70 per cent (Table 4.37), respectively. The soils associated with this pedon were moderately alkaline, medium in organic carbon content. The pH increased with increasing soil depth (Fig. 4.20). The increase of pH with depth may be

attributed to movement of salts of sodium and mineralization of CaCO_3 in lower horizons. Besides, the increase in pH with depth may be due to the liberation of free OH^- ions as a result of hydrolysis and desiccation of calcium carbonate (Liord and Peterson, 1964) as follows :



The EC decreased from 0.30 dSm^{-1} in the surface to 0.20 dSm^{-1} in B_{21} horizon and remained constant upto substratum (Fig. 4.27). The EC was higher at the surface horizon, probably due to upward movement of soluble salts to the surface through capillary rise of water, which evaporated leaving behind the salts at the surface under isohyperthermic temperature regime. Shallow ground water during rainy season also facilitated the capillary movement of ground water. The organic carbon content was higher in surface horizon and it decreased with increasing depth (Fig. 4.22). This may be due to the addition of organic carbon to the surface of the cultivated soils by crop residues (Khanna *et al.*, 1968) which were readily decomposed under isohyperthermic temperature regime prevailing in this area and it may also due to maximum biological activities which at surface (Sharma, 1995). The CaCO_3 and CEC ranged from 26.00 to 46.00 per cent and 18.31 to 21.13 $\text{cmol (p}^+)\text{kg}^{-1}$, (Table 4.34) respectively. The weighted mean of CaCO_3 was 36.00 per cent (Table 4.37) indicating that the soils are strongly calcareous in nature. Gundalia and Savalia (2000) also reported that the strongly calcareous soil in the Vansaj area of Una taluka in southern Saurashtra region. The CaCO_3 content increase with increasing depth (Fig. 4.23) indicating the lithogenic origin of lime (Gundalia and Savalia, 2000).

The CEC in the soils of Shingoda command area ranged from 14.00 to 48.00 $\text{cmol (P}^+)\text{kg}^{-1}$. The CEC decreased with increasing soil depth. The exchangeable Ca^{2+} , Mg^{2+} , Na^+ and K^+ ranged from 10.95 to 15.35, 2.30 to 5.90, 1.44 to 1.71 and 0.13 to 0.23 $\text{cmol (p}^+)\text{kg}^{-1}$, respectively (Table 4.34). The exchangeable Ca^{2+} and K^+ decreased with an increasing depth. However, the vertical distribution of exchangeable Mg^{2+} and K^+ was not found systematic. The exchangeable Ca^{2+} was the dominant cation followed by Mg^{2+} , Na^+ and K^+ . The BSP, ESP and CEC/clay ratio ranged from 87.5 to 91.4, 6.81 to 8.21 and 0.62 to 0.74, respectively. The vertical distribution of ESP and CEC/clay ratio was found irregular. However, BSP decreased with increasing depth.

Pedon 6 (Kareda) from the Lower piedmont : The pH, EC and organic carbon varied from 8.10 to 8.23, 0.20 to 0.30 and 0.02 to 0.42 (Table 4.34) with the weighted mean of 8.15, 0.25 dSm^{-1} , 0.15 per cent, (Table 4.37) respectively. The soils were moderately alkaline in reaction and low in organic carbon content. The vertical distribution of pH (Fig. 4.20) and EC (Fig. 4.21) found irregular. However, organic carbon was high 0.42 per cent in the surface as a result of addition of organic carbon to the surface soils by crop residues (Khanna *et al.*, 1968), thereafter abruptly decreased up to 0.02 per cent in lower horizons. The CaCO_3 and CEC varied between 14.00 to 26.00 per cent and 13.97 to 17.33 $\text{cmol (P}^+)\text{kg}^{-1}$ (Table 4.34) with the weighted mean of 20.33 per cent and 16.11 $\text{cmol (p}^+)\text{kg}^{-1}$, respectively (Table 4.37). The soils were highly calcareous in nature and low in CEC. The CaCO_3 content increased with increasing soil depth (Table 4.23) indicating the lithogenic origin of lime in these soils. The low CEC observed in

these soils might be due to the low clay (14.20 to 17.20 per cent, (Table 4.7) and organic carbon content. CEC decreased with increasing depth. Exchangeable cations ranged from 3.70 to 11.45, 2.30 to 6.10, 1.59 to 2.46 and 0.34 to 0.66 cmol (P⁺) kg⁻¹, respectively. The exchangeable Ca²⁺ and K⁺ decreased with increasing depth on the other hand in case of exchangeable Mg²⁺, the reverse trend was observed as that was noted with exchangeable Ca²⁺. The depth distribution in exchangeable Na⁺ was irregular. The proportion of exchangeable cations was in the decreasing

sequence of $\text{Ca}^{2+} > \text{Mg}^{2+} > \text{Na}^+ > \text{K}^+$. The BSP, ESP and CEC/clay ratio varied between 89.5 to 93.4, 9.17 to 16.89 and 0.96 to 1.01, (Table 4.34) respectively. The soils associated with this pedon have relatively higher ESP (9.17 to 16.89), which projects the possible potential alkalinity hazard in the near future (Table 4.34). There is a caution to take adequate measures to overcome this problem. The vertical distribution of BSP and CEC/clay ratio was irregular, however, ESP increased with increasing depth probably due to the better leaching conditions.

Pedon 7 (Devali) from the Piedmont plain : The pH, EC and organic carbon content varied from 7.89 to 8.31, 0.20 to 0.35 and 0.35 to 0.80 (Table 4.34) with the weighted mean of 8.19, 0.26 dSm^{-1} and 0.53 per cent (Table 4.37), respectively, indicating the soils were moderately alkaline in reaction and medium in organic carbon content. The vertical distribution of pH (Fig. 4.20), EC (Fig. 4.21) and organic carbon (Fig. 4.22) was found irregular probably indicated stratified nature of soils. A fact also corroborated by the finding of Suri (1976). The vertical distribution of organic carbon was irregular (Fig. 4.22) which indicates its recent deposition and fluvial characteristics. Similar observation was also recorded by Kaswala *et al.* (1999) and Velayutham *et al.* (1999). The very high content of organic carbon (0.80 per cent) in Ap horizon was observed might be due to addition of FYM and crop residues by the progressive farmers which may be readily decomposed under isohyperthermic temperature regime prevailing in the areas and maximum biological activities occurred at the surface (Sharma, 1995). A fact also corroborated by the finding of Khanna *et al.* (1968) and Barua (1989). The CaCO_3 and CEC ranged from 14.00 to 25.00 per cent and 16.20 to 23.65 $\text{cmol (p}^+) \text{ kg}^{-1}$ (Table 4.34). The weighted mean of CaCO_3 was 19.28 per cent (Table 4.35).

The CEC of the pedon P₁₀ of Mitiaj village of Shingoda command area ranged from 17.00 to 23.00 $\text{cmol (P}^+) \text{ kg}^{-1}$ (NWR & WSD, 2000). The weighted mean of CaCO_3 was 19.28 per cent (Table 4.37) indicating highly calcareous soils. The depth distribution of CaCO_3 was irregular (Fig. 4.23) indicating the mixed (Pedogenic and Lithogenic) development of lime. Similar, observations have also been recorded by Savalia *et al.* (2000) in Vertic Calcicustepts soils of Uben irrigation command area in Saurashtra region. The depth distribution of CEC was also found irregular. The exchangeable Ca^{2+} , Mg^{2+} , Na^+ and K^+ ranged between 8.25 to 15.00, 4.30 to 9.25, 1.78 to 2.11 and 0.10 to 0.69 $\text{cmol (P}^+) \text{ kg}^{-1}$, respectively. The exchangeable Ca^{2+} and K^+ decreased regularly from 15.00 to 8.25 $\text{cmol (p}^+) \text{ kg}^{-1}$ in the surface horizon to the 8.25 and 0.10 $\text{cmol (p}^+) \text{ kg}^{-1}$ in the parent material at IIIC₃ horizon, respectively. The vertical distribution of exchangeable Mg^{2+} and Na^+ was irregular. The distribution of exchangeable cations were in the decreasing order of $\text{Ca}^{2+} > \text{Mg}^{2+} > \text{Na}^+ > \text{K}^+$. The BSP, ESP and CEC/clay ratio ranged from 89.1 to 95.6, 7.95 to 10.99 and 0.61 to 1.59, respectively (Table 4.34). The soils associated with this pedon have comparatively higher ESP (7.95 to 10.99) which project the possible alkalinity hazard in the near future hence there is a need to take adequate amending measures and drainage improvement. The vertical distribution of BSP, ESP and CEC/clay ratio were found irregular.

Pedon 8 (Chauhani Khan) from the Coastal plain : The pH, EC, organic carbon and CaCO_3 ranged from 7.99 to 8.21, 0.40 to 0.80, 0.26 to 0.59 and 2.50 to

17.50 (Table 4.34) with the weighted mean of 8.05, 0.67 dSm⁻¹, 0.36 per cent and 9.17 per cent (Table 4.37), respectively, indicating the soils were moderately alkaline in reaction, low in organic carbon status and slightly calcareous in nature. Velayutham *et al.* (1999) also reported the soils of coastal Kathiawar peninsula to be predominantly calcareous and slightly to moderately alkaline in reaction. The organic carbon content in these soils was very poor which reflects the high ESP of the soil. The vertical distribution of pH (Fig. 4.20) and EC (Fig. 4.21) was irregular. The highest pH (8.21) recorded in parent material at IIC₂ horizon because of high ESP value (22.81).

The irregular distribution of organic carbon content with increased more than 10 per cent was within the profile indicates the fluvial nature of soils of this pedon. The CaCO₃ content decreased with increasing depth indicating the lime has been transported from elsewhere and deposited at the point.

The CEC ranges from 19.68 to 31.52 cmol (p⁺) kg⁻¹. The CEC increased with increasing depth. Similar, trend in case of clay content is observed in the solum of this profile. The exchangeable Ca²⁺, Mg²⁺, Na⁺ and K⁺ ranged from 12.30 to 17.85, 4.80 to 5.70, 0.69 to 7.19 and 0.06 to 0.10 cmol (p⁺) kg⁻¹, respectively. The exchangeable Ca²⁺ increased with increasing depth above the parent material while the similar increasing trend was observed in case of exchangeable Na⁺ throughout the profile. However, vertical distribution of exchangeable Mg²⁺ was irregular. While in case of exchangeable K⁺, it slightly increased from the surface to the B₂₁ horizon, thereafter it remained constant throughout the profile. The distribution of exchangeable cations was in the decreasing sequence of Ca²⁺ > Mg²⁺ > Na⁺ > K⁺. The BSP, ESP and CEC/clay ratio ranged from 88.7 to 93.7, 3.49 to 22.81 and 0.76 to 1.24, respectively (Table 4.34). The vertical distribution of BSP was irregular. However, ESP was increased from 3.49 in the surface horizon to the maximum upto 22.81 in the parent material at IIC₂ horizon which may due to the highest amount of exchangeable Na⁺ (7.19 cmol (P⁺) kg⁻¹) found in IIC₂ horizon in this pedon. These soils face the danger of the alkalinity hazard in near future and there is need to take proper amending and drainage improvement efforts. The CEC/clay ratio decreased with increasing depth in the solum thereafter it was abruptly increasing in parent material at IIC₂ horizon.

4.4.1.3 Machhundri Toposequence (T₃)

A perusal of data of different chemical characteristic of pedons P₉ to P₁₂ of Machhundri toposequence are depicted in Table 4.35 and portrayed graphically in Fig. 4.20 to 4.25.

Pedon 9 (Fatsar) from the Upper piedmont : The pH, EC and organic carbon ranged from 8.12 to 8.16, 0.17 to 0.20 dSm⁻¹ and 0.20 to 0.81 per cent (Table 4.35) with the weighted mean of 8.13, 0.19 dSm⁻¹ and 0.56 per cent (Table 4.37), respectively indicating the soils were moderately alkaline in reaction and medium in organic carbon content. These results are parallel to those of NWR & WSD (1999). The pH increased with increasing soil depth (Fig. 4.20) whereas EC (Fig. 4.21) and organic carbon (Fig. 4.22) decreased with increasing soil depth. The high content of organic carbon at the surface might be due to the application of crop residues/FYM in cultivated soil which were readily decomposed under hyperthermic temperature regime prevailing in this area (Khanna *et al.*, 1968). It may also be the maximum biological activities at surface (Sharma, 1995). The CaCO₃ and CEC ranged from 2.50 to 5.00 per cent and 24.11 to 30.12 cmol (p⁺) kg⁻¹, respectively. NWR & WSD (1998) also found the CEC varied from 28.0 to 33.0 cmol (p⁺) kg⁻¹ in the pedon P₁₇ of Fatsar village in Machhundri command area. The CaCO₃ increased from 2.50 per cent at surface horizon to the 5.00 per cent in AC horizon (Fig. 4.23) indicating the soils were slightly calcareous in nature. The vertical distribution of CEC was irregular. The exchangeable Ca²⁺, Mg²⁺, Na⁺ and K⁺ ranged from 15.85 to 23.85, 2.40 to 3.65, 1.53 to 2.06 and 0.06 to 0.07 cmol (p⁺) kg⁻¹, respectively. The exchangeable Ca²⁺ was decreased with increasing depth. However, vertical distribution of exchangeable Mg²⁺ and Na⁺ was irregular. The exchangeable K⁺ was slight higher at surface horizon than lower horizons. The BSP, ESP and CEC/clay ratio ranging from 88.5 to 95.2, 5.08 to 9.13 and 0.69 to 0.89, respectively (Table 4.35). The vertical distribution of BSP and CEC/clay ratio was irregular. However, ESP increased with increasing soil depth.

Pedon 10 (Judavadali) from the Lower piedmont : The pH, EC, organic carbon and CaCO_3 ranged from 8.10 to 8.21, 0.19 to 0.23 dSm^{-1} , 0.39 to 1.10 and 25.00 to 45.00 per cent (Table 4.35) with the weighted mean of 8.16, 0.22 dSm^{-1} , 0.93 per cent and 35.35 per cent (Table 4.37), respectively indicating the soils were moderately alkaline in reaction, high in organic carbon content and strongly calcareous in nature. The pH (Fig. 4.20) and organic carbon (Fig. 4.22) content decreased with increasing soil depth. The EC value remained constant (0.23 dSm^{-1}) throughout profile (Fig. 4.21) except B₂₁ horizon (0.19 dSm^{-1}). The CaCO_3 content increased from 25.00 per cent in the surface horizon to 45.00 per cent in parent material in BC horizon (Fig. 4.23) indicating the lithogenic development of lime. The thick compact layer of CaCO_3 at 45 cm depth in BC horizon of this pedon indicates the possibility of development of parched water table consequent upon the introduction of irrigation (Nayak *et al.*, 1999). The CEC ranged from 23.57 to 28.46 $\text{cmol (p}^+) \text{ kg}^{-1}$ and it decreased with increasing depth. NWR & WSD (1998) observed the CEC to range from 25.0 to 35.0 $\text{cmol (p}^+) \text{ kg}^{-1}$ in the pedon-53 of Judavadali village of Machhundri command area. The exchangeable Ca^{2+} , Mg^{2+} , Na^+ and K^+ ranged from 14.85 to 21.65, 2.65 to 3.95, 2.00 to 2.28 and 0.06 to 0.09 $\text{cmol (p}^+) \text{ kg}^{-1}$, respectively (Table 4.35). The exchangeable Ca^{2+} decreased with increasing soil depth. However, depth distribution of exchangeable Mg^{2+} and Na^+ was not systematic. The exchangeable K^+ was slightly higher in surface horizon (0.09 $\text{cmol (p}^+) \text{ kg}^{-1}$), thereafter, it was found constant (0.06 $\text{cmol (p}^+) \text{ kg}^{-1}$) in subsequent horizons of studied pedon. The distribution of exchangeable cations was in the decreasing order of $\text{Ca}^{2+} > \text{Mg}^{2+} > \text{Na}^+ > \text{K}^+$. The BSP, ESP and CEC/clay ratio varied from 88.5 to 94.4, 8.55 to 9.92 and 0.73 to 1.12, respectively (Table 4.35). The vertical distribution of BSP, ESP and CEC/clay ratio was irregular.

Pedon 11 (Delawada) from the Piedmont plain : The pH, EC organic carbon and CaCO_3 ranged from 8.18 to 8.35, 0.20 to 0.29 dSm^{-1} , 0.08 to 0.29 per cent and 2.00 to 7.50 per cent (Table 4.35) with the weighed mean of 8.24, 0.23 dSm^{-1} , 0.17 per cent and 3.93 per cent (Table 4.37), respectively indicating the soils to be moderately alkaline in reaction, low in organic carbon content and slightly calcareous in nature. The low organic carbon status of these soils warrant liberal addition of organic wastes like press mud of sugarcane, filter cakes, compost, FYM, etc. to improve the soil physical conditions and thereby productivity. The vertical distribution of pH, EC and organic carbon was not found to be regular (Fig. 4.20 to 4.22). However, CaCO_3 content decreased with increasing soil depth (Fig. 4.23). CEC ranged from 17.65 to 26.40 $\text{cmol (p}^+) \text{ kg}^{-1}$. The vertical distribution of CEC was irregular. The irregular pattern of organic carbon indicates a fluvial nature. The exchangeable Ca^{2+} , Mg^{2+} , Na^+ and K^+ ranged from 8.25 to 13.10, 6.10 to 11.05, 2.22 to 2.89 and 0.02 to 0.24 $\text{cmol (p}^+) \text{ kg}^{-1}$, respectively. The exchangeable Ca^{2+} increased with soil depth. However, exchangeable Mg^{2+} and Na^+ were not systematically distributed within the profile. The exchangeable K^+ slightly increased with increasing soil depth except in IIC₃ horizon. The distribution of exchangeable cations were in the sequence of $\text{Ca}^{2+} > \text{Mg}^{2+} > \text{Na}^+ > \text{K}^+$. The BSP, ESP and CEC/clay ratio ranged from 90.0 to 95.1, 9.78 to 13.70 and 0.64 to 0.87, respectively (Table 4.35). The comparatively slightly higher ESP observed indicates that there is need for due to possibility of cuation alkalinity hazard developing in near future, and which may require proper

reclamation and drainage improvement measures. The vertical distribution of BSP, ESP and CEC/clay ratio was found irregular.

Pedon 12 (Rampara) from the Coastal plain : The pH, EC, organic carbon and CaCO_3 varied from 8.11 to 8.62, 0.15 to 0.30 dSm^{-1} , 0.03 to 0.20 per cent and 3.00 to 15.00 per cent (Table 4.35) with the weighted mean of 8.39, 0.24 dSm^{-1} , 0.12 per cent and 11.05 per cent (Table 4.37), respectively indicating the soils to be moderately alkaline in reaction, low in organic carbon status and moderately calcareous in nature. The low organic carbon status of these soils indicate the need for care to additions of organic wastes, FYM, fish manures, etc., to improve the soil physical conditions and hence sustainability. The pH increased with increasing depth (Fig. 4.20). Similar, trend in depth distribution was observed in case of CaCO_3 (Fig. 4.23). The soils from the IIC_1 horizon to the IIC_3 horizon exhibited strongly alkaline soil (>8.4 pH). The depth distribution of EC was not systematic (Fig. 4.21). The depth distribution of organic carbon was also found irregular (Fig. 4.22) indicating the soils exhibited fluventic characteristics. The CaCO_3 increased from 3.00 per cent at surface horizon to the 15.00 per cent at IIC_3 horizon (Fig. 4.23) indicating lithogenic origin of lime. The CEC varied from 16.84 to 36.83 $\text{cmol (p}^+) \text{ kg}^{-1}$. The vertical distribution of CEC was found irregular. The exchangeable Ca^{2+} , Mg^{2+} , Na^+ and K^+ ranged from 3.75 to 9.20, 4.80 to 24.15, 1.81 to 4.43 and 0.01 to 0.14 $\text{cmol (p}^+) \text{ kg}^{-1}$, respectively. The vertical distribution of exchangeable Ca^{2+} , Mg^{2+} and Na^+ was found irregular. While the exchangeable K^+ was uniform and higher in surface as well as subsurface horizons than rest of the lower horizons. The distribution of exchangeable cations was in the decreasing order of $\text{Mg}^{2+} > \text{Ca}^{2+} > \text{Na}^+ > \text{K}^+$. The BSP, ESP and CEC/clay ratio varied from 87.8 to 93.5, 10.81 to 17.00 and 0.56 to 1.72 (Table 4.35), respectively. Due to higher ESP (10.81 to 17.00) observed in this area which project the possible alkalinity hazard in the near future hence there is a caution to take adequate amending measures and drainage improvement efforts. The vertical distribution of BSP, ESP and CEC/clay ratio was found irregular.

4.4.1.4 Rayadi Toposequence (T_4)

The data concerning the different chemical characteristic of the pedons P_{13} to P_{16} of Rayadi toposequence are presented in Table 4.36 and graphically arranged in Fig. 4.20 to 4.23.

Pedon 13 (Dedan) from the Hill slope : The data on chemical characteristics of pedon P_{13} are presented in Table 4.36. The results revealed that pH, EC, organic carbon and CaCO_3 varied from 7.86 to 7.88, 0.15 to 0.20 dSm^{-1} , 0.47 to 0.65 per cent and 1.50 to 2.50 per cent (Table 4.36 & Fig. 4.20 to 4.23) with the weighted mean of 7.87, 0.18 dSm^{-1} , 0.57 per cent and 1.96 per cent (Table 4.37), respectively, indicating the soils were moderately alkaline in reaction, medium in organic carbon status and non-calcareous. The reason for low pH is

due to the soils situated at higher elevation (MSL: 160m). These findings also corroborated to report of Deshmukh and Bapat (1993). The organic carbon was higher in surface horizon. This may be attributed to comparatively high rainfall in this region having dense vegetation results in leaf fall/ decay in surface (Sharma *et al.*, 2004). The slight increase of CaCO_3 in AC horizon than A_{11} horizon. The CEC ranged from 20.30 to 23.93 $\text{cmol (p}^+) \text{ kg}^{-1}$ and it was higher in surface horizon than AC horizon. The exchangeable Ca^{2+} , Mg^{2+} , Na^+ and K^+ ranged from 10.55 to 11.80, 6.30 to 8.10, 1.63 to 2.06 and 0.03 to 0.06 $\text{cmol (p}^+) \text{ kg}^{-1}$, respectively (Table 4.36). All these exchangeable cations were higher in surface horizon than AC horizon. The distribution of exchangeable cations was in the order of $\text{Ca}^{2+} > \text{Mg}^{2+} > \text{Na}^+ > \text{K}^+$. The BSP, ESP and CEC/clay ratio ranged between 91.2 to 92.0, 8.03 to 8.61 and 0.68 to 0.69, respectively (Table 4.36). The BSP and ESP were higher in A_{11} horizon than AC horizon. However, CEC/clay ratio was slightly higher in AC horizon than A_{11} horizon.

Pedon 14 (Dedan) from the Upper piedmont : The pH, EC, organic carbon and CaCO_3 varied from 8.11 to 8.17, 0.20 to 0.30 dSm^{-1} , 0.23 to 0.38 per cent and 3.00 to 5.00 per cent (Table 4.36 & Fig. 4.20 to 4.23), with the weighted mean of 8.13, 0.23 dSm^{-1} , 0.34 per cent and 3.75 per cent (Table 4.37), respectively, indicating soils were moderately alkaline in reaction, low in organic carbon status and slightly calcareous in nature. The pH increased with increasing depth (Fig. 4.20) might be linked with the movement of salts. This is in line with the findings of Das and Chatterjee (1982), Verma and Tripathi (1982) and Paramasivam (1992). The organic carbon decreased with an increasing soil depth (Fig. 4.22). The organic carbon was higher in Ap horizon may be due to the addition of organic carbon to the surface of the cultivated soils by crop residues which were readily decomposed under hyperthermic temperature regime prevailing in this area. (Khanna *et al.*, 1968). The CaCO_3 increased with an increasing the soil depth (Fig. 4.23) indicating the lithogenic lime development. The CEC varied from 27.29 to 27.44 $\text{cmol (p}^+) \text{ kg}^{-1}$ and it was found more or less uniform throughout the profile. The exchangeable Ca^{2+} , Mg^{2+} , Na^+ and K^+ ranged from 12.60 to 15.05, 8.50 to 10.25, 1.62 to 2.09 and 0.21 to 0.28 $\text{cmol (p}^+) \text{ kg}^{-1}$, respectively (Table 4.36). The exchangeable Ca^{2+} and K^+ decreased with increasing depth, while, exchangeable Mg^{2+} increased with increasing soil depth with the vertical distribution of exchangeable Na^+ being irregular. The distribution of exchangeable cations was in order of $\text{Ca}^{2+} > \text{Mg}^{2+} > \text{Na}^+ > \text{K}^+$. The BSP, ESP and CEC/clay ratio varied from 90.0 to 94.7, 5.92 to 7.66 and 0.62 to 0.76, respectively (Table 4.36). The vertical distribution of BSP, ESP and CEC/clay ratio found irregular.

Pedon 15 (Chotara) from the Lower piedmont : A perusal of data presented in table 4.36 reveals that the pH, EC, organic carbon and CaCO_3 varied between 8.14 to 8.27, 0.26 to 0.35 dSm^{-1} , 0.45 to 0.75 per cent and 1.00 to 4.00 per cent (Table 4.36 & Fig. 4.20 to 4.23) with the weighted mean of 8.21, 0.31 dSm^{-1} of 0.55 per cent and 2.55 per cent (Table 4.37), respectively indicating the soils to be moderately alkaline in reaction, medium in organic carbon status and non calcareous in nature. The pH and CaCO_3 decreased with increasing soil depth (Fig. 4.20 to 4.23). The pH was higher in surface horizon than that of immediate subsurface horizons (Fig. 4.26) might be due to higher accumulation of CaCO_3 in the surface horizons. The vertical distribution of EC was irregular (Fig. 4.21). The organic carbon was higher (i.e. 0.75 per cent) in Ap horizon than lower

horizons. This may be due to the addition of FYM and crop residues in cultivated fields by progressive farmers of this area. The higher amount of organic carbon may also be due to transportation from upper levels and deposition in the lower physiographic position. Further fine textured soils could have favoured the fixation of humic substances in form of clay-humic complex (Stevenson, 1986 and Paramasivam, 1992). However, the vertical distribution of organic carbon was irregular (Fig. 4.22) indicating the soils to be Fluventic in nature (Sharma and Dev, 1985a and Paramasivam, 1992). The CaCO_3 decreased with increasing depth (Fig.

4.23). The CEC ranged from 23.01 to 28.82 $\text{cmol (p}^+) \text{ kg}^{-1}$ and it decreased with increasing soil depth. The exchangeable Ca^{2+} , Mg^{2+} , Na^+ and K^+ ranged from 14.25 to 17.05, 3.35 to 7.50, 2.54 to 3.57 and 0.03 to 0.17 $\text{cmol (p}^+) \text{ kg}^{-1}$, respectively. The exchangeable Ca^{2+} , Mg^{2+} and K^+ decreased with increasing soil depth. However, the vertical distribution of exchangeable Na^+ was irregular. The distribution of exchangeable cations was in the sequence of $\text{Ca}^{2+} > \text{Mg}^{2+} > \text{Na}^+ > \text{K}^+$. The BSP, ESP and CEC/clay ratio ranged between 87.5 to 95.0, 8.54 to 12.87 and 0.43 to 0.65, respectively (Table 4.36). The soils associated with this pedon have relatively higher ESP (8.54 to 12.87), indicating a possible potential for alkalinity hazard in the near future. There is a need to take adequate amending measures and drainage improvement in this area. The vertical distribution of BSP and ESP was found irregular. However, CEC/clay ratio decreased with increasing depth.

Pedon 16 (Kadiyali) from the Coastal plain : The pH, EC, organic carbon and CaCO_3 ranged from 8.53 to 8.73, 0.67 to 1.42 dSm^{-1} , 0.12 to 0.69 per cent and 31.50 to 65.00 per cent (Table 4.36) with the weighted mean of 8.59, 1.01 dSm^{-1} , 0.34 per cent and 47.05 per cent (Table 4.37), respectively indicating the soils to be strongly alkaline in reaction, low in organic carbon status and strongly calcareous in nature. The pH (8.73) was higher in surface horizon thereafter it decreased upto 8.53 in BC horizon (Fig. 4.20). This is due to higher accumulation of salts of bicarbonates of Na^+ in the surface horizon than the immediate subsurface horizons as indicated by composition of saturation extract. The vertical distribution of EC was irregular (Fig. 4.21). However, the organic carbon content decreased with increasing depth. The status of organic carbon was medium in the surface and subsurface horizons (Fig 4.22). The CaCO_3 content increased with increasing depth indicating the lithogenic lime development. Gundalia and Savalia (2000) also noted the lithogenic lime development in

Pedon-20 of Vansaj village of Una taluka (Junagadh district) in which CaCO_3 increased from 67.3 per cent at surface horizon to the 70.00 per cent at lower most horizon.

The CEC ranged from 21.32 to 26.65 $\text{cmol (p}^+) \text{ kg}^{-1}$ and it decreased with increasing depth. The exchangeable Ca^{2+} , Mg^{2+} , Na^+ and K^+ ranging from 13.40 to 16.60, 3.50 to 6.55, 2.03 to 3.28 and trace to 0.02 (Table 4.36), respectively. The exchangeable Ca^{2+} and Mg^{2+} decreased with an increasing the depth. While the value of exchangeable Na^+ remains constant (3.28 $\text{cmol (p}^+) \text{ kg}^{-1}$) from Ap to B₂₂ horizon thereafter it was decreased in B₂₃ horizon than again it was slightly increased in BC horizon. The distribution of exchangeable cations was in the decreasing order of $\text{Ca}^{2+} > \text{Mg}^{2+} > \text{Na}^+ > \text{K}^+$. The BSP, ESP and CEC/clay ratio

ranged from 95.31 to 96.69, 9.70 to 14.56 and 0.77 to 1.06 (Table 4.36). The soils associated with this pedon have relatively higher ESP (9.70 to 14.56) which projects the potential alkalinity hazard and required to take appropriate amending measures and drainage improvements in this area. The vertical distribution of BSP, ESP and CEC/clay ratio were found irregular.

4.4.1.5 Land slopes

In order of understand the specificity of relationship between the soils and physiography, it is imperative to analyse the results of different chemical characteristic in lights of microtopographical variations imposed by variations in land slopes of the area. The weighted mean data pertaining to different chemical characteristic of different land slopes across the toposequences of the area are presented in Table 4.37.

(A) Hill slope : The pH, organic carbon and CaCO_3 ranged from 7.70 to 7.87, 0.57 to 0.81 per cent and 1.96 to 10.09 per cent with the mean value of 7.78, 0.69 per cent and 6.03 per cent (Table 4.37), respectively indicating the soils were mildly alkaline in reaction, moderate in organic

carbon status and slightly calcareous in nature. The EC was observed same i.e. 0.18 dSm^{-1} in pedon P₁ (Sasan) of Hiran toposequence (T₁) and P₁₃ (Dedan) of Rayadi toposequence. The highest pH observed in pedon P₁₃ (Dedan) followed by P₁ (Sasan). However, organic carbon and CaCO₃ content recorded highest in P₁ followed by P₁₃. The maximum CEC ($25.77 \text{ cmol (p}^+) \text{ kg}^{-1}$) was recorded in pedon P₁ followed by P₁₃ ($22.24 \text{ cmol (p}^+) \text{ kg}^{-1}$), with a mean value of $24.01 \text{ cmol (p}^+) \text{ kg}^{-1}$. The exchangeable Ca²⁺, Mg²⁺, Na⁺ and K⁺ ranging from 11.22 to 19.25, 2.49 to 7.26, 1.80 to 1.86 and 0.05 to 0.22 $\text{cmol (p}^+) \text{ kg}^{-1}$ with the mean value of 15.24, 4.88, 1.83 and 0.14 $\text{cmol (p}^+) \text{ kg}^{-1}$, respectively. The distribution of exchangeable cations was in decreasing sequence of $\text{Ca}^{2+} > \text{Mg}^{2+} > \text{Na}^+ > \text{K}^+$ in both the pedons. The BSP and ESP ranged between 91.63 to 92.26 and 7.00 to 8.34 with the mean value of 91.95 and 7.67, respectively.

(B) Upper piedmont : The pH, EC, organic carbon and CaCO₃ varied from 8.08 to 8.13, 0.19 to 0.24 dSm^{-1} , 0.34 to 0.70 per cent and 3.27 to 36.00 per cent with the mean value of 8.12, 0.21 dSm^{-1} , 0.56 per cent and 12.20 per cent (Table 4.37), respectively indicating the soil situated at upper piedmont area were moderately alkaline in reaction, medium in organic carbon status and moderately calcareous in nature. There was no wide variation in pH within the pedons. The highest Ec was recorded in pedon P₅ (Jamwala) of Shingoda toposequence followed by P₁₄ (Dedan) of Rayadi toposequence and P₂ (Borvav) of Hiran toposequence (T₁) as well as P₉ (Fatsar) of Machhundri toposequence. The highest organic carbon was observed in pedon P₅ (Jamwala) followed by P₂ (Borvav), P₉ (Fatsar) and P₁₄ (Dedan). The pedons P₂, P₅ and P₉ were medium in organic carbon status while P₁₄ was low in organic carbon status.

The highest CaCO₃ (36.00 per cent) was observed in pedon P₅ (Jamwala) followed by P₂ (Borvav), P₁₄ (Dedan) and P₉ (Fatsar). The P₅ (Jamwala) was highly calcareous while P₂ (Borvav), P₉ (Fatsar) and P₁₄ (Dedan) were slightly calcareous. The CEC varied from 20.55 to 28.10 with the mean value of $25.17 \text{ cmol (p}^+) \text{ kg}^{-1}$. The highest CEC ($28.10 \text{ cmol (p}^+) \text{ kg}^{-1}$) was observed in P₉ (Fatsar) followed by P₁₄ (Dedan), P₂ (Borvav) and P₅ (Jamwala). The exchangeable Ca²⁺, Mg²⁺, Na⁺ and K⁺ ranged from 12.73 to 21.47, 3.06 to 8.97, 1.56 to 1.93 and 0.03 to 0.26 $\text{cmol (p}^+) \text{ kg}^{-1}$ with the mean value of 15.98, 5.53, 1.69 and 0.14 $\text{cmol (p}^+) \text{ kg}^{-1}$, respectively (Table 4.37). The highest exchangeable Ca²⁺ was found in P₉ (Fatsar) followed by P₂ (Borvav), P₁₄ (Dedan) and P₅ (Jamwala). The maximum exchangeable Mg²⁺ ($8.97 \text{ cmol (p}^+) \text{ kg}^{-1}$) was observed in P₁₄ (Dedan) followed by P₂ (Borvav), P₅ (Jamwala) and P₉ (Fatsar). The maximum exchangeable Na⁺ ($1.93 \text{ cmol (p}^+) \text{ kg}^{-1}$) was recorded in P₁₄ (Dedan) followed by P₉ (Fatsar), P₂ (Borvav) and P₅ (Jamwala). The highest exchangeable K⁺ ($0.26 \text{ cmol (p}^+) \text{ kg}^{-1}$) was found in pedon P₁₄ (Dedan) followed by P₅ (Jamwala), P₉ (Fatsar) and P₂ (Borvav). The distribution of exchangeable cations was in the decreasing order of $\text{Ca}^{2+} > \text{Mg}^{2+} > \text{Na}^+ > \text{K}^+$ through out the land slope. The BSP and ESP varied from 90.95 to 93.50 and 6.38 to 7.62 with the mean value of 92.47 and 6.95, respectively. There was not wide variation in BSP and ESP within the pedons in upper piedmont area.

(C) Lower piedmont : The pH, EC, organic carbon and CaCO₃ varied from 7.99 to 8.21, 0.22 to 0.31 dSm^{-1} , 0.15 to 0.93 per cent and 2.55 to 35.35 per cent with the mean value of 8.13, 0.27 dSm^{-1} , 0.58 per cent and 18.97 per cent, respectively (Table 4.37) indicating the soils situated in lower piedmont area were

moderately alkaline in reaction, medium in organic carbon status and highly calcareous in nature. The highest pH (8.21) was observed in pedon P₁₅ (Chotara) of Rayadi toposequence followed by P₁₀ (Judavadali) of Machhundri toposequence, P₆ (Kareda) of Shingoda toposequence and P₃ (Maljinjava) of Hiran toposequence. There was not wide variation in EC within the pedons in lower piedmont area. The highest organic carbon (0.93 per cent) was recorded in pedon P₁₀ (Judavadali) followed by P₃ (Maljinjava), P₁₅ (Chotara) and P₆ (Kareda). The soils of pedon P₁₀ (Judavadali) were high in organic carbon status, while P₃ (Maljinjava) and P₁₅ (Chotara) were in medium whereas P₆ (Kareda) were low in organic carbon status. As far as CaCO₃ is concerned, the highest CaCO₃ (35.35 per cent) was recorded in pedon P₁₀ (Judavadali) followed by P₆ (Kareda), P₃ (Maljinjava) and P₁₅ (Chotara). The soils associated in the P₁₀ (Judavadali) were strongly calcareous while P₃ (Maljinjava) and P₆ (Kareda) were highly calcareous, whereas P₁₅ (Chotara) were non calcareous. The CEC ranged between 16.11 to 28.80 cmol (p⁺) kg⁻¹ with the mean value of 24.19 cmol (p⁺) kg⁻¹. The highest CEC (28.80 cmol (p⁺) kg⁻¹) was observed in pedon P₃ (Maljinjava) followed by P₁₅ (Chotara), P₁₀ (Judavadali) and P₆ (Kareda). The exchangeable Ca²⁺, Mg²⁺, Na⁺ and K⁺ ranging from 7.42 to 18.46, 3.15 to 8.43, 2.14 to 2.96 and 0.07 to 0.49 cmol (p⁺) kg⁻¹ with the mean value of 14.53, 5.40, 2.42 and 0.21 cmol (p⁺) kg⁻¹, respectively (Table 4.32). The lowest exchangeable Ca²⁺ was recorded in pedon P₆ (Kareda). The highest exchangeable Mg²⁺ (8.43 cmol (p⁺) kg⁻¹) was observed in P₃ (Maljinjava) followed by P₁₅ (Chotara), P₆ (Kareda) and P₁₀ (Judavadali). There was no wide variation observed in case of exchangeable Na⁺ and K⁺ within the pedons in lower piedmont area. The distribution of exchangeable Ca²⁺ was highest followed by Mg²⁺, Na⁺ and K⁺ in lower piedmont. The BSP and ESP varied from 91.73 to 94.35 and 7.86 to 13.50 with the mean value of 92.99 and 10.58, respectively (Table 4.37). There was no wide variation in BSP observed within the pedons. The highest ESP (13.50) was recorded in pedon P₆ (Kareda) followed by P₁₅ (Chotara), P₁₀ (Judavadali) and P₃ (Maljinjava).

(D) Piedmont plain : The pH, EC, organic carbon and CaCO₃ ranged between 8.00 to 8.24, 0.23 to 1.06 dSm⁻¹, 0.17 to 0.53 per cent and 3.93 to 22.83 per cent with the mean value of 8.14, 0.52 dSm⁻¹, 0.36 per cent and 15.35 per cent, respectively (Table 4.37) indicating the soils situated in piedmont plain area were moderately alkaline in reaction, low in organic carbon status and highly calcareous in nature. The highest pH (8.24) was observed in pedon P₁₁ (Delawada) of Machhundri toposequence followed by P₇ (Devali) of Shingoda toposequence and P₄ (Kajali) of Hiran toposequence. The EC recorded highest (1.06 dSm⁻¹) in pedon P₄ (Kajali) followed by P₇ (Devali) and P₁₁ (Delawada). The highest organic carbon (0.53 per cent) was observed in pedon P₇ (Devali) followed by P₄ (Kajali) and P₁₁ (Delawada). The soils of the pedon P₇ (Devali) were medium in organic carbon status while the soils of the P₄ (Kajali) and P₁₁ (Delawada) were low in organic carbon status. The highest CaCO₃ (22.83 per cent) was recorded in pedon P₄ (Kajali) followed by P₇ (Devali). The soils of pedon P₄ (Kajali) and P₇ (Devali) were highly calcareous while the P₁₁ (Delawada) was slightly calcareous. The CEC varied from 20.32 to 26.34 cmol (p⁺) kg⁻¹ with the mean value of 23.72 cmol (p⁺) kg⁻¹. The highest CEC (26.84 cmol (p⁺) kg⁻¹) was observed in pedon P₄ (Kajali) followed by P₁₁ (Delawada) and P₇ (Devali). The exchangeable Ca²⁺, Mg²⁺, Na⁺ and K⁺ varied from 10.99 to

14.12, 5.84 to 7.78, 1.86 to 4.00 and 0.13 to 0.88 cmol (p⁺) kg⁻¹ with the mean value of 12.22, 6.55, 2.84 and 0.44 cmol (p⁺) kg⁻¹, respectively (Table 4.37). There was no wide variation in exchangeable cations observed within the studied pedons in piedmont plain area. The distribution of exchangeable cations was in the sequence of Ca²⁺ > Mg²⁺ > Na⁺ > K⁺. The BSP and ESP varied from 92.40 to 93.26 and 9.26 to 14.90 with the mean value of 92.87 and 11.79, respectively. There was no wide variation observed in BSP within the pedons in piedmont plain area. The highest ESP (14.90) recorded in pedon P₄ (Kajali) followed by P₁₁ (Delawada) and P₇ (Devali).

(E) Coastal plain : The pH, EC, organic carbon and CaCO₃ ranged from 8.05 to 8.59, 0.24 to 1.01 dSm⁻¹, 0.12 to 0.36 per cent and 9.17 to 47.05 per cent with the mean value of 8.34, 0.64 dSm⁻¹, 0.27 per cent and 22.42 per cent (Table 4.37), respectively indicating the soils situated in the coastal plain area were moderately alkaline in reaction, low in organic carbon status and highly calcareous in nature. The highest pH (8.59) was observed in pedon P₁₆ (Kadiyali) of Rayadi toposequence followed by P₁₂ (Rampara) of Machhundri toposequence and P₈ (Chauhani Khan) of Shingoda toposequence. The highest EC (1.01 dSm⁻¹) was recorded in pedon P₁₆ (Kadiyali) followed by P₈ (Chauhani Khan) and P₁₂ (Rampara). The maximum organic carbon (0.36 per cent) observed in P₈ (Chauhani Khan) followed by P₁₆ (Kadiyali) and P₁₂ (Rampara). The highest CaCO₃ (47.05 per cent) was found in pedon P₁₆ (Kadiyali) followed by P₁₂ (Rampara) and P₈ (Chauhani Khan). The soils associated in the pedon-16 (Kadiyali), pedon-12 (Rampara) and P₈ (Chauhani Khan) were strongly, moderately and slightly calcareous, respectively. The CEC varied from 23.27 to 26.21 cmol (p⁺) kg⁻¹ with a mean value of 24.54 cmol (p⁺) kg⁻¹, respectively. There was no wide variation in CEC within the pedons in coastal plain area. The exchangeable Ca²⁺, Mg²⁺, Na⁺ and K⁺ ranged between 7.46 to 15.82, 4.46 to 11.23, 2.48 to 3.12 and trace to 0.08 cmol (p⁺) kg⁻¹ with the mean value of 12.80, 7.03, 2.79 and 0.05 cmol (p⁺) kg⁻¹, respectively (Table 4.37). The highest exchangeable Ca²⁺ (15.82 cmol (p⁺) kg⁻¹) was observed in pedon P₈ (Chauhani Khan) followed by P₁₆ (Kadiyali) and P₁₂ (Rampara). The highest exchangeable Mg²⁺ (11.23 cmol (p⁺) kg⁻¹) was observed in pedon P₁₂ (Rampara) followed by P₈ (Chauhani Khan) and P₁₆ (Kadiyali). However, there was no wide variation in exchangeable Na⁺ and K⁺ within the pedons in coastal plain area. The distribution of exchangeable cations was in the decreasing order of Ca²⁺ > Mg²⁺ > Na⁺ > K⁺. The BSP and ESP ranged from 90.89 to 93.11 and 8.62 to 12.92 with the mean value of 91.72 and 11.28, respectively. There was no wide variation in BSP within the pedons in coastal plain. The highest ESP (12.92) recorded in pedon P₁₂ (Rampara) followed by P₁₆ (Kadiyali) and P₈ (Chauhani Khan).

Overall Different Chemical Characteristics of Southern Saurashtra

In general, looking to overall picture for the different chemical characteristic (Table 4.37) of the soils of southern Saurashtra, the pH, EC, organic carbon and CaCO₃ ranged from 7.70 to 8.59, 0.18 to 1.06 dSm⁻¹, 0.12 to 0.93 per cent and 1.96 to 47.05 per cent with the overall mean value of 8.13, 0.36 dSm⁻¹, 0.49 per cent and 17.24 per cent, respectively, indicating the soils of southern Saurashtra were moderately alkaline in reaction, low in organic carbon status and highly calcareous in nature. The pH of the soils of southern Saurashtra was observed in

the increasing sequence of Hill slope < Upper piedmont < Lower piedmont < Piedmont plain < Coastal plain (Fig. 4.24). A thorough examination of the data reveals that an increase in soil pH gradually along the topography from hill slope to coastal plain could be the result of continuous flow of bases from higher topography to lower topography of southern Saurashtra. This finding is in conformity with that of Gaikwad *et al.* (1974), Fitzpatrick and Leroux (1977), Tiwary *et al.* (1989), Datta *et al.* (1990), Singh *et al.* (1991), Rathore (1973) and Sharma (1995) and Sharma *et al.* (1996). The low pH observed in hill slope area might be due to the soils being situated at higher elevations (MSL: 150 to 170 mm). These findings are similar to those of Singh *et al.* (1991), Deshmukh and Bapat (1993). The higher values of pH in piedmont plain and coastal plain might be due to calcareous parent material and accumulation of salts (Arnold and Venkateshwarlu, 1982 and Singh, 1999). The electrical conductivity of the soils of southern Saurashtra was recorded in the order of Hill slope < Upper piedmont < Lower piedmont < Piedmont plain < Coastal plain (Fig. 4.24). The data clearly indicate that the electrical conductivity increases from hill slope to coastal plain indicating that appreciable amount of salts have moved down the slope along with flowing water. The results are in concurrence with those obtained by Gaikwad *et al.* (1974), Fitzpatrick and Leroux (1977), Tiwary *et al.* (1989), Datta *et al.* (1990), Sharma (1994) and Sharma (1995). However, the variations in electric conductivity from hill slope to lower piedmont were not pronounced. The higher values of EC in piedmont plain and coastal plain soils indicated the accumulation of salts received through flowing water from adjoining area. These findings are similar to those reported by Sharma (1995). Sharma and Roychowdhary (1988) also reported that accumulation of soluble salts in soils occurring on flood plain and adjoining piedmont and valley was comparatively higher and was mainly due to their relatively poor drainage, high water table conditions high evaporative demand from the soil, which alternately regulate the salt regime (EC). The organic carbon content of the soils of southern Saurashtra was found in the sequence of Coastal plain < Piedmont plain < Upper piedmont < Lower piedmont < Hill slope (Fig. 4.25). Thus, the results clearly indicates that the higher values of organic carbon (0.57 to 0.81 per cent) recorded the hill slope. This might be due to the vegetative cover and less

erosion (Deshmukh and Bapat, 1993 and Sharma *et al.*, 1993) and partly to its topographical position which precludes the rapid oxidation of organic matter (Sharma, 1994). The lower values of organic carbon were observed in piedmont plain (0.17 to 0.53 per cent) and in coastal plain (0.12 to 0.36 per cent) due to more alluvium depositional activities, continuing erosion and less vegetative cover (Deshmukh and Bapat, 1993). Sharma (1995) also concluded that in flood plain, the pedogenic activities were not sufficiently advanced which could obliterate the mark of stratification indicating continuous recent depositional activities. However, the content of organic carbon in lower piedmont was slightly higher (0.58 per cent) than upper piedmont (0.56 per cent). Looking to overall position while traversing from soils of hill slopes to the coastal plain a gradual decrease in the content of organic carbon was observed (Fig. 4.25). A number of scientists (Singh *et al.*, 1991, Ramana Murthy and Sharma, 1992 and Sharma, 1994) have clearly indicated an increase in organic matter content with an increase in the altitude (MSL).

The CaCO_3 content was found in the increasing order of Hill slope < Upper piedmont < Piedmont plain < Lower piedmont < Coastal plain (Fig. 4.25). The soils of hill slopes recorded a lower value of CaCO_3 (6.03 per cent), whereas an abrupt rise (12.20 to 22.42 per cent) was observed from upper piedmont to the coastal plain. Thus the content of CaCO_3 in general increased along with down the slope and it registered its maximum value in coastal plain (22.42 per cent) (Table 4.37). The comparable results were also reported by Gaikwad *et al.* (1974), Rathore (1993) and Sharma (1995) along the transact. The cation exchange capacity in the soils of southern Saurashtra vary between 16.11 to 28.80 $\text{cmol (P}^+) \text{ kg}^{-1}$ with the mean value of 24.39 $\text{cmol (p}^+) \text{ kg}^{-1}$. The CEC was recorded in the increasing order of Piedmont plain < Hill slope < Lower piedmont < Upper piedmont < Coastal plain. Thus, there was no definite trend in distribution of CEC from hill slope to coastal plain. The exchangeable Ca^{2+} , Mg^{2+} , Na^+ and K^+ ranged from 7.42 to 21.47, 2.49 to 11.23, 1.56 to 4.00 and trace to 0.49 $\text{cmol (p}^+) \text{ kg}^{-1}$ with the overall mean value of 14.22, 5.89, 2.31 and 0.20 $\text{cmol (p}^+) \text{ kg}^{-1}$, respectively (Table 4.37). Thus the exchangeable Ca^{2+} was the dominant cation followed by $\text{Mg}^{2+} > \text{Na}^+ > \text{K}^+$. Yeresheemi *et al.* (1997) while studying the upper Krishna command area in Karnataka also recorded together, Ca^{2+} and Mg^{2+} accounted for greater portion of soil CEC and exchangeable Na^+ was the next in order of dominance.

The content of exchangeable Ca^{2+} in the soils of southern Saurashtra was found in the increasing order of Piedmont plain < Coastal plain < Lower piedmont < Hill slope < Upper piedmont. Whereas exchangeable Mg^{2+} was in increasing sequence of Hill slope < Lower piedmont < Upper piedmont < Piedmont plain < Coastal plain. The content of exchangeable Na^+ was observed in the increasing order of Upper piedmont < Hill slope < Lower piedmont < Coastal plain < Piedmont plain whereas exchangeable K^+ was in the increasing order of Coastal plain < Hill slope and Upper piedmont < Lower piedmont < Piedmont plain. Thus, there was no proper systematic pattern observed in content of exchangeable cations from hill slope to coastal plain. The BSP and ESP ranged from 90.95 to 94.35 and 6.38 to 14.90 with the mean value of 92.47 and 9.67, respectively (Table 4.37). The BSP was not influenced by the position of soil under main frame work of physiography (Sharma, 1995). The content of ESP was found in the increasing sequence of Upper piedmont < Hill slope < Lower piedmont < Coastal plain < Piedmont plain.

The ESP was recorded > 10.00 from Lower piedmont to coastal plain, which may be due to its mobility and position of profile in transect. A fact corroborated by the finding of Sharma (1995).

4.4.2 Composition of Saturation Extract

The data on composition of saturation extract (Ca^{2+} , Mg^{2+} , Na^+ , K^+ , CO_3^{2-} , HCO_3^- and Cl^-) in the soils of different toposequences across land slopes are presented in Table 4.38 to 4.42, graphically depicted in Fig. 4.26 and 4.27 and discussed as per the following:

4.4.2.1 Hiran toposequence (T_1)

4.4.2.2 Singoda toposequence (T_2)

4.4.2.3 Machhundri toposequence (T_3)

4.4.2.4 Rayadi toposequence (T_4)

4.4.2.5 Land slopes

4.4.2.1 Hiran Toposequence (T_1)

The data on composition of saturation extract of the soils of different pedon P_1 to P_4 of Hiran toposequence are depicted in Table. 4.38.

Pedon 1 (Sasan (Gir)) from the Hill slope : The saturation percentage varied from 44.55 in A_{11} to 51.50 percent in AC horizon and was increased with increasing depth. The pHs and ECe varied from 7.82 to 8.00 (Fig. 4.26) and 0.60 to 0.84 dSm^{-1} (Table 4.38 and Fig. 4.27) with the weighted means of 7.97 and 0.76 dSm^{-1} (Table 4.42), respectively, indicated that the soils were non sodic and non saline. The higher value of ECe was observed in subsurface as compared to surface horizon (Fig. 4.27). The water soluble Ca^{2+} , Mg^{2+} , and Na^+ ranged from 1.20 to 3.80, 2.00 to 4.80 and 1.13 to 1.63 me l^{-1} , respectively. The

soluble cations of the saturation extract of the studied pedon were dominated by Mg^{2+} , followed by Ca^{2+} , Na^+ and K^+ . The soluble Ca^{2+} decreased with increasing depth, which followed the same trend as that of CaCO_3 . The vertical distribution of water soluble Mg^{2+} with depth was irregular. The content of water soluble K^+ was trace (0.02me l^{-1}). Among the anions, the carbonate was absent. The content of HCO_3^- and Cl^- ranged from 2.20 to 3.80 and 3.60 to 4.60 me l^{-1} , respectively. The vertical distribution of bicarbonate decreased with depth, following the same trend as was noted that of CaCO_3 . However, the vertical distribution of chloride with depth was irregular. Among the anions, chloride was the dominant followed by bicarbonate. The SAR ranged from 0.71 to 0.96 (Table 4.38) and was decreased with increasing depth. This

might be due to accumulation of Ca^{2+} at the sub surface horizons as was equilibrium by mineralization of nature CaCO_3 .

Pedon 2 (Borvav) from the Upper piedmont : The saturation percentage varied between 41.95 to 53.25. The pHs and was ECe varied from 8.02 to 8.16 and 0.59 to 0.90 dSm^{-1} (Table 4.38), with the weighted mean of 8.08 and 0.77 dSm^{-1} , respectively (Table 4.42), indicating the soils were non sodic and non saline.

A glance at Table 4.38 insinuated that depth distribution of pHs was irregular (Fig. 4.26). It is obvious that, the ECe value decreased with increasing depth (Fig. 4.27). The water soluble Ca^{2+} , Mg^{2+} , Na^+ and K^+ ranged from 1.20 to 3.20, 2.00 to 4.20 and 1.50 to 2.29 me l^{-1} , respectively. Among the soluble cations, Mg^{2+} was found to be the most dominant followed by Ca^{2+} , Na^+ and K^+ . The vertical distribution of water soluble Ca^{2+} and Mg^{2+} with depth was irregular (Tale 4.38). Among the anions Cl^- was dominant followed by HCO_3^- . The HCO_3^- in saturation extract was found uniform (2.80 me l^{-1}) in surface and subsurface. However, it was slightly decreased in AC horizon. The Cl^- was highest (6.60 me l^{-1}) in surface horizon thereafter it was drastically decreased upto 1.40 me l^{-1} in subsurface layer then it was increased in AC horizon up to 2.80 me l^{-1} (Table 4.38). The SAR ranged from 1.01 to 1.39. The vertical distribution of SAR with depth was irregular (Table 4.38).

Pedon 3 (Maljinjava) from the Lower piedmont : The saturation percent varied from 55.25 to 66.65 (Table 4.38). The saturation percent decreased with depth up to B_{21} horizon thereafter it was slightly increased in AC horizon. The pHs and ECe ranged from 7.97 to 8.08 and 0.80 to 1.32 dSm^{-1} (Table 4.38) with the weighted mean of 7.98 and 1.07 me l^{-1} , respectively (Table 4.42). The vertical distribution of pHs with depth was irregular (Fig. 4.26), while the ECe increased with increasing soil depth upto the solum (Fig. 4.27). The maximum salt accumulation (high ECe values) was observed in lower horizon (B_{21} and IIC_1). It could be ascribed to the cementing nature of secondary lime which restricted to movement of soil water beyond this point, resulting in the

maximum accumulation of salts in the studied pedon (Naidu *et al.*, 1993; Pal *et al.*, 1999 and Sharma, 2000). The minimum amount at the surface and its gradual increase down to the soil depth to a point of maxima might be as a result of differential leaching of salts and its subsequent accumulation (Verma, 1995). The water soluble Ca^{2+} , Mg^{2+} , Na^+ and K^+ ranged between 1.40 to 2.40, 4.20 to 8.60, 2.29 to 3.29 and 0.02 to 0.04, respectively (Table 4.38). Among the water soluble cations in the studied pedon Mg^{2+} was the dominant cation followed by Na^+ , Ca^{2+} and K^+ . The vertical distribution of water soluble Ca^{2+} with depth was irregular. However, water soluble Mg^{2+} increased with increasing depth. Water soluble Na^+ increased with increasing depth up to B_{21} horizon thereafter it decreased in IIC_1 horizon. Among the anions, carbonate was absent while the chloride was dominant and ranged from 4.20 to 7.80 me l^{-1} its increase with increasing depth might be due to the downward leaching. These observations corroborate to those made by Pachiammal (1997). HCO_3^- was the next water soluble anion after Cl^- was ranging from 2.40 to 3.80 me l^{-1} (Table 4.38). The vertical distribution of HCO_3^- with depth was irregular. The SAR ranged from 1.27 to 1.47. The SAR increased with increasing depth upto B_{21} horizon thereafter it decreased at IIC_1 horizon (Table 4.38).

Pedon 4 (Kajali) from the Piedmont plain : The saturation percentage observed varied from 56.00 to 70.40 (Table 4.38) which was in higher as compared to other pedons. The saturation percentage increased with increasing depth up to IIC_2 horizon thereafter it decreased at IIIC_3 horizon. The depth distribution of saturation percentage followed the same trend as that of clay distribution (Table 4.23). The pHs and ECe varied from 7.91 to 8.23 and 1.60 to 4.50 dSm^{-1} (Table 4.38) with the weighted mean of 7.99 and 3.45 dSm^{-1} (Table 4.42), respectively indicating the soils were non sodic and very slightly saline. The pHs and ECe decreased with increasing depth (Fig. 4.26 & 4.27). The ECe was higher in the surface layer as compared to in subsurface layers. Higher values of ECe at surface layer were also reported by a number of workers (Tiwarly *et al.*, 1983; Sahu and Dash, 1993; Yaresheemi *et al.*, 1997

and Mandal and Sharma, 1997). The water soluble Ca^{2+} , Mg^{2+} , Na^+ and K^+ ranged from 1.20 to 12.80, 5.80 to 20.20, 9.00 to 16.43 and 0.02 to 0.77 me l⁻¹, respectively (Table 4.38). The proportion of Mg^{2+} was dominant followed by Na^+ , Ca^{2+} and K^+ (Maji *et al.*, 2001). The water soluble Ca^{2+} and Mg^{2+} decreased with increasing depth. The vertical distribution of Na^+ and K^+ with depth was irregular. Among the water soluble anions, Cl^- was the dominant which ranged from 14.00 to 33.60 me l⁻¹ followed by HCO_3^- ranged from 2.20 to 7.00 me l⁻¹ (Table 4.38). These findings are in accordance with those of Sharma *et al.* (1968), Derra *et al.* (1970), Sharma and Bhargava (1993), Mandal and Sharma (1997), Yeresheemi *et al.* (1997) and Sharma (2000). The vertical distribution of HCO_3^- and Cl^- with depth was irregular. The CO_3^{2-} was absent. The SAR ranged from 2.81 to 4.81. The vertical distribution of SAR with depth was irregular.

4.4.2.2 Shingoda Toposequence (T₂)

The data on composition of saturation extract of the pedons P₅ to P₈ are presented in Table 4.39.

Pedon 5 (Jamwala) from Upper piedmont : The saturation percentage varied between 52.04 to 54.52 (Table 4.39). The vertical distribution of saturation percentage with depth was irregular. The pHs and ECe varied from 7.33 to 8.20 and 0.80 to 1.10 dSm⁻¹ (Table 4.39) indicating the soils were sodic and non saline with the weighted mean values of 8.03 and 0.91 dSm⁻¹ (Table 4.42), respectively. The pHs decreased with increasing depth. The ECe was the highest in surface as compared to subsurface horizons. The water soluble Ca^{2+} , Mg^{2+} and Na^+ ranged from 1.80 to 3.00, 3.20 to 4.60 and 2.14 to 3.14 me l⁻¹, respectively. The content of K^+ was found in trace amount i.e. 0.02 me l⁻¹, throughout the profile (Table 4.39). The water soluble Ca^{2+} decreased with increasing depth. The vertical distribution of Mg^{2+} and Na^+ with depth was

irregular. The Na^+ was higher in surface as compared to subsurface which decreased in B_{21} thereafter increased in BC horizon. Suri (1976) has also reported different trends of depth distribution of soluble Na^+ . Dry climatic condition under hyper thermic temperature regime appears to cause the accumulation of soluble Na^+ in the surface horizon due to the continuous evaporation. On the other hand, during monsoon soluble Na^+ leached down to lower horizon. This caused a decreasing trend followed by an increasing depth of soluble Na^+ , where evaporation dominated over leaching (Barua, 1989). Among the cations, water soluble Mg^{2+} was dominant followed by Na^+ , Ca^{2+} and K^+ . Among the anions, CO_3^{2-} was absent. The HCO_3^- and Cl^- ranged from 4.00 to 4.40 and 2.60 to 3.20 me l^{-1} . The vertical distribution of HCO_3^- with depth was found to be irregular. However, Cl^- decreased with increasing depth (Table 4.39). The proportion of HCO_3^- was dominant followed by Cl^- . The SAR ranged from 1.24 to 1.61 and the vertical distribution of SAR with depth was not systematic.

Pedon 6 (Kareda) from Lower piedmont : The saturation percentage ranged from 31.64 to 50.28 (Table 4.39). The pHs and ECe ranged from 8.00 to 8.24 and 0.87 to 1.70 (Table 4.39) with the weighted mean value of 8.16 and 1.32 dSm^{-1} (Table 4.42), respectively indicating the soils were non sodic and non saline. The vertical distribution of pHs (Fig. 4.26) and ECe (Fig.4 27) with depth was irregular. The water soluble Ca^{2+} , Mg^{2+} , Na^+ ranged from 1.00 to 5.00, 3.00 to 5.60 and 2.57 to 10.40 me l^{-1} , respectively (Table 4.39). The water soluble Ca^{2+} was the highest in AC horizon as compared to surface horizon. The vertical distribution of Mg^{2+} and Na^+ with depth was irregular. The water soluble K^+ was present (0.02 me l^{-1}) in trace amount throughout the profile. The proportion of Na^+ was dominant followed by Mg^{2+} , Ca^{2+} and K^+ . Similar trend was observed by Maji *et al.* (2001). Among the anions, CO_3^{2-} was absent. The HCO_3^- and Cl^- ranged from 2.20 to 5.40 and 3.00 to 5.00 me l^{-1} , respectively. The HCO_3^- increased with increasing depth (Table 4.39) and the trend was same as that of CaCO_3 (Table 4.39). The proportion of HCO_3^- was higher than Cl^- throughout the profile. However, the proportion of Cl^- was dominated

in solum as compared to HCO_3^- . The SAR ranged from 1.46 to 5.73. The vertical distribution of SAR with depth was in regular (Table 4.39).

Pedon 7 (Develi) from the Piedmont plain : The saturation per cent ranged from 28.40 to 62.44. The vertical distribution of saturation per cent with depth was irregular (Table 4.39). The pHs and ECe ranged from 7.89 to 8.14 and 0.70 to 1.10 dSm^{-1} (Table 4.39) with weighted mean values of 8.01 and 1.00 dSm^{-1} (Table 4.42), respectively. The vertical distribution of ECe (Fig. 4.27) with depth was in regular. The water soluble Ca^{2+} , Mg^{2+} , Na^+ and K^+ ranged between 1.40 to 3.00, 2.80 to 4.00, 3.14 to 7.27 and 0.02 to 0.04 me l^{-1} , respectively (Table 4.39). The vertical distribution of Ca^{2+} , Mg^{2+} and Na^+ with depth was irregular. The proportion of Na^+ was dominant followed by Mg^{2+} , Na^+ and K^+ . Among the anions, CO_3^{2-} was absent. The HCO_3^- and Cl^- ranged from 4.20 to 5.80 and 2.25 to 8.00 (Table 4.39) with the weighted mean values of 4.75 and 4.58 me l^{-1} (Table 4.42), respectively indicating the HCO_3^- domination followed by Cl^- . The vertical distribution of HCO_3^- and Cl^- with depth was irregular. The SAR ranging between 2.17 and 4.27. The depth distribution of SAR with depth was irregular (Table 4.39).

Pedon 8 (Chauhani Khan) from the Coastal plain : The saturation percentage varied between 48.24 from surface to the highest i.e. 61.92 in B₂₁ horizon indicating the vertical distribution of saturation percent with depth was irregular. The pHs and ECe ranged from 7.99 to 8.12 and 1.40 to 3.00 (Table 4.39) with the weighted mean values of 7.94 and 2.30 dSm^{-1} (Table 4.42) respectively indicating the soils were non sodic and very slightly saline. No definite depth distribution in pHs and ECe was observed in this pedon (Fig. 4.26 & 4.27). However, ECe value was higher in surface layer as compared to sub surfaces. The reason for this is discussed as per the pedon P₄ (Kajali) of Hiran toposequence in this text. The water soluble Ca^{2+} , Mg^{2+} , Na^+ and K^+ ranged from 1.40 to 4.20, 2.80 to 11.20, 7.50 to 16.43 and 0.02 to 0.04 me l^{-1} (Table 4.39) with the weighted mean values of 2.57, 8.97, 11.92 and 0.04 me l^{-1} (Table 4.42) respectively indicating the Na^+ was the dominant cation followed

by Mg^{2+} , Ca^{2+} and K^+ (Maji *et al.*, 2001). The vertical distribution of Ca^{2+} , Mg^{2+} and K^+ with depth was not found in systematic manner. The Na^+ was higher in surface thereafter decreased in B_{21} horizon and again it was increased upto IIC_2 horizon. This finding is in conformity with the work of Suri (1976). Among the anions CO_3^{2-} was absent. The HCO_3^- and Cl^- ranged from 2.40 to 6.60 and 8.60 to 17.20 me l^{-1} , respectively (Table 4.39). The proportion of Cl^- was higher than HCO_3^- . A higher value of chloride as compared to other anions in salt affected soils has also been reported by Sharma *et al.* (1968). Sharma and Bhargava (1993), Mandal and Sharma (1997), Yeresheemi *et al.* (1997) and Maji *et al.* (2001). The HCO_3^- was decreased with increasing depth. The Cl^- was the highest 17.20 me l^{-1} in IIC_2 horizon followed by Ap, B_{22} and IIC_1 horizons (Table 4.39). The SAR was ranged from 4.07 to 6.21. The vertical distribution of SAR with depth was irregular.

4.4.2.3 Machhundri Toposequence (T_3)

The data on composition of saturated extract of the pedons P_9 to P_{12} of Machhundri toposequence are furnished in Table 4.40.

Pedon 9 (Fatsar) from the Upper piedmont : The saturation percentage varied from 44.00 to 52.80. The saturation percentage was higher in A_{12} horizon as compared to Ap horizon. The pHs and ECe were ranged from 7.79 to 7.87 and 0.66 to 0.82 dSm^{-1} (Table 4.40) with the weighted mean values of 7.84 and 0.78 dSm^{-1} , (Table 4.42) respectively indicating the soils were non sodic and non saline. The pHs decreased with increasing soil depth (Fig. 4.26). The vertical distribution of ECe with depth was irregular (Fig. 4.27). The water soluble Ca^{2+} , Mg^{2+} and Na^+ ranged from 1.00 to 1.60, 3.80 to 5.00 and 1.37 to 2.29 me l^{-1} , respectively. The water soluble K^+ was slightly present uniform throughout the profile. The water soluble Ca^{2+} decreased with increasing depth. Of course water soluble Mg^{2+} decreased with increasing the soil depth upto A_{12} horizon but thereafter it increased in AC horizon. The water soluble Na^+ increased with increasing depth. The proportion of cations was observed

in the decreasing order of $Mg^{2+} > Na^+ > Ca^{2+} > K^+$. Similar results were also reported by Maji *et al.* (2001). The CO_3^{2-} was absent. The HCO_3^- and Cl^- ranged from 2.40 to 3.00 and 2.60 to 3.60 (Table 4.40) with the weighted mean values of 2.84 and 2.83 $me\ l^{-1}$ (Table 4.42). The SAR ranged from 0.75 to 1.32 which was increased with increasing depth (Table 4.40).

Pedon 10 (Judavadali) from the Lower piedmont : The saturation percent varied from 48.44 to 52.92. The vertical distribution of saturation percent was irregular. The pHs and ECe ranged from 7.76 to 7.89 and 0.70 to 0.83 dSm^{-1} (Table 4.40) with the weighted mean values of 7.79 and 0.76 dSm^{-1} (Table 4.42), respectively indicating the soils were non sodic and non saline. The vertical distribution of pHs (Fig. 4.26) and ECe (Fig. 4.27) with depth was irregular. The water soluble Ca^{2+} , Mg^{2+} , Na^+ and K^+ ranged from 1.00 to 2.00, 2.00 to 4.20, 2.86 to 3.71 and 0.02 to 0.04 (Table 4.40) with the weighted mean values of 1.56, 3.02, 3.22 and 0.03 $me\ l^{-1}$ (Table 4.42), respectively indicating the proportion of water soluble Na^+ was dominant followed by Mg^{2+} , Ca^{2+} and K^+ . The similar results were also reported by Maji *et al.* (2001). The vertical distribution of water soluble Ca^{2+} and Mg^{2+} with depth was irregular. The water soluble Na^+ was decreased with increasing depth upto B₂₂ horizon thereafter it was remains constant in BC horizon. The water soluble K^+ was slightly higher at upper horizons as compared to lower horizons. The water soluble CO_3^{2-} was absent, while The HCO_3^- and Cl^- ranged between 2.60 to 3.60 and 2.60 to 3.40 $me\ l^{-1}$ (Table 4.40) with the weighted mean values of 3.36 and 3.01 $me\ l^{-1}$ (Table 4.42) indicating the proportion of HCO_3^- was higher than Cl^- . The HCO_3^- decreased with increasing depth while reverse trend was observed in case of Cl^- where it was increased with increasing depth upto B₂₂ horizon thereafter it remain constant in BC horizon. The SAR ranged from 1.71 to 2.62, which decreased with increasing depth upto B₂₂ thereafter it was remain constant in BC horizon.

Pedon 11 (Delawada) from the Piedmont plain : The saturation percent ranged from 44.40 to 57.80. The vertical distribution of saturation percent with

depth was irregular (Table 4.40). The pHs ranged from 7.84 to 8.10 and 0.74 to 1.18 dSm⁻¹ (Table 4.40) with the weighted mean values of 7.93 and 0.90 dSm⁻¹ (Table 4.42), respectively indicating that the soils were non sodic and non saline. The vertical distribution of pHs (Fig. 4.26) and ECe (Fig. 4.27) with depth was irregular. The water soluble Ca²⁺, Mg²⁺, Na⁺ and K⁺ ranged from 1.20 to 1.80, 3.00 to 5.60, 3.14 to 5.47 and 0.02 to 0.04 me l⁻¹ (Table 4.40) with the weighted mean values of 1.46, 3.53, 4.09 and 0.04 (Table 4.42), respectively indicating that the proportion of Na⁺ was dominant followed by Mg²⁺ Ca²⁺ and K⁺. Similar trend was observed by Maji *et al.* (2001). The vertical distribution of water soluble Ca²⁺ and Mg²⁺ with depth was irregular. The water soluble Na⁺ decreased with increasing depth. This might be due to insufficient water available to completely leach the salts leading to the observed accumulation of soluble Na⁺ in the surface horizon. This is also corroborated by the finding of Suri (1976). Among the anions, CO₃²⁻ was absent, while the HCO₃⁻ and Cl⁻ ranged from 2.60 to 3.80 and 3.20 to 4.60 (Table 4.40) with the weighted mean values of 3.67 and 3.92 me l⁻¹ (Table 4.42), respectively indicating that the proportion of Cl⁻ was slightly higher than that of HCO₃⁻ in saturation extract. The SAR ranged from 2.12 to 3.53 and it decreased with increasing depth (Table 4.40).

Pedon 12 (Rampara) from the Coastal plain : The saturation percent ranged from 27.52 to 42.80. The saturation percent decreased with increasing the depth upto B₂₂ horizon but thereafter it slightly increased upto IIC₁ horizon and again it decreased at IIC₃ horizon (Table 4.40). The pHs and ECe varied from 7.92 to 8.09 and 0.57 to 0.90 dSm⁻¹ (Table 4.40) with the weighted mean values of 7.99 to 0.75 dSm⁻¹ (Table 4.42), respectively indicating that the soils were non sodic and non saline. The vertical distribution of pHs (Fig. 4.26) and ECe (Fig. 4.27) with depth was not systematic. The water soluble Ca²⁺, Mg²⁺, Na⁺ and K⁺ varied between 1.20 to 2.40, 1.80 to 3.00, 1.88 to 4.54 and 0.00 to 0.04 (Table 4.40) with the weighted mean values of 1.94, 2.37, 3.21 and 0.02 me l⁻¹ (Table 4.42), respectively indicating that the water soluble Na⁺ was the dominant cation followed by Mg²⁺, Ca²⁺ and K⁺ (Maji *et al.*,

2001). The vertical distribution of water soluble Ca^{2+} , Mg^{2+} and Na^+ with depth was irregular. The water soluble K^+ was slightly higher in upper horizon (0.04 me l^{-1}) as compared to B_{22} horizon thereafter it was found absent in lower depth of IIC_1 to IIC_3 horizon. Among the anions, the water soluble CO_3^{2-} was absent, while the HCO_3^- and Cl^- varied from 0.80 to 4.20 and 2.40 to 7.50 me l^{-1} (Table 4.40) with the weighted mean values of 2.57 to 4.30 me l^{-1} (Table 4.42), respectively indicating the proportion of Cl^- was higher than HCO_3^- in saturation extract. A fact also corroborated by the findings of Sharma *et al.* (1968), Derra *et al.* (1970), Sharma and Bhargava (1993), Mandal and Sharma (1997), Yeresheemi *et al.* (1997) and Maji *et al.* (2001). The vertical distribution of HCO_3^- and Cl^- with depth was irregular. The SAR ranged from 1.36 to 3.29. The SAR values did not show any consistent pattern with depth which were indicative of the alluvial nature of these soils. The similar result was also reported by Maji *et al.* (1998).

4.4.2.4 Rayadi Toposequence (T_4)

The data on composition of saturation extract of the pedons P_{13} to P_{16} of Rayadi toposequence are depicted in Table 4.41.

Pedon 13 (Dedan) from the Hill slope : The saturation percentage ranged from 37.80 to 55.08 which was higher in surface horizon as compared to AC horizon (Table 4.41). The pHs and ECe varied from 7.85 to 7.92 and 0.73 to 0.78 dSm^{-1} (Table 4.41 and Fig. 4.26 to 4.27) with the weighted mean value of 7.89 and 0.75 dSm^{-1} (Table 4.42), respectively indicating the soils were non sodic and non saline. The water soluble Ca^{2+} , Mg^{2+} and Na^+ ranged from 1.80 to 2.00, 2.20 to 3.60, 1.88 to 3.85 (Table 4.41) with the weighted mean values of 1.91, 2.95 and 2.79 me l^{-1} (Table 4.42), respectively indicating the proportion of water soluble Mg^{2+} was dominant followed by Na^+ and Ca^{2+} , while the water soluble K^+ and CO_3^{2-} were absent. The HCO_3^- , Cl^- and SAR ranged from 3.60 to 4.40 me l^{-1} , 2.00 to 2.40 me l^{-1} and 1.12 to 2.72, respectively (Table 4.41). The proportion of HCO_3^- was higher than Cl^- .

Pedon 14 (Dedan) from the Upper piedmont : The saturation percentage varied from 50.16 to 55.16. The saturation percentage decreased with increasing soil depth (Table 4.41). The pHs and ECe ranged from 7.68 to 7.89 and 0.77 to 1.20 dSm⁻¹ (Table 4.41) with the weighed mean value of 7.84 to 0.86 dSm⁻¹ (Table 4.42), respectively indicating the soils were non sodic and non saline. The pHs decreased with increasing depth (Fig. 4.26). The vertical distribution of ECe with depth was irregular (Fig. 4.27). The water soluble Ca²⁺, Mg²⁺, Na⁺ and K⁺ ranged fro 1.40 to 1.80, 2.20 to 8.40, 2.57 to 4.13 and 0.02 to 0.04 me l⁻¹ (Table 4.41) with the weighed mean value of 1.65, 3.37, 3.75 and 0.02 me l⁻¹ (Table 4.42), respectively indicating the proportion of water soluble Na⁺ was higher followed by Mg²⁺, Ca²⁺ and K⁺ (Maji *et al.*, 2001). The water soluble Ca²⁺ and Na⁺ decreased with increasing depth, while the Mg²⁺ increased with increasing depth. The CO₃²⁻ was absent. The HCO₃⁻ and Cl⁻ ranged from 3.00 to 3.50 and 2.40 to 6.00 me l⁻¹ (Table 4.41) with the weighed mean values of 2.97 and 3.19 me l⁻¹ (Table 4.42), respectively indicating the proportion of Cl⁻ was higher than HCO₃⁻ in saturation extract (Yresheemi *et al.*, 1997 and Maji *et al.*, 2001). The SAR decreased from 2.92 me l⁻¹ in surface horizon upto the 1.16 me l⁻¹ in AC horizon (Table 4.41).

Pedon 15 (Chotara) from the Lower piedmont : The saturation percentage varied between 58.80 and 64.28. The depth distribution of saturation percentage was irregular (Table 4.41). The pHs and ECe ranged from 7.77 to 8.07 and 0.90 to 1.10 dSm⁻¹ (Table 4.41) with the weighted mean value of 7.92 and 1.01 dSm⁻¹ (Table 4.42), respectively indicting the soils were non sodic and non saline. The pHs decreased with increasing depth (Fig. 4.26). The vertical distribution of ECe with depth was irregular (Fig. 4.27). The water soluble Ca²⁺, Mg²⁺, Na⁺ and K⁺ ranged from 1.40 to 2.00, 2.10 to 4.60, 4.80 to 6.13 and 0.02 to 0.04 me l⁻¹ (Table 4.41) with the weighted mean values of 1.70 3.11, 5.20 and 0.02 me l⁻¹ (Table 4.42), respectively indicating the proportion of water soluble Na⁺ was higher followed by Mg²⁺, Ca²⁺ and K⁺. The water soluble Ca²⁺ increased from increasing the depth, which followed the same trend as that of clay. The water soluble Mg²⁺ decreased with increasing upto

IIC₁ horizon thereafter, but it was increased in parent material at IIC₂ horizon. The vertical distribution of water soluble Na⁺ with depth was irregular. Among the anions, CO₃²⁻ was absent. The HCO₃⁻ and Cl⁻ ranged from 2.40 to 4.00 and 5.00 to 5.60 me l⁻¹ (Table 4.41) with the weighted mean values of 3.34 and 4.19 me l⁻¹ (Table 4.42), respectively indicating the proportion of Cl⁻ was higher than HCO₃⁻ in saturation extract. The SAR ranged from 2.93 to 4.39, which increased with an increasing the depth upto IIC₁ horizon thereafter, it was decreased at IIC₂ horizon (Table 4.41).

Pedon 16 (Kadiyali) from the Coastal plain : The saturation percentage ranged from 53.64 to 56.44. The vertical distribution of saturation extract with depth was irregular. The pHs and ECe varied from 7.92 to 8.13 and 2.45 to 5.10 dSm⁻¹ (Table 4.41) with the weighted mean value of 8.01 and 3.66 dSm⁻¹ (Table 4.42), respectively indicating the soils were non sodic and very slightly saline. The vertical distribution of pHs with depth was irregular (Fig. 4.26). While ECe increased with increasing depth upto B_{23ck} horizon thereafter, it decreased in BC_{ck} horizon. The salt accumulation (high ECe values) was observed in intermediate layers could be ascribed to the cementing nature of secondary lime which restricted the movement of soluble beyond this point, resulting in the maximum accumulation of salts. Similar observations were also reported by several workers (Naidu *et al.*, 1993; Pal *et al.* 1999 and Sharma, 2000). The water soluble Ca²⁺, Mg²⁺, Na⁺ and K⁺ varied from 0.40 to 1.40, 1.60 to 7.60, 20.10 to 46.25 and 0.03 to 0.06 me l⁻¹ (Table 4.41) with the weighted mean values of 0.90, 5.28, 30.63 and 0.04 me l⁻¹ (Table 4.42), respectively indicating the proportion of water soluble Na⁺ was dominant followed by Mg²⁺, Ca²⁺ and K⁺ (Maji *et al.*, 2001). The vertical distribution of Ca²⁺, Mg²⁺ and K⁺ with depth was not systematic, while the water soluble Na⁺ increased from 22.68 me l⁻¹ in surface horizon upto the 46.25 me l⁻¹ in B_{23ck} horizon thereafter, it was decreased upto 20.10 me l⁻¹ in BC horizon. Among the water soluble anions, CO₃²⁻ was absent. The HCO₃⁻ and Cl⁻ ranged between 2.40 to 4.60 and 19.60 to 43.00 me l⁻¹ (Table 4.41) with the weighted mean value of 4.27 and 28.11 me l⁻¹ (Table 4.42), respectively indicating the

proportion of water soluble Cl^- was very high followed by HCO_3^- in saturated extract. A higher value of Cl^- as compared to other anions in salt affected soils have also been reported by Sharma *et al.* (1968), Derra *et al.* (1970), Sharma and Bhargava (1993), Mandal and Sharma (1997), Yeresheemi *et al.* (1997) and Sharma (2000). The vertical distribution of HCO_3^- with depth was irregular. However, Cl^- increased with increasing depth upto $\text{B}_{23\text{ck}}$ horizon thereafter, it was decreased in BC_{ck} horizon (Table 4.14). The SAR was observed in higher range which varied from 9.69 to 29.25. The SAR was increased from 16.04 me l^{-1} in Ap horizon upto 29.25 me l^{-1} in B_{23} horizon thereafter, it decreased upto 9.69 me l^{-1} in BC_{ck} horizon (Table 4.41). Thus SAR values did not show any consistent trend with depth which were indicative of the alluvial nature of these soils (Maji *et al.*, 1998).

4.4.2.5 Land Slope

The weighted mean data of composition of saturation extract of some pedons from different land slope across the toposequences of southern Saurashtra are depicted in Table 4.42.

(A) Hill slope : The saturation percentage was ranged from 47.06 to 48.54 with a mean value of 47.80 (Table 4.42). The saturation percentage was higher in pedon P_1 (Sasan) of Hiran toposequence followed by P_{13} (Dedan) of Rayadi toposequence. The pHs and ECe ranged from 7.89 to 7.97 and 0.75 to 0.76 dSm^{-1} with the mean value of 7.93 and 0.76 dSm^{-1} , respectively (Table 4.42) indicating the soils of hill slopes were non sodic and non saline. The water soluble Ca^{2+} , Mg^{2+} , Na^+ and K^+ ranged from 1.91 to 2.56, 2.95 to 3.51, 1.54 to 2.79 and 0.00 to 0.02 with the mean value of 2.24, 3.23, 2.17 and 0.01 me l^{-1} , respectively. The proportion of water soluble Mg^{2+} was higher followed by Ca^{2+} , Na^+ and K^+ . The water soluble Ca^{2+} and Mg^{2+} were higher in pedon P_1 (Sasan) of Hiran toposequence followed by P_{13} (Dedan) of Rayadi toposequence, while the water soluble Na^+ was higher in P_{13} (Dedan) followed by P_1 (Sasan). The water soluble K^+ was slightly present in pedon P_1 (Sasan)

only (Table 4.42). Among the anions, CO_3^{2-} was absent in saturation extract. The HCO_3^- and Cl^- varied from 3.00 to 3.27 and 2.19 to 4.02 me l^{-1} with mean value of 3.14 and 3.11 me l^{-1} . The HCO_3^- was higher in pedon P_{13} (Dedan) as compared to P_1 . Contrary to this, the proportion of Cl^- was higher in pedon P_1 compared to P_{13} . The SAR ranged from 0.88 to 1.86 with a mean value of 1.37. The SAR was higher in pedon P_{13} (Dedan) than P_1 (Sasan).

(B) Upper piedmont : The saturation percentage varied from 47.82 to 54.01 (Table 4.42). The pHs and ECe ranged between 7.84 to 8.08 and 0.77 to 0.91 dSm^{-1} with a mean value of 7.95 and 0.83 dSm^{-1} , respectively, indicating the soils were non sodic and non saline. The pHs was in decreasing sequence of $\text{P}_2\text{T}_1 > \text{P}_5\text{T}_2 > \text{P}_9\text{T}_3$ and P_{14}T_4 . The ECe was in decreasing order of $\text{P}_5\text{T}_2 > \text{P}_{14}\text{T}_4 > \text{P}_9\text{T}_3 > \text{P}_2\text{T}_1$. The water soluble Ca^{2+} , Mg^{2+} , Na^+ and K^+ ranged from 1.65 to 2.72, 3.20 to 4.76, 1.63 to 3.75 and 0.02 to 0.04 me l^{-1} with the mean value of 2.06, 3.79, 2.50 and 0.03 me l^{-1} , respectively. The proportion of water soluble Mg^{2+} was found higher followed by Na^+ , Ca^{2+} and K^+ . The pedon P_5 (Jamwala) of Shingoda toposequence contain relatively high amount of soluble cations (9.19 me l^{-1}) followed by P_{14} (Dedan) of Rayadi toposequence. The relatively least value of total cation (7.74 me l^{-1}) in P_2 (Borvav) of Hiran toposequence clearly indicate the highly leached, depleted and drained nature of soil. The similar results were also observed by Gupta *et al.* (1986), Brar *et al.* (1988) and Paramshivam (1992). Among the anions, CO_3^{2-} was absent in saturation extract. The HCO_3^- and Cl^- ranged from 2.66 to 4.18 and 2.83 to 4.18 me l^{-1} with the mean value of 3.16 and 3.31 me l^{-1} , respectively. The HCO_3^- was in decreasing order of $\text{P}_5\text{T}_2 > \text{P}_{14}\text{T}_4 > \text{P}_9\text{T}_3 > \text{P}_2\text{T}_1$, while the Cl^- was in order of $\text{P}_2\text{T}_1 > \text{P}_{14}\text{T}_4 > \text{P}_5\text{T}_2 > \text{P}_9\text{T}_3$. The SAR was observed in the decreasing sequence of $\text{P}_{14}\text{T}_4 > \text{P}_5\text{T}_2 > \text{P}_2\text{T}_1 > \text{P}_9\text{T}_3$.

(C) Lower piedmont : The saturation percentage ranged from 39.07 to 61.10 with a mean value of 52.76 (Table 4.42). The saturation percentage was in decreasing order of $\text{P}_{15}\text{T}_4 > \text{P}_3\text{T}_1 > \text{P}_{10}\text{T}_3 > \text{P}_6\text{T}_2$, which followed the same trend as that of clay. The pHs and ECe varied from 7.79 to 8.16 and 0.76

to 1.32 dSm^{-1} with a mean value of 7.96 and 1.04 dSm^{-1} , respectively, indicating the soils of lower piedmont area are non sodic and non saline. The pHs and ECe observed in decreasing order of $P_6T_2 > P_3T_1 > P_{15}T_4 > P_{10}T_3$. The water soluble Ca^{2+} , Mg^{2+} , Na^+ and K^+ ranged between 1.56 to 2.33, 3.02 to 6.30, 2.76 to 6.38 and 0.02 to 0.03 me l^{-1} with mean value of 1.87, 4.26, 4.39 and 0.03 me l^{-1} , respectively, indicating the proportion of water soluble Na^+ was higher followed by Mg^{2+} , Ca^{2+} and K^+ . Similar trend was also reported for water soluble cations by Maji *et al.* (2001). The total soluble cations were observed higher in pedon P_6 (Kareda) in Shingoda toposequence followed by P_3 (Maljinjava) of Hiran toposequence, P_{15} (Chotara) of Rayadi toposequence and P_{10} (Judavadali) of Machhundri toposequence. Among the anions, CO_3^{2-} was absent in saturation extract. The HCO_3^- and Cl^- were ranged from 2.85 to 4.20 and 3.01 to 5.85 dSm^{-1} with a mean value of 3.44 and 4.51 me l^{-1} , respectively indicating the proportion of Cl^- was higher than HCO_3^- in saturation extract. These findings are in conformity with the work of Sharma *et al.* (1968), Derra *et al.* (1970), Sharma and Bhargava (1993), Mandal and Sharma (1997), Yeresheemi *et al.* (1997) and Sharma (2000). The SAR ranged between 1.37 and 3.43 with a mean value of 2.59. The SAR was observed in the decreasing sequence of $P_6T_2 > P_{15}T_4 > P_{10}T_3 > P_3T_1$.

(D) Piedmont plain : The saturation percentage ranged from 48.35 to 63.21 with a mean value of 54.55 (Table 4.42). The saturation percentage found in decreasing sequence of $P_4T_1 > P_{11}T_3 > P_7T_2$, which followed the same trend as that of clay (Table 4.27). The pHs and ECe were ranged from 7.93 to 8.01 and 0.90 to 3.45 dSm^{-1} with the mean value of 7.98 and 1.78 dSm^{-1} , respectively indicating the soils of piedmont plain area are non sodic and non saline. However, the soils associated with pedon P_4 (Kajali) of Hiran toposequence exhibit slightly saline having ECe value of 3.45 dSm^{-1} (between 2 to 4 dSm^{-1}). The pHs observed in decreasing order of $P_7T_2 > P_4T_1 > P_{11}T_3$, while ECe exhibit the decreasing sequence of $P_4T_1 > P_7T_2 > P_{11}T_3$. The water soluble Ca^{2+} , Mg^{2+} , Na^+ and K^+ varied from 1.46 to 6.15 3.53 to 19.33 4.09 to 10.93 and 0.03 to 0.32 me l^{-1} with the mean value of 3.28, 8.81, 6.54 and 0.13

me l⁻¹, respectively indicating water soluble Mg²⁺ was highly dominant followed by Na⁺, Ca²⁺ and K⁺ in saturation extract of piedmont plain area. The total water soluble cations was observe highest (36.73 me l⁻¹) in pedon P₄ (Kajali) of Hiran toposequence followed by P₇ (Devali) of Shiagoda toposequence and P₁₁ (Delawada) of Machhundri toposequence. Among the anions, CO₃²⁻ was absent in saturation extract. The HCO₃⁻ and Cl⁻ ranged from 3.67 to 4.75 and 3.92 to 25.42 me l⁻¹ with mean value of 4.20 and 11.31 me l⁻¹, respectively indicating Cl⁻ was highly dominant followed by HCO₃⁻ in saturation extracts in the soils of pediment plain area (Mandal and Sharma, 1997, Yeresheemi *et al.*, 1997 and sharma, 2000). The Cl⁻ content was highest (25.42 me l⁻¹) in pedon P₄ (Kajali) followed by P₇ (Devali) and P₁₁ (Delawada). The SAR ranged from 2.59 to 3.72 with a mean value of 3.01. The SAR was found in decreased sequence of P₄T₁ > P₇T₂ > P₁₁T₃.

(E) Coastal Plain : The saturation percentage ranged between 34.17 and 58.12 with the mean value of 49.01. The saturation percentage was observe in decreasing sequence of P₈T₁₂ > P₁₆T₄ > P₁₂T₃. The pHs and ECe ranged from 7.94 to 8.01 and 0.75 to 3.66 dSm⁻¹ with mean value of 7.98 and 2.24 me l⁻¹ (Table 4.42) indicating the soils were non sodic and slightly saline (ECe between 2 to 4 dSm⁻¹). However, the soils associated with pedon P₁₂ (Rampara) does not exhibits the salinity problem having ECe value of 0.75 dSm⁻¹. The highest ECe (3.66 dSm⁻¹) was observed in pedon P₁₆ (Kadiyali) of Rayadi toposequence followed by P₈ (Chauhani Khan) of Shingoda toposequence. The water soluble Ca²⁺, Mg²⁺, Na⁺ and K⁺ ranged from 0.90 to 2.57, 2.37 to 8.97, 3.21 to 30.63 and 0.02 to 0.04 me l⁻¹ with mean value of 1.80, 5.54, 15.25 me l⁻¹ and 0.03 me l⁻¹, respectively, indicating water soluble Na⁺ was the dominated cation followed by Mg²⁺, Ca²⁺ and K⁺ (Maji *et al.*, 2001). The highest total water soluble cation (36.85 me l⁻¹) observed in P₁₆ (Kadiyali) followed by P₈ (Chauhani Khan) and P₁₂ (Rampara). Among the water soluble anions, CO₃²⁻ was absent in saturation extract. The HCO₃⁻ and Cl⁻ ranged from 2.57 to 4.27 and 4.30 to 28.11 me l⁻¹ with mean value of 3.57 and 15.57 me l⁻¹, respectively indicating water soluble Cl⁻ was dominant followed

by HCO_3^- in saturation extract of coastal plain (Yeresheemi *et al.*, 1997 and Sharma, 2000). The SAR ranged from 2.16 to 17.85 with mean value of 8.30. The highest SAR (17.85) was observed in pedon P₁₆ (Kadiyali) of Rayadi toposequence followed by P₈ (Chauhani Khan) and P₁₂ (Rampara).

Overall Southern Saurashtra

The weighted mean data of the composition of saturation extract from different land slope across the toposequences of southern Saurashtra are presented in Table 4.42. The results reveal that saturation percentage ranged from 34.17 to 63.21 with overall mean value of 51.38 in the soils of southern Saurashtra. The saturation percentage was found in the decreasing order of Piedmont plain > Lower piedmont > Upper piedmont > Coastal plain > Hill slope.

The pHs and ECe ranged from 7.79 to 8.16 and 0.75 to 3.66 dSm^{-1} with overall mean value of 7.96 and 1.32 dSm^{-1} , respectively indicating the soils of southern Saurashtra are in general non sodic and non saline, except some part of coastal plain. The pHs in different land slopes were in the decreasing order of Coastal plain and Piedmont plain > Lower piedmont > Upper piedmont > Hill slope (Fig. 4.28), while in case of ECe, it was in order of Coastal plain > Piedmont plain > Lower piedmont > Upper piedmont > Hill slope. The pHs increased with decreasing the topography from hill slope to piedmont plain, while ECe increased with decreasing the topography from hill slope to coastal plain.

The water soluble Ca^{2+} , Mg^{2+} , Na^+ and K^+ ranged from 0.90 to 6.15, 2.37 to 19.33, 1.54 to 30.63 and 0.00 to 0.32 me l^{-1} with overall mean value of 2.21, 5.11, 6.08 and 0.04 me l^{-1} , respectively in the soils of southern Saurashtra. The proportion of water soluble Na^+ was dominant followed by Mg^{2+} , Ca^{2+} and K^+ in the soils of southern Saurashtra. A fact also corroborated with the findings of Maji *et al.* (2001). The total water soluble cation ranged from 7.65

to 36.85 with overall mean value of 13.45 me l⁻¹. The distribution of total water soluble cation in different land slope were in the order of Coastal plain > Piedmont plain > Lower piedmont > Upper piedmont > Hill slope. Thus, total water soluble cation increased from hill slope to coastal plain of southern Saurashtra. This might be due to the effect of hydraulic distribution of soluble ion in the soils from higher to lower altitude and soil depth. Among the water soluble anions, CO₃⁻ was absent. The HCO₃⁻ and Cl⁻ ranged from 2.66 to 4.75 and 2.19 to 28.11 me l⁻¹ with overall mean value of 3.50 and 7.38 me l⁻¹, respectively indicating the proportion of Cl⁻ was dominant followed by HCO₃⁻ in saturation extract of the soils of southern Saurashtra. A fact also corroborated by the findings of Sharma *et al.* (1968), Derra *et al.* (1970), Sharma and Bhargava (1993), Mandal and Sharma (1997), Yeresheemi *et al.* (1997) and Sharma (2000).

It is inferred from the data presented in Table 4.42 that the distribution of HCO₃⁻ in different land slopes was observed in order of Piedmont plain > Coastal plain > Lower piedmont > Upper piedmont > Hill slope. Thus, HCO₃⁻ increased graphy from hill slope to the piedmont plain, thereafter, it decreased in the coastal plain, while the Cl⁻ gradually increased from hill slope to the coastal plain.

The SAR ranged from 0.88 to 17.85 with overall mean value of 3.32. The distribution of SAR observed in different land slopes was in the order of Coastal plain > Piedmont plain > Lower piedmont > Upper piedmont > Hill slope (Fig. 4.28). Thus the SAR increased gradually topography from hill slope to coastal plain of southern Saurashtra.

4.5 AVAILABLE NUTRIENT STATUS

The nutrient status is an indication of the soil fertility and one of the important factor which determine the crop productivity of the soils. In the present study, the findings with respect to available macro and micronutrients of different

toposequences and land slopes are presented in Table 4.43 to 4.47 and described in following subheads :

- 4.5.1 Hiran toposequence (T_1)
- 4.5.2 Shingoda toposequence (T_2)
- 4.5.3 Machhundri toposequence (T_3)
- 4.5.4 Rayadi toposequence (T_4)
- 4.5.5 Land slopes

4.5.1 Hiran Toposequence (T_1)

The data on available nutrients of pedons P_1 to P_4 of Hiran toposequence are presented in Table 4.43 and the weighted mean values are depicted in Table 4.47. The content of available N, P_2O_5 and K_2O were recorded between the range of 97.2 to 476.7, 7.5 to 26.1 and 38.4 to 1433.5 kg ha⁻¹ with the over all weighted mean values of 252.8, 16.1 and 402.7 kg ha⁻¹, respectively, in the soils of different pedons of Hiran toposequence indicating the soils of Hiran toposequence could be categorized as medium in available N, low in available P_2O_5 and high in available K_2O which decreased with increasing depth in the pedons P_1 to P_4 . A high value of available N in the surface soils, which was decreased down the depth could be attributed to the corresponding decrease in organic carbon. The observations recorded in present study are in agreement with Sharma *et al.* (1968), Derra *et al.* (1970), Goyal and Singh (1987), Aggarval *et al.* (1990), Paramsivam (1992), Kumar and Kumar (1993), Rathore (1993), Kumar *et al.* (1995) and Sharma (2000).

Based on weighted mean data, the available nitrogen (Table 4.47) was found to be in following decreasing sequence of Hill slopes (P_1) > Lower piedmont (P_3) > Upper piedmont (P_2) > Piedmont plain (P_4). The high available N in elevated topography probably due to sparse vegetation which

have in turn resulted in higher organic carbon content of the soil and thereby a higher status of available nitrogen (Biddappa & Venkata Rao, 1973; Minhas and Bora, 1982; Paramsivam, 1992 and Sharma, 1994). At the lower topography the soils were subjected to intensive cultivation, encouraging the oxidation of organic carbon. The data reveals that the surface horizons of pedons P₁ to P₄ would have been enriched due to periodic fertilizer applications, high organic matter and high microbial activity. The available N content of subsurface horizons of the pedons P₂ to P₄ (Table 4.43) reveals that generally all these pedons come under low category. This stresses the need for adequate N fertilizer application to pedons P₂ to P₄ for sustaining productivity. The decreasing trend of available N with depth in pedon P₂ (Borvav) and P₄ (Kajali) suggests undoubtedly the need for judicious application of nitrogenous fertilizers as the age of the crop advances, especially for deep rooted crops. This kind of low N status might be the result of intensive cultivation of high yielding varieties in the soils of Hiran toposequence.

The soils of Hiran toposequence were categorized as low for available P₂O₅. This might be due to the high CaCO₃ and clay content which results in fixation of phosphorus in these soils. As far as available P₂O₅ is concerned, it was found to be in the order of Piedmont plain (P₄) > Lower piedmont (P₃) > Hill slope (P₁) > Upper piedmont (P₂) and was almost opposite in trend to available N. The comparatively higher values of available P₂O₅ registered in soils of surface and subsurface horizons from lower piedmont to piedmont plain area as compared to hill slope and upper piedmont area might be due to highly undulating, shallow and weathered soils of the elevated area (Datta *et al.*, 1990). The P₂O₅ content was higher in surface horizon in pedon P₂ which decreased down the depth of pedon this may be attributed to a higher CaCO₃ and increase in finer fraction of mechanical separates in subsurface horizons of the studied pedon (Singh, 1999) resulting in fixation of phosphorus

and thereby decreasing its availability (Sharma, 2000). While the available P_2O_5 content showed an increase with an increase in the depth in pedon P_1 (Sasan) and P_4 (Kajali). This might be attributed to the better translocation of P. The available P_2O_5 status is low in the soils of Hiran toposequence and therefore adequate phosphatic fertilizer is necessary to achieve desirable yields.

Based on weighted mean data the available K_2O (Table 4.47) content was found to be in the order of Piedmont plain (P_4) > Hill slope (P_1) > Lower piedmont (P_3) > Upper piedmont (P_2). The soils of Hiran toposequence are categorized as high in K status. This may be attributed to mineralogy of the soil containing a greater proportion of feldspar group of minerals. (Miller and Donahu, 1982 and Bardy, 1984) The soils of pedon P_2 (Borvav) of upper piedmont had relatively lower values of available K_2O . This may be due to susceptibility of these soils to faster and deeper leaching down of easily mobile K into the profile (Badrinath *et al.*, 1986). The soils of the pedon P_2 (Borvav) revealed the most depleted nature and therefore adequate K application in more splits is required to maintain the productivity of these soils. The increasing pattern of available K_2O in pedon P_4 (Kajali) in piedmont plain area might probably be due to the adsorption and fixation of K on the exchange complex in the presence of K bearing mineral and degree of weathering of K minerals. The results can be explained from the conclusion of Rangnathan and Sathyanarayana (1980) and Vijaykumar *et al.* (1986). The soils of pedon P_4 (Kajali) was drastically high available K status throughout the profile depth suggesting the sufficiency of this nutrient and requires only restricted quantities of K application.

Regarding the availability of micronutrients viz., Fe, Mn, Zn and Cu contents ranged from 8.6 to 48.5, 5.2 to 23.3, 0.6 to 3.5 and 1.6 to 11.0 ppm with the weighted mean values of 22.9, 16.4, 1.6 and 4.8 ppm (Table 4.43), respectively indicating the soils of Hiran toposequence to be high category in available Fe, Mn, Zn and Cu. This might be due to the high vegetation in Gir forest area in higher elevations of Hiran toposequence.

It can be further seen from the Table 4.43 and 4.47 that available Fe content was found to decrease as on traverse from hill slope to piedmont plain in surface and subsurface horizons. The distribution of available Fe was observed in the decreasing sequence of Hill slope (P_1) > Upper piedmont (P_2) > Lower piedmont (P_3) > Piedmont plain (P_4). The similar results were also reported by Singh *et al.* (1988), Jalali *et al.* (1989), Kumar *et al.* (1990) and Sharma (1995). The high Fe, Mn and Cu contents observed in higher elevation might be due the high sparse vegetation in forest Gir area in higher elevations of Hiran toposequence results in high organic matter and high microbial activities increase the availability of Fe, Mn and Cu. The available Fe content was found to decrease with the depth in pedons P_1 and P_2 . Similar, results were also reported by Lal and Biswas (1974), Singh *et al.* (1988), Rathore (1993) and Bhaskar *et al.* (2004).

The distribution of available Mn, Zn and Cu in different land slopes of Hiran toposequence observed as per under (Table 4.47).

Mn : Hill slope (P_1) > Lower piedmont (P_3) > Piedmont plain (P_4) > Upper piedmont (P_2)

Zn : Upper piedmont (P_2) > Hill slope (P_1) > Piedmont plain (P_4) > Lower piedmont (P_3)

Cu : Hill slope (P_1) > Lower piedmont (P_3) > Upper piedmont (P_2) > Piedmont plain (P_4)

Jalali *et al.* (1989) reported that the more amount of available Mn in high elevated soils than valley basin soils. The available Mn was uniformly distributed throughout the profile in pedon P_1 (Sasan). While it was decrease with increasing depth in pedon P_2 (Borvav) and P_4 (Kajali). A fact also corroborated by the findings of Singh *et al.* (1988), Prasad and Sahi (1989), Tiwary and Mishra (1990), Gupta and Srivastava (1990), Gupta *et al.* (2003) and Bhaskar *et al.* (2004). The available Zn was higher in surface horizons as compared to lower horizons in pedon P_2 to P_4 (Rathore, 1993 and Gupta *et al.*,

2003). The vertical distribution of available Zn with depth was irregular in pedon P₁.

The available Cu decreased with an increasing depth in pedon P₄ (Kajali). There was no definite trend with respect to depthwise distribution of available Cu in the pedons P₁ to P₃. The similar results were also reported by Kavimandan *et al.* (1964), Singh *et al.* (1988) and Kumar *et al.* (1990).

4.5.2 Shingoda Toposequence (T₂)

The data concerning on available nutrients of pedons P₅ to P₈ of Shingoda toposequence are depicted in Table 4.44. The available N, P₂O₅ and K₂O ranged from 98.1 to 313.6, 11.2 to 56.0 and 76.8 to 744.3 kg ha⁻¹ with the weighted mean values of 194.4, 32.2 and 292.7 kg ha⁻¹, respectively indicating the soils of Shingoda toposequence were low in available N, medium in available P₂O₅ and high in available K₂O. The available N, P₂O₅ and K₂O decreased with increasing depth in the pedon P₅ (Jamwala) of upper piedmont and P₇ (Devali) of piedmont plain. The available N and K₂O decreased with increasing depth in pedon P₆ (Kareda) of lower piedmont while the available P₂O₅ content decreased with increasing depth in pedon P₈ (Chauhani Khan) of coastal plain. The reason for such type of trend is already discussed in this text as per the available nutrient status of Hiran toposequence (4.5.1). The vertical distribution of available P₂O₅ with depth was irregular in pedon P₆ (Kareda) while in case of available N and K₂O irregular depth distribution pattern was observed in pedon P₈ (Chauhani Khan).

Based on the weighted mean values of available N, P₂O₅ and K₂O (Table 4.47) of pedons P₅ to P₈, the distribution of major nutrients in different land slopes of Shingoda toposequence were observed as under :

N : Upper piedmont (P₅) > Piedmont plain (P₇) > Coastal plain (P₈)
> Lower piedmont (P₆)

P_2O_5 : Piedmont plain (P_7) > Lower piedmont (P_6) > Upper piedmont (P_5) > Coastal plain (P_8)

K_2O : Lower piedmont (P_6) > Piedmont plain (P_7) > Upper piedmont (P_5) > Coastal plain (P_8)

The soils of pedons P_6 (Kareda), P_7 (Devali) and P_8 (Chauhani Khan) were low in available N. This may be due to the intensive cultivation, encouraging the oxidation of organic carbon. The soils need adequate nitrogenous fertilization along with organic manures. The soils of pedon P_5 (Jamwala) contain medium available N hence adequate amount of nitrogenous fertilization should be applied along with organic manures to maintain the plant requirement which likely to be equal to the expected crop removal and other losses.

The soils of pedon P_8 (Chauhani Khan) of coastal plain were low in available phosphorus due to high $CaCO_3$ which results in fixation of P. These soils do not contain enough phosphorus for maximum crop production and need adequate P fertilization along with organic manures to restore soils fertility. While the soils of pedon P_5 (Jamwala), P_6 (Kareda) and P_7 (Devali) contain medium status of phosphorus. Hence, adequate amount of phosphatic fertilizer should be applied to maintain to plant requirement, which is likely to be expected crop removal and other losses.

The soils of pedon P_5 (Jamwala) contain medium status of available K_2O . Hence, adequate amount of potashic fertilizer should be applied to maintain the adequacy of K after depletion caused by crop removal and other losses. The soils of pedon P_6 (Kareda) and P_7 (Devali) have high available K status, suggesting its sufficiency and therefore requires only restricted quantities of potashic fertilization. The soils of pedon P_8 (Chauhani Khan) contain very low amount of available potash. It might be due to intensive cultivation and therefore K fertilization should be in splits alongwith addition of organic manures to restore the soil fertility and sustain the productivity of these soils.

As far as available micronutrients are concerned, the Fe, Mn, Zn and Cu contents ranged from 10.00 to 22.9, 4.49 to 22.5, 0.7 to 1.9 and 1.4 to 5.2 ppm (Table 4.44) with the weighted means of 15.8, 16.4, 1.1 and 3.6 ppm (Table 4.47), respectively indicating the soils of Shingoda toposequence to be categorized as high in available Fe, Mn, Zn and Cu. Therefore, only restricted quantities of micronutrients fertilization in the soils of Shingoda toposequences is necessary to maintain productivity of these soils. Based on weighted mean values of available Fe, Mn, Zn and Cu (Table 4.47) of pedon P₅ to P₈, the distribution of micronutrients in different land slopes of Shingoda toposequence was observed as under :

Fe and Cu : Upper piedmont (P₅) > Coastal plain (P₈) > Lower piedmont (P₆) > Piedmont plain (P₇)

Mn : Coastal plain (P₈) > Upper piedmont (P₅) > Lower piedmont (P₆) > Piedmont plain (P₇)

Zn : Upper piedmont (P₅) > Lower piedmont (P₆) > Piedmont plain (P₇) > Coastal plain (P₈)

It is inferred from the data in Table 4.47 that the available Zn showed a wide variation with a gradual decrease in its content as one traverses down from upper piedmont to coastal plain. The available Fe decreased with increasing depth in the pedons P₅ (Jamwala) and P₈ (Chauhani Khan) while the available Mn, Zn and Cu decreased with increasing depth in pedon P₅ and P₆. The vertical distribution of available Mn, Zn and Cu with depth was irregular in pedon P₇ (Devali) (Table 4.44).

4.5.3 Machhundri Toposequence (T₃)

The data on available nutrients of pedons P₉ to P₁₂ of Machhundri toposequence (T₃) are presented in Table 4.45. The results shows that the available N, P₂O₅ and K₂O ranged from 78.4 to 269.7, 3.7 to 18.7 and 38.4 to 268.7 kg ha⁻¹ (Table 4.45) with the overall weighted mean value of 178.1, 9.2 and 152.7 kg ha⁻¹ (Table 4.47), respectively indicating the soils of Machhundri toposequence were low in available nitrogen and phosphorus and medium in available potash. The available N decreased with increasing depth in pedon P₉ (Fatsar), P₁₁ (Delawada) and P₁₂ (Rampara) while the vertical distribution of available N with depth found irregular in pedon P₁₀ (Judavadali). The vertical distribution of available P₂O₅ and K₂O found irregular in pedon P₁₀ (Judavadali) and P₁₁ (Delawada). The vertical distribution of available P₂O₅ with depth of pedons P₉ (Fatsar) and P₁₂ (Rampara) was irregular.

Based on the weighted mean data of available N, P₂O₅ and K₂O (Table 4.47) of pedons P₉ to P₁₂, the distribution of major nutrients in different land slopes of Machhundri toposequence were observed as under:

- N : Upper piedmont (P₉) > Lower piedmont (P₁₀) > Piedmont plain (P₁₁) > Coastal plain (P₁₂)
- P₂O₅ : Coastal plain (P₁₂) > Upper piedmont (P₉) > Piedmont plain (P₁₁) > Lower piedmont (P₁₀)
- K₂O : Coastal plain (P₁₂) > Piedmont plain (P₁₁) > Lower piedmont (P₁₀) > Upper piedmont (P₉)

It can be seen that the content of available N was also found to decrease from upper piedmont to the coastal plain in Macchundri toposequence while in case of available potash the reverse trend was observed where it increased along the transect from upper piedmont to coastal plain (Table 4.47). In case of available P₂O₅ there was no regular trend in its distribution from upper piedmont to coastal plain. The probable reasons for the above are already

discussed in the section dealing with Hiran toposequence (4.5.1) and Shingoda toposequence (4.5.2).

The low content of available N in soils of pedons P₉ to P₁₂ of Machhundri toposequence might be due to intensive cultivation. Judicious efforts of soil fertility management require adequate and regular addition of nitrogenous fertilizers along with organic manures.

The low available P₂O₅ in soils of pedons P₉ to P₁₂ might be due to the dominance of smectite clay, high CaCO₃ along with finer fractions resulting in P fixation, thereby decreasing its availability (Sharma, 2000). Adequate P fertilization along with organic manures is required to restore the soil fertility and improve the soil health. The soils of pedons P₉ (Fatsar) and P₁₀ (Judavadali) were very low in available potash due to faster weathering through water erosion. The high K fixation in black shallow soil due to dominance of smectitic clay

The available Fe, Mn, Zn and Cu ranged from 3.9 to 19.5, 7.06 to 23.10, 0.5 to 3.4 and 0.4 to 4.4 ppm with the overall weighted mean value of 14.1, 18.4, 1.1 and 2.7 ppm (Table 4.45), respectively indicating the soils of Machhundri toposequence were in high category of available Fe, Mn, Zn, and Cu, suggesting the sufficiency of available micronutrients and requires only restricted quantities of micronutrients fertilization in the soils of Machhundri toposequence.

Based on the weighted mean values of available Fe, Mn, Zn, and Cu (Table 4.47) of pedons P₉ to P₁₂, the distribution of micronutrients in different land slopes of Machhundri toposequence were observed as under:

Fe and Cu : Upper piedmont (P₉) > Piedmont plain (P₁₁) > Coastal plain (P₁₂)
> Lower piedmont (P₁₀)

Mn : Lower piedmont (P_{10}) > Piedmont plain (P_{11}) > Upper piedmont (P_9) > Coastal plain (P_{12})

Zn : Lower piedmont (P_{10}) > Piedmont plain (P_{11}) > Coastal plain (P_{12}) > Upper piedmont (P_9)

It can be seen that no systematic trend was observed in the distribution of available micronutrients from upper piedmont to coastal plain of Machhundri toposequence.

The available Fe was uniformly distributed throughout the profile in pedon P_9 (Fatsar) while in pedon P_{10} (Judavadali), it decreased with increasing depth of solum. The vertical distribution of available Fe with depth was irregular in pedons P_{11} (Delawada) and P_{12} (Rampara). The available Mn decreased with increasing depth of pedon P_9 (Fatsar). The vertical distribution of available Mn with depth was not systematic in pedons P_{10} to P_{12} . The vertical distribution of available Zn with depth was irregular in pedons P_{11} (Delawada) and P_{12} (Rampara). The vertical distribution of available Cu with depth was observed irregular (Table 4.46).

4.5.4 Rayadi Toposequence (T_4)

The data on available nutrients of pedons P_{13} to P_{16} of Rayadi toposequence (T_4) in Table 4.46 reveal that the content of available N, P_2O_5 and K_2O ranged from 81.5 to 319.9, 11.2 to 48.5 and trace to 307.1 kg ha⁻¹ with the overall weighted mean values of 194.8, 23.2 and 108.2 kg ha⁻¹ (Table 4.46), respectively indicating that the soils of Rayadi toposequence could be categorized as low in available N, P_2O_5 and K_2O . This might be attributed to the low rainfall accompanied with high temperature causing the high volatilization losses due to rapid decomposition of organic carbon, scarce use of organic manures, smectitic type of clay, high $CaCO_3$, low moisture, fast weathering, low vegetation cover and ingress of salinity near the coastal area rendering in poor soil fertility of soils in Rayadi toposequence as compared to the Hiran, Shingoda

and Machhundri toposequence of southern Saurashtra, which require judicious efforts of fertility management to maintain the balance nutrients through straight and complex fertilizers alongwith bulkey and concentrated organic manures to restore the soil fertility, sustain the productivity and maintain the soil health.

Based on the weighted mean data of available N, P_2O_5 and K_2O (Table 4.46) of pedons P_{13} to P_{16} , the distribution of major nutrients in different land slopes of Rayadi toposequence were observed as under :

N : Hill slope (P_{13}) > Lower piedmont (P_{15}) > Upper piedmont (P_{14})
> Coastal plain (P_{16})

P_2O_5 : Hill slope (P_{13}) > Upper piedmont (P_{14}) > Lower piedmont (P_{15})
> Coastal plain (P_{16})

K_2O : Coastal plain (P_{16}) > Hill slope (P_{13}) > Lower piedmont (P_{15}) > Upper piedmont (P_{14})

Thus, it is inferred from the above that available phosphorus increased with decreasing the elevation from hill slope to coastal plain of Rayadi toposequence while the available nitrogen and potash values did not showed any consistent pattern with the elevation in the soils of Rayadi toposequence. The available N and potash decreased with increasing depth in pedon P_{13} to P_{16} . The vertical distribution of available phosphorus with depth was observed an irregular in all the pedons except pedon P_{13} .

The available Fe, Mn, Zn and Cu ranged from 9.0 to 24.9, 3.3 to 23.2, 0.7 to 1.8 and 2.3 to 11.7 ppm with the overall weighted mean 15.1, 18.8, 0.9 and 5.4 ppm (Table 4.46), respectively indicating the soils of Rayadi toposequence were medium in available Zn and high in available Fe, Mn and Cu.

Based on weighted mean values of available Fe, Mn, Zn and Cu (Table 4.47) of pedons P₁₃ to P₁₆, the distribution of available micronutrients in different land slopes of Rayadi toposequence observed as under :

Fe : Hill slope (P₁₃) > Upper piedmont (P₁₄) > Coastal plain (P₁₆) > Lower piedmont (P₁₅)

Mn : Hill slope (P₁₃) > Upper piedmont (P₁₄) > Lower piedmont (P₁₅) > Coastal plain (P₁₆)

Zn : Lower piedmont (P₁₅) > Upper piedmont (P₁₄) > Hill slope (P₁₃) > Coastal plain (P₁₆)

Cu : Hill slope (P₁₃) > Coastal plain (P₁₆) > Lower piedmont (P₁₅) > Upper piedmont (P₁₄)

It is inferred that available Mn was decreasing down the elevation, while available Fe, Zn and Cu did not show consistent trend with elevation in the soils of Rayadi toposequence. The available Fe decreased with increasing the depth in pedon P₁₃ (Dedan) of hill slope, while there was no definite depth distribution in available Fe content was observed in pedons P₁₅ and P₁₆. The available Mn was uniformly distributed in pedon P₁₄ (Dedan) of upper piedmont while it decreased with increasing depth in pedons P₁₃ (Dedan), P₁₅ (Chotara) and P₁₆ (Kadiyali). The available Zn decreased with increasing depth in pedons P₁₃ and P₁₆. The vertical distribution of available Zn with depth was irregular in pedon P₁₅. The available Cu decreased with an increasing depth in pedon P₁₃. The vertical distribution of available Cu with depth was irregular in pedons P₁₄ to P₁₆. The reasons for increase or decrease of micronutrients with increasing depth are discussed as per the Hiran and Shingoda toposequence of this text.

4.5.5 Land Slopes

The weighted mean data of available nutrients of some pedons from different land slopes across the toposequences of southern Saurashtra are presented in Table 4.47.

(A) Hill slope : The available N, P_2O_5 and K_2O ranged from 250.8 to 360.3, 12.6 to 13.2 and 59.0 to 238.4 kg ha⁻¹ with the mean value of 305.6, 12.9 and 148.7 kg ha⁻¹, respectively (Table 4.47) indicating the soils of hill slope of southern Saurashtra were medium in available nitrogen and potash and low in available phosphorus. The soils of pedon P₁ (Sasan) of Hiran toposequence contain high available N and potash as compared to pedon P₁₃ (Dedan) of Rayadi toposequence. The available Fe, Mn, Zn and Cu ranged from 21.8 to 42.5, 23.0 to 23.2, 0.8 to 2.0 and 6.1 to 8.3 ppm with the mean values of 32.2, 23.1, 1.4 and 7.2 ppm (Table 4.47), respectively indicating the soils of hill slopes were high in available Fe, Mn, Zn and Cu, suggesting the sufficiency in available micronutrients and demanding only to restricted quantities of micronutrients fertilizers. The soils of pedon P₁ (Sasan) contain higher amount of available Fe, Mn, Zn and Cu as compared to pedon P₁₃ (Dedan) might be due to high sparse vegetation and organic matter in Sasan (Gir) area of Hiran toposequence as compared to pedon P₁₃ (Dedan) of Rayadi toposequence.

(B) Upper piedmont : The available N, P_2O_5 and K_2O varied from 187.1 to 267.7, 11.1 to 27.8 and 55.5 to 278.3 kg ha⁻¹ with the mean values of 223.0, 16.7 and 156.6 kg ha⁻¹, respectively (Table 4.47) indicating the soils of upper piedmont area were low in available N and phosphorus and medium in available potassium status, which might be due to intensive cultivation, low organic carbon, smectitic clay minerals, high $CaCO_3$, and scare use of organic manures hence these soils need adequate nitrogenous and phosphatic fertilizers or complex fertilizers along with bulkey or concentrated organic manures to restore the soil fertility and sustainability. The soils of upper piedmont area require adequate amount of potashic fertilizer to maintain the potassium

requirement to plant, which is likely to be expected crop removal and other losses. The distribution of available major nutrients was observed as per the following decreasing sequence (Table 4.47).

$$\text{N} : \quad P_5T_2 > P_2T_1 > P_3T_3 > P_{14}T_4$$

$$P_2O_5 : \quad P_5T_2 > P_{14}T_4 > P_2T_1 > P_3T_3$$

$$K_2O : \quad P_{14}T_4 > P_5T_2 > P_3T_3 > P_2T_1$$

The available Fe, Mn, Zn and Cu varying from 16.1 to 20.4, 11.5 to 22.5, 0.9 to 2.1 and 3.7 to 4.6 ppm with the mean values of 18.1, 17.6, 1.3 and 4.2 ppm (Table 4.47), respectively indicating the soils of upper piedmont area were very high in available Fe, Mn, Zn and Cu and demanding only restricted quantities of micronutrient fertilization, under intensive cropping. The distribution of available micronutrients was observed as per the following decreasing order as under :

$$\text{Fe} : \quad P_5T_2 > P_2T_1 > P_{14}T_4 > P_9T_3$$

$$\text{Mn} : \quad P_{14}T_4 > P_5T_2 > P_9T_3 > P_2T_1$$

$$\text{Zn} : \quad P_2T_1 > P_5T_2 > P_9T_3 \text{ and } P_{14}T_4$$

$$\text{Cu} : \quad P_5T_2 > P_{14}T_4 > P_9T_3 > P_2T_1$$

(C) Lower piedmont : The available N, P_2O_5 and K_2O ranged from 137.0 to 257.8, 5.6 to 31.0 and 74.1 to 495.3 kg ha⁻¹ with the mean values of 201.0, 19.3 and 222.3 kg ha⁻¹ (Table 4.47), respectively indicating the soils of lower piedmont area were low in available N and phosphorus and medium in available potassium which need adequate nitrogenous and phosphatic fertilizers alongwith bulkey and concentrated organic manures to restore the soil fertility and maintain the soil health. The available N, P_2O_5 and K_2O were observed in following order. (Table 4.47)

$$\text{N} \quad : \quad \text{P}_3\text{T}_1 > \text{P}_{15}\text{T}_4 > \text{P}_{10}\text{T}_4 > \text{P}_6\text{T}_2$$

$$\text{P}_2\text{O}_5 \quad : \quad \text{P}_6\text{T}_2 > \text{P}_{15}\text{T}_4 > \text{P}_3\text{T}_1 > \text{P}_{10}\text{T}_4$$

$$\text{K}_2\text{O} \quad : \quad \text{P}_6\text{T}_2 > \text{P}_3\text{T}_1 > \text{P}_{15}\text{T}_4 > \text{P}_{10}\text{T}_4$$

The available Fe, Mn, Zn and Cu varied from 9.1 to 18.5, 16.6 to 22.3, 1.0 to 1.6 and 0.9 to 5.2 ppm with the mean values of 12.9, 18.9, 1.2 and 3.4 ppm, respectively (Table 4.47) indicating the soils of lower piedmont area were high in available Fe, Mn, Zn and Cu. The available micronutrients were observed in following decreasing order :

$$\text{Fe} \quad : \quad \text{P}_3\text{T}_1 > \text{P}_6\text{T}_2 > \text{P}_{10}\text{T}_4 > \text{P}_{15}\text{T}_4$$

$$\text{Mn} \quad : \quad \text{P}_{10}\text{T}_4 > \text{P}_3\text{T}_1 > \text{P}_{15}\text{T}_4 > \text{P}_6\text{T}_2$$

$$\text{Zn} \quad : \quad \text{P}_{10}\text{T}_4 > \text{P}_6\text{T}_2 > \text{P}_{15}\text{T}_4 > \text{P}_3\text{T}_1$$

$$\text{Cu} \quad : \quad \text{P}_{15}\text{T}_4 > \text{P}_3\text{T}_1 > \text{P}_6\text{T}_2 > \text{P}_{10}\text{T}_4$$

(D) Piedmont plain : The available N, P_2O_5 and K_2O ranged between 166.1 to 204.5, 8.00 to 37.2 and 142.9 to 1036.7 kg ha⁻¹ with the mean values of 179.5, 21.9 and 520.0 kg ha⁻¹, respectively (Table 4.47) indicating the soils of piedmont plain area were low in available N and P_2O_5 and high in available potash, which require judicious efforts of the application of nitrogenous and phosphatic fertilizers or complex fertilizers alongwith the bulkey or concentrate organic manures to restore the soils fertility and sustain the productivity. The distribution of available N, P_2O_5 and K_2O was observed in following decreasing order :

$$\text{N \& P}_2\text{O}_5 \quad : \quad \text{P}_7\text{T}_2 > \text{P}_4\text{T}_1 > \text{P}_{11}\text{T}_3$$

$$\text{K}_2\text{O} \quad : \quad \text{P}_4\text{T}_1 > \text{P}_7\text{T}_2 > \text{P}_{11}\text{T}_3$$

The available Fe, Mn, Zn and Cu ranged from 10.8 to 15.4, 10.8 to 20.1, 1.0 to 1.1 and 2.6 to 3.3 ppm with the mean values of 12.5, 14.5, 1.1 and 2.9 ppm, respectively indicating the soils of piedmont plain of Rayadi

toposequence (T₄) were high in available micronutrients. The available Fe, Mn, Zn and Cu was observed in the following sequence :

Fe : $P_{11}T_3 > P_7T_2 > P_4T_1$

Mn and Cu : $P_{11}T_3 > P_4T_1 > P_7T_2$

Zn : $P_{11}T_3 > P_4T_1 > P_7T_2$

(E) Coastal plain : The available N, P₂O₅ and K₂O ranged from 125.5 to 168.3, 11.9 to 42.2 and 21.5 to 301.8 kg ha⁻¹ with the mean values of 144.8, 25.0 and 134.2 kg ha⁻¹, respectively (Table 4.47) indicating that the soils of coastal plain area were low in available nitrogen, phosphorus and potash. This might be due to high CaCO₃, smectitic clay, high Na salts, low rainfall with strong drying condition, high temperature, low organic matter, fixation of P and K, scare use of organic manures and ingress of salinity. This requires judicious efforts of balance fertilization alongwith integrated nutrient management to restore the soil fertility and sustain the productivity of the soils of coastal area.

It is inferred from the data presented in Table 4.47 that the distribution of available N, P₂O₅ and K₂O were observed in order as under :

N : $P_8T_2 > P_{12}T_3 > P_{16}T_4$

P₂O₅ : $P_{16}T_4 > P_8T_2 > P_{12}T_3$

K₂O : $P_{12}T_3 > P_8T_2 > P_{16}T_4$

The available Fe, Mn, Zn and Cu ranged from 12.9 to 19.2, 11.4 to 22.3, 0.8 to 0.9 and 2.6 to 5.6 ppm with the mean value of 15.1, 15.8, 0.8 and 4.1 ppm (Table 4.47), respectively indicating that the soils of coastal area of southern Saurashtra were high in available Fe, Mn and Cu and medium in available Zn. The distribution of available Fe, Mn, Zn and Cu was observed in order as under :

Fe and Mn : $P_8T_2 > P_{12}T_3 > P_{16}T_4$

Zn : $P_{12}T_3 > P_8T_2 > P_{16}T_4$

Cu : $P_{16}T_4 > P_8T_2 > P_{12}T_3$

Overall of Southern Saurashtra

Looking to the overall picture of the available nutrients in the soils of different land slopes across the toposequences of southern Saurashtra (Table 4.47) reveals that the available N, P_2O_5 and K_2O ranged from 125.5 to 360.3, 5.6 to 42.2 and 21.5 to 1036.7 $kg\ ha^{-1}$ with the overall mean value of 205.0, 19.4 and 236.0 $kg\ ha^{-1}$, respectively indicating the soils of southern Saurashtra were low in available N and phosphorus and medium in available potash. The reasons for low available N and phosphorus due to the high temperature and low organic matter, high $CaCO_3$ scarce use of bulkey and concentrated organic manures high clay content, low moisture, smectitic. Clay minerals, fixation of P with clay particles hence adequate amount of nitrogenous and phosphatic fertilizer need to apply along with bulkey or contrated organic manures to restore the soil fertility and sustainability in crop production. The soils of southern Saurashtra were medium in available potash which require adequate amount of potassic fertilizer to maintain the plant requirement which is likely to be expected crop removal and other losses. The distribution of available major nutrients was found to be in the following decreasing order (Table 4.47).

N : Hill slope > Upper piedmont > Lower piedmont > Piedmont plain > Coastal plain

P_2O_5 : Coastal plain > Piedmont plain > Lower piedmont > Upper piedmont > Hill slope

K_2O : Piedmont plain > Lower piedmont > Upper piedmont > Hill slope > Coastal plain

Thus, it is inferred that the available N decreased with decreasing the elevation while available phosphorus decreased with increasing elevation. In case of available potash, it was increased from hill slope to piedmont plain but it was lowest in coastal plain.

As far as available micronutrients are concerned, the Fe, Mn, Zn and Cu contents varied from 9.1 to 42.5, 10.8 to 23.2, 0.8 to 2.1 and 0.9 to 8.3 ppm, with the overall mean values of 17.0, 17.7, 1.2 and 4.1 ppm, respectively

(Table 4.47) indicating the soils of southern Saurashtra were high in available Fe, Mn, Zn and Cu, which suggesting the sufficiency of available micronutrients and demanding only restricted quantities of micronutrient fertilization under intensive cultivation in the soils of southern Saurashtra.

Based on weighted mean values of available micronutrients, the distribution of available Fe, Mn, Zn and Cu in different land slopes across the toposequences of southern Saurashtra were observed as under :

Fe and Mn	:	Hill slope > Upper piedmont > Coastal plain > Lower piedmont > Piedmont plain
Mn	:	Hill slope > Lower piedmont > Upper piedmont > Coastal plain > Piedmont plain
Zn	:	Hill slope > Lower piedmont > Upper piedmont > Coastal plain > Piedmont plain

4.6 SOIL TAXONOMIC CLASSIFICATION

Taxonomy helps in providing an uniform platform for proper understanding of soils occurring throughout the world by formulating a common international system of naming the soils. Such a nomenclature provides a strong basis for transferring the information across the world for quality and clarity.

Based on morphological, mineralogical and physico-chemical characteristics of the 16 representative pedons of different land slopes across the toposequences, the soils of the southern Saurashtra have been classified (Appendix-IV) according to Soil Taxonomy (Soil Survey Staff, 1998) as given below :

4.6.1 Hiran toposequence (T₁)

4.6.2 Shingoda toposequence (T₂)

4.6.3 Machhundri toposequence (T_3)

4.6.4 Rayadi toposequence (T_4)

4.6.1 Hiran Toposequence (T_1)

The soils of the pedons P_1 to P_4 of Hiran toposequence were classified as per Soil Taxonomy (Appendix-IV) as under.

Pedon 1 (Sasan (Gir)) from the Hill slope : The soil depth of the pedon P_1 was only 43 cm. The pedon has no diagnostic subsurface horizons hence it keys out as Entisols order. The soils do not have stratification as evidenced by a regular decrease in organic carbon with depth. This qualifies the soils of this pedon to be placed in Orthants sub order. The Ustic moisture regime of the soil places the soils of this pedon in Ustorthent great group. The shallow depth of soils (<50 cm) and the occurrence of a hard rock qualifies the soils to be placed in Lithic sub group. Thus the soils represented by pedon P_1 occurring on a hill slopes were classified as Lithic Ustorthents. Kalyansundaram and Patil (1995) noted Lithic Ustorthents was occur extensively in the hilly soils of south Saurashtra. The same classification was also reported by Gundalia and Savalia (2000) in the hilly soils of southern Saurashtra.

Pedon 2 (Borvav) from the Upper piedmont : The depth of the soil of pedon P_2 was only 45 cm and is without any diagnostic subsurface horizons. Hence it was placed in Entisols order. Since, there was a regular decrease in organic carbon with depth, the soils keys out as Orthents at sub order level. The ustic moisture regime of the soil places the soils in Ustorthent great group. Based on the physical properties of the soils and the dominance of clay texture, places the soils in the clayey family class. The pedon belong to the hyperthermic temperature regime hence the soils of pedon P_2 were classified as clayey Lithic Ustorthents. Kalyanasundaram and Patil (1995) also reported clayey Lithic Ustorthents occur to a small extent in the shallow medium black soils of south Saurashtra. The same classification was also noted by the

Gundalia and Savalia (2000) in the shallow to medium black soils of Saurashtra region.

Pedon 3 (Maljinjava) from the Lower piedmont : The soils of pedon P₃ was moderately developed as evidenced by structural peds as well as presence of A and B horizons. Hence these soils keys out as Inceptisols order. Due to presence of Ochric epipedon, ustic moisture regime and hyperthermic temperature, the soils be placed in Ustochrepts, now, it named as Haplustepts as per Soil Survey Staff (2003). These soils have expansion > 15%, 2 to 2.5 cm wide cracks that extend up to 40 cm depth. These vertic properties quality these soils to be classified as Vertic Ustochrepts at sub group level. Similar, classification was also noted by Gundalia and Savalia (2000) in the medium black soils of southern Saurashtra.

Pedon 4 (Kajali) from the Piedmont plain : The soils of pedon P₄ keyed out as Inceptisols because of sufficient alteration in the from of structure development and increase in clay content with depth. Taking into consideration the ustic soil moisture regime these soils keyed out as Ustepts at sub order level. At great group level, the soils of pedon P₄ were keyed out as Calciustepts because they posses a calcic horizon having 15% or more CaCO₃ in > 1.25 m depth. An irregular decrease of organic carbon content with depth in different horizons indicated its recent deposition and fluventic characteristics qualifying the same for classification as Fluventic Calciustepts at sub group level.

4.6.2 Shingoda Toposequence (T₂)

The soils of the pedons P₅ to P₈ of Shingoda toposequence were classified as per Soil Taxonomy (Appendix-IV) as under.

Pedon 5 (Jamwala) from the Upper piedmont : The soils of pedon P₅ were characterized by presence of B-horizon hence it keys out as order Inceptisols. Due to the presence of Ochric epipedon, hyperthermic temperature and ustic moisture regime, the soils were classified as Ustochrepts at great group level.

Prasad et al. (1977) also classified the medium black soils of an area around Junagadh, Gujarat as Ustochrepts at great group level. The soils of pedon P₅ to be classified as Typic Ustochrepts at sub group level.

Pedon 6 (Kareda) from the Lower piedmont : The soils of the pedon P₆ lack any diagnostic sub-surface horizon and shallow depth (60 cm) and therefore were placed under Entisols order. The soils have a Lithic contact, very low amount of organic carbon in lower depth and have an Orchic epipedon. Hence soils to be classified as Typic Ustorthents at sub group level.

Pedon 7 (Devali) from the Piedmont plain : The soils of pedon P₇ were characterized by cambic horizon, an ochric epipedon, a regular decrease of organic carbon with depth, ustic moisture regime and isohyperthermic temperature which keys out as a Ustropepts at great group level, now it named as Haplustepts iso-hyperthermic according to Soil Survey Staff (2003) and classified as Typic Ustropepts at sub group level.

Pedon 8 (Chauhani Khan) from the Coastal plain : The soils of pedon P₈ were key out as Inceptisols because of sufficient alteration as evidenced structural development and increase in clay content with depth in the solum. The irregular distribution of organic carbon with the depth of the soils indicate the fluventic character of the soils. Due to the presence of an Ochric epipedon, isohyperthermic temperature and Ustic moisture regime hence the soils were classified as Fluvenitic Ustropepts at sub group level. Similar, classification was also reported by Velayutham *et al.* (1999) in the soils of coastal Kathiawar peninsula of Gujarat.

4.6.3 Machhundri Toposequence (T₃)

The soils of pedons P₉ to P₁₂ of Machhundri toposequence were classified as per Soil Taxonomy (Appendix-IV) as under.

Pedon 9 (Fatsar) from the Upper piedmont : The soils of the pedon P₉ were classified under Entisols order due to absence of subsurface diagnostic horizons, shallow soils depth (35 cm) and poor profile development with a

regular decrease in organic carbon content with depth. The soils were classified into Orthents at suborder level. The Ustic moisture regime of this area makes these soils to fall under the category of Ustorthents at great group level. The soils of this area to be classified as a Lithic Ustorthents at sub group level.

Pedon 10 (Judavadali) from the Lower piedmont : The soils of pedon P₁₀ were characterized by cambic horizon and hence keys out as Inceptisols order. The Ustic moisture regime, hyperthermic temperature and presence of an Ochric opipedon these soils of full under the category of Ustochrepts at great group level. These soils to be classified at Typic Ustochrepts at sub group level.

Pedon 11 (Delawada) from the Piedmont plain and Pedon 12 (Rampara) from the Coastal plain : The soils of pedons P₁₁ and P₁₂ were placed in order Inceptisols due to presence of cambic subsurface diagnostic horizons. Due to Ustic moisture regime and isohyperthermic temperature, the soils of peons P₁₁ and P₁₂ qualify for great group Ustropepts. The irregular distribution of organic with the depth of the soils indicate the fluventic character of the soils hence the soils were classified as Fluventic Ustropepts at sub group level. The fact also has been corroborated by the Velayutham *et al.* (1999) in the soils of coastal Kathiawar peninsula of Gujarat.

4.6.4 Rayadi Toposequence (T₄)

The soils of pedons P₁₃ to P₁₆ of Rayadi toposequence were classified as per Soil Taxonomy (Appendix-IV) as under.

Pedon 13 (Dedan) from the Hill slope and Pedon 14 (Dedan) from the Upper piedmont : The soils associated with the pedons P₁₃ and P₁₄ were classified as Entisols order due to the lack of B horizon and showed very poor profile development as well as shallow depth (< 50 cm). There was a regular decrease of organic carbon content with depth in different horizons. The soils to be classified into Orthents at suborder level. The Ustic moisture regime of

this area makes these soils to fall under the category of Ustorthents at great group level. The soils associated with the pedon P₁₃ and P₁₄ to be classified as a Lithic Ustorthents at sub group level.

Pedon 15 (Chotara) from the Lower piedmont : The soils of the pedon P₁₅ were keys out as Inceptisols order due to presence of cambic horizon and regular increase in clay content with depth in solum. Taking into consideration the ustic soil moisture regime, these soils keyed out as Ochrepts at the sub order level. At great group level, the soils of pedon P₁₅ keys out as Ustochrepts. Due to presence of 2 to 3 cm wide cracks upto the depth of 40 cm and high expansion the soils were of vertic nature hence the soils associated with the pedon P₁₅ to be classified as a Vertic Ustochrepts as sub group level. The similar classification has been reported by the Prasad *et al.* (1977) and Gawande and Biswas (1977).

Pedon 16 (Kadiyali) from the Coastal plain : The soils of pedon P₁₆ were keys out as Inceptisols order due to presence of cambic subsurface diagnostic horizons. Due to Ustic moisture regime and isohyperthermic temperature, the soils of pedon P₁₆ qualify for great group Ustrophepts. The CaCO₃ content increase from 31.50 per cent with increasing the depth and reaches upto 65.00 per cent at BC horizon indicate the 'calcic' horizons. The calcic horizon has been reported at great group / sub group level in soils of arid to semi arid climates in the state of Gujarat by earlier workers (Murthy *et al.*, 1982 and Bhattacharya *et al.*, 1994). The soils associated with the pedon P₁₆ could be classified as a Calcic Ustrophepts as sub group level.

4.7 CHARACTERIZATION AND CLASSIFICATION OF WATER RESOURCES

Besides the soil, water is a natural resource, which is essential for crop production. The semi arid region is dependent on irrigated agriculture. Irrigation water of good quality is usually not available in sufficient quantities to satisfy the water requirement of all the crops grown in the southern Saurashtra region as there are limited canal water facilities. Under these conditions, the farmers are obliged to

use irrigation water with high quantities of dissolved salts, invariably accompanied with yield reduction in most of the crops being grown. Indiscriminate use of such water often leads to crop failures and to the development of the saline or sodic soils, which in turn, require expensive treatment to make them productive again. On the other hand, when saline water is judiciously used, it can contribute to the sustainable production of a variety of crops particularly grown in light textured well drained soils.

The data on depth of underground water table, pH, EC, water soluble cations (Ca^{2+} , Mg^{2+} , Na^+ and K^+) and anions (CO_3^{2-} , HCO_3^- and Cl^-) of irrigation water from different wells/tube wells adjoining to selected profiles of different toposequences and land slopes are presented in Table 4.48 to 4.52 and are discussed in following sub heads :

4.7.1 Hiran toposequence

4.7.2 Shingoda toposequence

4.7.3 Machhundri toposequence

4.7.4 Rayadi toposequence

4.7.5 Land slopes

4.7.1 Hiran Toposequence

The data on depth of water table and chemical composition of underground water from different wells / tube wells adjoining to pedons P_1 to P_4 are depicted in Table 4.48. The results reveal that the water table depth ranged from 5 to 26 m with the overall mean of 13.75 m. The depth of underground water table of Hiran toposequence was found in the order of Piedmont plain < Upper piedmont < Lower piedmont < Hill slope. It is observed that the availability of ground water was scarce and at great depth in hill slope as compared to piedmont plain area.

The pH of underground water of well / tube well No. 1 to 12 of Hiran toposequence ranged between 8.00 to 8.34 with the overall mean of 8.13. The

pH increased with decreasing elevation up to piedmont plain (Fig. 4.29). This may be due to the proportional increase in Na^+ ion (SAR) towards the down slopes. The EC ranged between 0.65 and 6.80 dSm^{-1} with the overall mean of 1.91 dSm^{-1} (Table 4.48). The EC increased with decreasing elevation from hill slope to piedmont plain of Hiran toposequence (Fig. 4.29). This can be ascribed to the accumulation of soluble salts at the lower piedmont carried by the percolating water.

Out of the 12 wells / tube wells water samples from only 3 samples were placed under very high (C_4) salinity water class (Table 4.48 and 4.52) as per the limits outlined by Richards (1954). Similar, results were also reported by Singh *et al.* (1967) and DACS (1988).

Among the cations, Ca^{2+} was dominant throughout the Hiran toposequence and varied from 4.00 to 30.80 me l^{-1} followed by Mg^{2+} , Na^+ and K^+ with a range of 1.20 to 18.0, 0.47 to 11.43 and 0.00 to 0.05 me l^{-1} , respectively. The corresponding mean values of these cations were 13.16, 5.53, 3.41 and 0.01 me l^{-1} (Table 4.48). The total water soluble cations ranged from 7.15 to 60.10 me l^{-1} with a mean value of 18.50 me l^{-1} , which increased with decreasing elevation from 7.46 me l^{-1} in the hill slope to 50.34 me l^{-1} at piedmont plain. The concentration of Na^+ increased with an increase in EC

(Gupta, 1986). Among the anions, CO_3^{2-} , HCO_3^- and Cl^- ranged from 0.00 to 0.40, 3.80 to 5.70 and 2.0 to 55.0 me l^{-1} with the mean values of 0.08, 4.57 and 12.98 me l^{-1} , respectively (Table 4.48). The HCO_3^- was the dominant anion except piedmont plain where Cl^- was dominant anion. Similar, results were also reported by Sharma (2000) and Mahendran and Arunachalam (2002). The total water soluble cations and anions were highest in piedmont plain. This might be due to the ingress of sea water (Patel *et al.*, 1982) caused as a result of over exploitation of groundwater for irrigation, in areas near to the sea.

The SSP of irrigation water ranged between 6.05 to 26.94 me l^{-1} with a mean value of 13.06 me l^{-1} indicating the irrigation water is not harmful (< 60 SSP) with respect to Na^+ ion. The SSP of irrigation water increased with decrease in elevation from 9.37 at the hill slope to 22.96 at piedmont plain (Table 4.48). The SAR of irrigation water ranged from 0.25 to 2.90 with a mean value of 0.98 indicating the irrigation water of Hiran toposequence have low sodium hazard. The SAR increased with increasing EC (Gupta, 1986). The RSC was absent in all water samples.

Out of 12 well / tube wells, water samples of only three wells in piedmont plain were poor in quality and become to C_4S_2 class as per the limit outlined by Richards (1954).

4.7.2 Shingoda Toposequence

The data of water table depth and chemical composition of underground water from different wells / tube well adjoining to pedons P_5 to P_8 are presented in Table 4.49. The depth of water table (during May month) ranged from 9 to 30 m with the overall mean value of 19 m. The pH ranged from 8.15 to 8.45 with the overall mean of 8.32. The EC ranged from 0.60 to 3.50 dSm^{-1} with the

overall mean value of 1.93 dSm^{-1} . The pH and EC increased with decreasing elevation from hill slope to coastal plain (Fig. 4.29).

Out of 12 wells / tube wells, water samples from 6 (Sr. No. 19 to 24) wells were placed under very high (C_4) salinity water class (Table 4.49 and 4.52) has the limits outlined by Richards (1954). The Ca^{2+} , Mg^{2+} , Na^+ and K^+ ranged from 3.00 to 6.40, 2.00 to 18.20, 0.80 to 12.86 and 0.02 to 0.07 me l^{-1} with the mean value of 4.48, 8.52, 6.12 and 0.04 me l^{-1} , respectively. Among the cations Mg^{2+} was dominant followed by Na^+ , Ca^{2+} and K^+ . The water soluble Ca^{2+} , Na^+ and total soluble cations increased with decreasing elevation from upper piedmont to the coastal plain. The total soluble cations ranged from 6.43 to 34.51 me l^{-1} with the overall mean value of 19.17 me l^{-1} . Among the anions, CO_3^{2-} was absent in upper piedmont area. The CO_3^{2-} , HCO_3^- and Cl^- ranged from 0.00 to 1.40, 3.60 to 5.60 and 2.60 to 27.00 me l^{-1} with the overall mean value of 0.87, 4.48 and 12.50 me l^{-1} , respectively (Table 4.49). The CO_3^{2-} and Cl^- increased with decreasing elevation which HCO_3^- remained uniform throughout the toposequence. The SSP ranged between 12.50 to 46.12 with the mean value of 30.85. The SAR ranged from 0.48 to 5.53 with a mean values of 2.52 indicating the underground water of Shingoda toposequence was low in sodium hazard. No relation was observed between SAR and topography (Fig. 4.29).

Out of the 12 wells / tube wells, water samples from three wells each in piedmont plain and coastal plain have qualified in water quality classes C_4S_1 and C_4S_2 (Table 4.53), respectively as per the limits outlined by Richards (1954).

4.7.3 Machhundri Toposequence

The data on water table and chemical composition of underground water samples collected from different wells adjoining to pedons P₉ to P₁₂ were depicted in Table 4.50. The data reveals that the depth of water table ranged between 9 to 25 m with a mean value of 17 m. The pH ranged from 8.13 to 8.85 with a mean value of 8.41 (Table 4.50). The pH increased with decreasing elevation from upper piedmont to coastal plain (Fig. 4.29). The EC ranged from 0.90 to 6.00 dSm⁻¹ with a mean value of 2.24 dSm⁻¹. The EC increased with decreasing elevation from upper piedmont to coastal plain (Fig. 4.29).

Out of 12 well/ tube well water samples, 8 and 3 placed under high (C₃) and very high (C₄) salinity water class, respectively (Table 4.50 and 4.53). The Ca²⁺, Mg²⁺, Na⁺ and K⁺ ranged from 3.20 to 9.60, 2.80 to 18.40, 2.00 to 40.00 and 0.00 to 1.28 me l⁻¹ with the mean values of 4.48, 6.87, 10.09 and 0.30 me l⁻¹, respectively (Table 4.50). Among the cations, Na⁺ was the dominant followed by Mg²⁺, Ca²⁺ and K⁺ indicating the salinity in piedmont plain and coastal plain area whereas in the upper area, Ca²⁺ was the dominant cation. A fact also corroborated by the findings of Mahendran and Arunachalam (2002). Among the anions, CO₃²⁻ was absent in well No. 25 to 27 adjoining to pedon P₉ (Fatsar) of upper piedmont. The CO₃²⁻, HCO₃⁻ and Cl⁻ ranged from 0.00 to 1.80, 3.20 to 9.00, 2.80 to 42.50 me l⁻¹ with the mean value of 1.17, 5.54 and 13.07 me l⁻¹, respectively (Table 4.50). Among the anions, Cl⁻ was the dominant followed by HCO₃⁻ and CO₃²⁻. The SSP ranged from 22.22 to 72.20 with a mean value of 37.94. The SSP increased with decrease in elevation up to piedmont plain. The SAR ranged from 1.07 to 14.42 with a mean value of 3.87 (Table 4.50) indicating that there was no problem of alkalinity except in coastal plain where it reaches at the marginal level of alkalinity on account of measuring salinity towards the coastal plain from piedmont plain area. The SAR increased with decreasing elevation (Fig. 4.29)

Out of 12 well water samples of Macchundri toposequence only 2 water samples were placed in C_4S_2 water quality class, while only one sample each was placed in C_3S_2 , C_4S_3 and C_5S_4 water quality class, respectively (Table 4.50), as per the limits outlined by Richards (1954).

4.7.4 Rayadi Toposequence (T_4)

The data on depth of water table and chemical composition of underground water samples collected from different wells / tube wells adjoining to pedons P_{13} to P_{16} are presented in Table 4.51. The depth of water table ranged from 12 to 22 m with a mean value of 18 m (Table 4.51). The pH ranged from 8.20 to 8.55 with a mean value of 8.34. There was no relation between pH and elevation (Fig. 4.28). The EC ranged from 0.80 to 3.70 dSm^{-1} with a mean value of 1.75 dSm^{-1} , respectively (Table 4.51). The EC increased with decreasing elevation up to coastal plain (Fig. 4.29).

Out of 12 wells / tube well water samples from only 3 wells were placed under very high (C_4) salinity water class (Table 4.53) as per the limits outlined by Richards (1954). The Ca^{2+} , Mg^{2+} , Na^+ and K^+ ranged from 3.20 to 10.80, 2.00 to 5.60, 2.43 to 20.00 and 0.01 to 1.60 $me\ l^{-1}$ with the mean values of 6.40, 4.01, 5.86 and 0.37 $me\ l^{-1}$, respectively (Table 4.51). The Ca^{2+} , Mg^{2+} , K^+ and total cations increased with decreasing elevation from hill slope to coastal plain. Among the cations Ca^{2+} was the dominant followed by Na^+ , Mg^{2+} and K^+ . Among the anions, CO_3^{2-} was absent in well No. 37 to 39 adjoining to pedon-13 (Dedan) of hill slope. The CO_3^{2-} , HCO_3^- and Cl^- ranged from 0.00 to 2.60, 3.20 to 8.50 and 3.70 to 28.10 $me\ l^{-1}$ with the mean value of 1.22, 5.16 and 11.58 $me\ l^{-1}$, respectively (Table 4.51). Among the anions, Cl^- was the dominant followed by HCO_3^- and CO_3^{2-} . Similar, results are also reported by Timbadiya (1988). The CO_3^{2-} and Cl^- increased with decrease elevation from hill slope to coastal plain. The SSP ranged from 18.76 to 62.50 with a mean value of 34.96. The SAR ranged from 1.04 to 8.13 with the mean value

of 2.99 (Table 4.51). There was no relation between SAR and elevation (Fig. 4.29).

Out of 12 wells / tube wells water samples from 3 wells in coastal plain were placed under C_4S_3 water quality class (Table 4.51) as per the limits outlined by Richards (1954).

4.7.5 Land Slopes

The mean data of chemical composition of underground water collected during month of May from different land slopes across the toposequences of southern Saurashtra is presented in Table 4.52 and are discussed in brief as under.

4.7.5.1 Hill slope

The depth of water table ranged from 21 to 24 with a mean of 23m. The pH and EC ranged from 8.01 to 8.22 and 0.68 to 0.90 dSm^{-1} with the mean of 8.12 and 0.79 dSm^{-1} , respectively (Table 4.52).

As per the limits proposed by USSL staff (Richards, 1954), wells adjoining to pedon P_1 (Sasan) of Hiran toposequence (T_1) and pedon P_{13} (Dedan) of Hill slope were placed under medium (C_2) and high (C_3) salinity water class, respectively (Table 4.52).

Among the cations Ca^{2+} was dominant and varied from 4.00 to 4.50 $me l^{-1}$ followed by Mg^{2+} , Na^+ and K^+ with the range of 2.20 to 3.00, 0.70 to 2.52 and 0.00 to 0.02 $me l^{-1}$, respectively. The corresponding mean values were 4.25, 2.60, 1.61 and 0.01 $me l^{-1}$ (Table 4.52). The total water soluble cations ranged from 7.46 to 9.55 with a mean of 8.51 $me l^{-1}$. Among the anions CO_3^{2-} was absent. HCO_3^- and Cl^- ranged between 4.13 to 4.75 and 2.20 to 3.76 $me l^{-1}$ with the mean value of 4.44 and 2.98 $me l^{-1}$, respectively (Table 4.52).

Among the anions, HCO_3^- was dominant followed by Cl^- . The SSP and SAR ranged from 9.37 to 25.70 and 0.38 to 1.35 with the mean of 17.54 and

0.87. As per the limits proposed by USSL staff (Richards, 1954), the wells of eastern part of hill slope adjoining to pedon P₁₃ fell in C₃S₁ water quality class.

4.7.5.2 Upper piedmont

The depth of water table of different wells / tube wells ranged from 11 to 18 m with the mean of 16 m. The depth of water table was observed in decreasing order of P₅T₂ > P₁₄T₄ > P₉T₃ > P₂T₁ (Table 4.52). The pH and EC ranged from 8.04 to 8.35 and 0.67 to 1.20 dSm⁻¹ with the mean of 8.17 and 0.90 dSm⁻¹, respectively. The pH of wells/tube wells water adjoining to different pedons was found in sequence of P₁₄T₄ > P₉T₃ > P₅T₂ and P₂T₁. The EC of different wells/tube wells water adjoining to different profiles was observed in sequence of P₁₄T₄ > P₉T₃ > P₂T₁ > P₅T₂. The water soluble cations of Ca²⁺, Mg²⁺, Na⁺ and K⁺ ranged from 3.37 to 4.80, 2.30 to 3.60, 0.77 to 5.72 and 0.00 to 0.03 me l⁻¹ with the mean of 4.16, 3.09, 2.43 and 0.02 me l⁻¹, respectively (Table 4.52). Among the cations, Ca²⁺ was the dominant followed by Mg²⁺, Na⁺ and K⁺. The total cations ranged between 7.56 to 12.15 me l⁻¹ with a mean of 9.19 me l⁻¹. The total cations increased with an increase in EC. The CO₃²⁻, HCO₃⁻ and Cl⁻ ranged from 0.00 to 1.53, 4.07 to 5.03 and 2.40 to 6.53 me l⁻¹ with the mean of 0.38, 4.46 and 3.77 me l⁻¹, respectively. Among the anions, HCO₃⁻ was the dominant followed by Cl⁻. The SSP and SAR ranged from 9.82 to 29.86 and 0.41 to 1.82 with the mean of 19.34 and 1.00, respectively (Table 4.52).

As per the limits proposed by USSL staff (Richards, 1954), the water samples from the wells / tube wells adjoining to P₂T₁, P₉T₃ and P₁₄T₄ were placed under C₃S₁ water quality class while the water samples from well adjoining to P₅T₂ was placed under C₂S₁ class (Table 4.52).

4.7.5.3 Lower piedmont

The depth of water table of different wells / tube wells adjoining to different pedons ranged from 12 to 24 m with a mean of 17 m. The depth of water table was observed in order of P₁₀T₃ > P₁₅T₄ > P₃T₁ > P₆T₂ (Table 4.52). The pH and EC ranged from 8.12 to 8.38 and 0.78 to 1.53 dSm⁻¹

with the mean of 8.29 and 1.19 dSm⁻¹, respectively. The pH was observed in decreasing order of P₁₀T₃ > P₁₅T₄ > P₆T₂ > P₃T₁. While the EC was in sequence of P₁₅T₄ > P₆T₂ > P₁₀T₃ > P₃T₁ (Table 4.52).

The Ca²⁺, Mg²⁺, Na⁺ and K⁺ ranged from 3.87 to 7.53, 2.40 to 4.17, 0.85 to 5.21 and 0.00 to 0.54 me l⁻¹ with the mean of 5.13, 3.43, 2.92 and 0.18 me l⁻¹, respectively (Table 4.52). The Mg²⁺ increased with an increase of EC. The total soluble cations ranged from 8.35 to 15.57 me l⁻¹ with the mean of 11.71 me l⁻¹. The total cations was observed in the decreasing sequence of P₁₅T₄ > P₆T₂ > P₁₀T₃ > P₃T₁. The CO₃²⁻, HCO₃⁻ and Cl⁻ ranged from 0.00 to 1.40, 4.03 to 4.83 and 2.60 to 12.47 me l⁻¹ with the mean of 0.93, 4.48 and 6.07 me l⁻¹, respectively. The Cl⁻ was increased with an increase of EC. Among the anions Cl⁻ was the dominant followed by HCO₃⁻ and CO₃²⁻ (Table 4.52).

The SSP and SAR ranged from 10.06 to 40.97 and 0.43 to 2.71 with the mean of 24.42 and 1.47, respectively. According to USLL staff (Richards, 1954) all the wells / tube wells situated in lower piedmont of southern Saurashtra were placed under C₃S₁ water quality class (Table 4.52).

4.7.5.4 Piedmont plain

The depth of water table ranged between 5 and 26 with a mean of 17m. The pH and EC ranged from 8.17 to 8.50 and 1.97 to 5.40 dSm⁻¹ with the mean of 8.35 and 3.35 dSm⁻¹, respectively (Table 4.52). The pH was observed in decreasing order of P₁₁T₃ > P₇T₂ > P₄T₁ while EC was P₄T₁ > P₇T₂ > P₁₁T₃. The Ca²⁺, Mg²⁺, Na⁺ and K⁺ ranged from 4.40 to 23.80, 4.53 to 15.20, 6.02 to 11.32 and 0.03 to 0.04 with the mean of 11.13, 11.29, 9.43 and 0.03 me l⁻¹, respectively (Table 4.52). Among the cations, Mg²⁺ was found dominant followed by Ca²⁺, Na⁺ and K⁺. The water soluble cations ranged from 19.94 to 50.34 me l⁻¹ with a mean of 31.89 me l⁻¹. The total soluble cations were observed in the decreasing sequence of P₄T₁ > P₇T₂ > P₁₁T₃. The CO₃²⁻, HCO₃⁻ and Cl⁻ ranging from 0.30 to 1.53, 4.25 to 5.20 and 12.23 to 44.77 me l⁻¹, respectively. The Cl⁻ increased with an increasing of EC. Among the anions, Cl⁻ was found dominant followed by HCO₃⁻ and CO₃²⁻. The SSP and SAR

varied from 22.96 to 52.35 and 2.20 to 4.98 with the mean of 34.55 and 3.29, respectively (Table 4.52). According to USLL staff (Richards, 1954), the wells/ tube wells adjoining to $P_{11}T_3$, P_7T_2 and P_4T_1 were placed under C_2S_2 , C_4S_1 and C_4S_2 , respectively (Table 4.52).

4.7.5.5 Coastal plain

The depth of water table ranged from 10 to 20 with a mean of 16 m. The depth of water table was observed in the decreasing sequence of $P_8T_2 > P_{16}T_4 > P_{12}T_3$. The pH and EC ranged from 8.42 to 8.55 and 3.10 to 4.90 dSm^{-1} with mean of 8.47 and 3.79 dSm^{-1} , respectively (Table 4.51). The pH and EC increased with an increase of both the pH and EC was observed in decreased sequence of $P_{12}T_3 > P_{16}T_4 > P_8T_2$. The Ca^{2+} , Mg^{2+} , Na^+ and K^+ ranged from 5.47 to 9.27, 5.27 to 16.07, 12.15 to 24.70 and 0.04 to 1.12 $me\ l^{-1}$ with the mean of 6.87 11.51 16.81 and 0.68 $me\ l^{-1}$, respectively (Table 4.52). Among the cations, Na^+ was the dominant followed by Mg^{2+} , Ca^{2+} and K^+ . The Na^+ was increase with increased EC. The total cations ranged between 30.84 and 47.76 $me\ l^{-1}$ with the mean of 37.65 $me\ l^{-1}$. The CO_3^{2-} , HCO_3^- and Cl^- ranged from 1.30 to 2.00, 4.30 to 8.23, 23.57 to 33.90 $me\ l^{-1}$ with the mean of 1.68, 6.82 and 27.03 $me\ l^{-1}$ respectively (Table 4.52). The SSP and SAR ranged from 7.38 to 50.87 and 4.54 to 8.06 with the mean of 32.59 and 6.66, respectively (Table 4.52). According to USLL staff (Richards, 1954), the wells/tube wells adjoining to P_8T_2 were placed under C_4S_2 while the $P_{12}T_3$ and $P_{16}T_4$ were placed under C_4S_3 (Table 4.52).

Overall Underground Water Quality in Southern Saurashtra

In general, looking to the overall picture for the depth of water table and composition of irrigation water of the southern Saurashtra, the data presented in Table 4.52 reveals that the depth of water table ranged from 5 to 26 m with the overall mean of 17 m. The depth of water table in different land slopes observed in the following decreasing order:

Hill slope > Lower piedmont and Piedmont plain > Upper piedmont and Coastal plain.

There was inverse relation of depth of water table and the height of an elevation.

The pH and EC of irrigation water of southern Saurashtra ranged from 8.01 to 8.55 and 0.67 to 5.40 dSm⁻¹ with the overall mean of 8.28 and 1.96 dSm⁻¹, respectively (Table 4.52). The pH and EC were observed in order of Hill slope < Upper piedmont < Lower piedmont < Piedmont plain < Coastal plain (Fig. 4.30). The pH of underground water increased with an increase of EC. The Ca²⁺, Mg²⁺, Na⁺ and K⁺ ranged from 4.00 to 23.80, 2.20 to 16.07, 0.70 to 24.70 and 0.00 to 1.12 me l⁻¹ with the overall mean of 6.23, 6.17, 6.40 and 0.23 me l⁻¹, respectively. The Ca²⁺ was found dominant in Hiran toposequence throughout the land slope (Table 4.48). The Mg²⁺ and Na⁺ were dominant in plain area (piedmont plain and coastal plain) as compared to elevated area (upper and lower piedmont) of Shingoda and Machhundri toposequences, respectively, where Ca²⁺ was the dominant cation (Table 4.49 & 4.50). The Na⁺ was dominant in upper piedmont and coastal plain area of Rayadi toposequence, whereas the Ca²⁺ was dominant in hill slope and lower piedmont of this sequence (Table 4.51). Among the anions, the CO₃²⁻ was absent in hill slope area, while the HCO₃⁻ was dominant in hill slope and upper piedmont, but at the lower piedmont and plain area (piedmont plain and coastal plain) the Cl⁻ was found dominant irrespective of toposequences of southern Saurashtra (Table 4.52). The total soluble cations ranged from 7.46 to 50.37 me l⁻¹ with the overall mean of 19.33 me l⁻¹ (Table 4.52). The CO₃²⁻, HCO₃⁻ and Cl⁻ ranged from 0.00 to 2.00, 4.07 to 8.23 and 2.20 to 44.77 me l⁻¹ with the overall mean of 0.83, 4.91 and 12.56 me l⁻¹, respectively (Table 4.52). The SSP and SAR ranged from 9.37 to 52.35 and 0.38 to 8.06 with the overall mean of 25.72 and 2.59, respectively (Table 4.52). The SAR increased with an increase of EC. The SSP and SAR (Fig. 4.30) were observed in the following increasing order viz., Hill slope > Upper piedmont > Lower piedmont > Piedmont plain >

Coastal plain. The SSP and SAR increased with decrease elevation. The SSP and SAR also increased with an increase in EC and pH. The RSC absent in all water samples (Table 4.48 to 4.52). As per the limits proposed by USLL staff (Richard, 1954), the underground water of hill slope, upper piedmont were placed under safe class of C_2S_1 and C_3S_1 , while the lower piedmont in C_3S_1 class. However, the piedmont plain and coastal plain were placed under doubtful class of C_4S_2 and C_4S_3 water quality. In general the underground water the southern Saurashtra were placed under C_3S_1 water quality class except the coastal plain area.

4.8 CLIMATIC CONDITIONS IN THE STUDY AREA OF SOUTHERN SAURASHTRA

Climatic factors are important indicators for sustainable use of soils and water resources because climate affects sustainability both directly and indirectly (Lal, 1994). The climatic condition in different land slopes of southern Saurashtra are presented in Table 4.53.

4.8.1 Hill slope : The rainfall is very high on the western side of Sasan (Gir) of pedon P_1 . It gradually decreased towards eastern side and became moderate at Dedan (P_{13}). Temperature was hyperthermic, at all places. Humidity also was moderate in western side but when we traverse towards eastern site, the humidity decreased and it was low at Dedan (P_{13}). The wind velocity was moderate (Table 4.53), at all places.

4.8.2 Upper piedmont : The rainfall was very high in pedon P_5 (Jamwala) while in P_2 (Borvav) and P_9 (Fatsar), the rainfall was high, whereas in P_{14} (Dedan), the rainfall was moderate (Table 4.53). The temperature was hyperthermic at all places, whereas the relative humidity was high at western side (P_2 and P_5) but it gradually decreased towards the eastern side (P_9 and P_{14}). The wind velocity was low in locations of pedons P_2 , P_5 and P_9 while it was moderate in Dedan (P_{14}) (Table 4.53).

4.8.3 Lower piedmont : The rainfall was moderate in the locations of pedons P₃ (Maljinjava), high in P₆ (Kareda) and P₁₀ (Judavadali) and low in P₁₅ (Chotara). The temperature was hyperthermic throughout lower piedmont area. Similarly, moderate humidity was also observed throughout the lower piedmont area. The wind velocity was moderate in pedons P₃, P₆ and P₁₅ while low wind velocity was observed in pedon P₁₀ (Table 4.53).

4.8.4 Piedmont plain : The rainfall was low in pedon P₄ (Kajali) while in P₇ and P₁₁, it was moderate. The isohyperthermic temperature regime was recorded the piedmont plain area. The humidity was recorded high throughout the piedmont plain area. The wind velocity in pedons P₄ and P₁₁ was moderate, while in P₇ it was low (Table 4.53).

4.8.5 Coastal area : The rainfall was moderate at pedon P₈ while it was low in P₁₂ and P₁₆. The temperature was found isohyperthermic throughout the coastal area. The humidity was high in pedons P₈ and P₁₂ but it was moderate in P₁₆. The wind velocity was low, moderate and high in pedons P₈, P₁₂ and P₁₆, respectively (Table 4.53).

4.9 NATURAL SOIL WATER AND CLIMATE RESOURCE CONSTRAINTS

To ensure food security and household nutritional security to the growing population in the country, the agricultural development scenario in the future must develop a full understanding of the assets and liabilities of our natural soil and water resources. This will ensure a scientific management of these soil and water resources to achieve high use efficiency of inputs that go in agriculture production with minimization of degradation of the natural resources, such a strategy forms corner stones of agricultural development policy [Division of Natural Resource Management (DNRM, 2000)].

For sustainable agriculture production, the optimum use of soil and water resources in prevailing climatic condition is highly essential. For the application of this concept, the basic information on the characteristics of soil and water resources is necessary. This will be useful to categorize the soil

sustainability and water quality for profitable agriculture production. This information will also provide guideline to select the most remunerative crops (field and orchards) for sustaining the soil health and wealth of the nation.

4.9.1 Constraints Analysis for Soil Sustainability

Sustainability of soil can be assessed by periodic evaluation and processes. An appropriate indicator is the one which provides a quantitative measure of the magnitude and intensity of environmental stress experienced by plants and animals. These indicators based on properties and processes can be assessed by field and laboratory analysis (Lal, 1994).

Soil sustainability can be assessed by monitoring indicators of soil quality. Attributes of soil quality assessment have been outlined and described by USDA (1992) and Acton (1993).

Indicators of soil sustainability, such as effective root depth, bulk density, texture, structure, available water capacity (AWC), sat. hydraulic conductivity, pH, EC, organic carbon and ESP were compared with the limits as proposed by Lal (1994) (Appendix-V) to understand the severity of constraints for sustainability. These would serve as a baseline indicators for future planning and also determine the crop yield and response to the management practices adopted. The indicators observed in the present investigation based on morphological and laboratory studies of different toposequences of southern Saurashtra are depicted in Table 4.54 and 4.55 with weighting score factors (Scoring). The soil constraints alongwith their remedial measures of different land slopes of southern Saurashtra are also presented in Table 4.56.

- (A) **Effective rooting depth** : Extreme limitation of effective rooting depth was observed in pedon P₁₃ from hill slope of Rayadi toposequence (Table 4.54) as a result of high erosion in side sloping area. The severe limitation of effective rooting depth was found in pedons P₁, P₂, P₆, P₉, P₁₀ and P₁₄ while moderate limitation was observed in pedons P₃, P₅, P₇, P₁₁, P₁₅ and P₁₆ (Table 4.54 and 4.55). This limitation was mainly because of petrocalcic substratum and/or compacted fine lime material. A fact also corroborated by the findings of Sharma (2000). The soils of pedon P₄ have no limitation while pedons P₈ and P₁₂ have slight limitation of effective rooting depth due to their location over piedmont plain and coastal plain area, respectively.
- (B) **Bulk density (B.D.)** : The bulk density of soil is responsible for compaction, root growth and transpiration of water. In present study the bulk density observed to range between 1.32 to 1.57 Mg m⁻³. Except for pedon P₁ where there was no limitation of bulk density (Table 4.54, 4.55 and Fig. 4.31), of the pedons, the limitation ranged from sufficient to extreme with respect to bulk density. Similar results were also observed by Sharma (2000).
- (C) **Structure** : In general, the soil structure for all the soils was moderate to strong sub angular blocky in surface and subsurfaces offering slight limitation in their workability (Table 4.54, 4.55) and sustainability (Fig. 4.31).
- (D) **Texture** : Clay (c) texture was observed only in pedon P₉ and posed extreme limitation form permeability of soil. The silty clay (sc) texture in pedons P₂, P₃, P₁₄ and P₁₅ posed severe limitation. But the silty clay loam texture in pedons P₁, P₄, P₅, P₆, P₇, P₈, P₁₀ (Table 4.54, 4.55 and Fig. 4.31) posed only slight limitation, for permeability.

- (E) **Available water capacity (AWC) :** The moderate degree of limitation was noted in pedons P₅, P₆ and P₁₆ in respect to AWC (Table 4.54 and 4.55). As a result during severe drought, injury to crops might occur more frequently in these soils as compared to rest of the pedons under study, which have only slight or no limitation for AWC. Singh (1999) have also reported similar observations.
- (F) **Saturated hydraulic conductivity (Sat. H.C.) :** The soils of P₈ and P₁₆ have extreme limitation with respect to very low hydraulic conductivity. In pedons P₄, P₁₁ and P₁₅ the problem was severe. High smectite dominant minerals aggravate problems of hydraulic conductivity leading to perched water table as well as secondary salinization especially in pedons near the sea coast area. This may also lead to susceptibility to drought, which will ultimately affect the soil physical quality and soil sustainability (Fig. 4.31) (Lal, 1994). Pedons P₂, P₃, P₅, P₆, P₇, P₉, P₁₀, P₁₂ and P₁₄ show moderate limitation, while soils associated with pedons P₁ and P₁₃ show slight limitation due to their location over hill slope.
- (G) **pH :** Soils with pH between 7.99 to 8.59 experience severe to extreme limitation (Table 4.54, 4.55) (Sharma, 1999). While moderate limitation was found in pedon P₁ only due to hill slope area (Sharma, 1999). High pH affects nutrient transformation nutrient absorption and nutrient fixation, and thus become a limiting factor. The nutrient dynamics in the soil is affected through the imbalance in nutrient availability, which ultimately results in drastic reduction in soil productivity (Fig. 4.32).
- (H) **Electrolyte concentration :** This was not a limitation in any of the pedons under study.
- (I) **Organic carbon :** The pedons P₂ to P₉ and P₁₁ to P₁₆ (Table 4.54 and 4.55) showed severe to extreme level of limitation, respectively on account of organic carbon content under situation of semi arid (dry) conditions. This indicates low fertility status on the soils (Lal, 1994; DNRM, 2000 and Sharma, 2000, Fig. 4.32). Problems of physical determination of

soils generally relate to reduction in organic carbon content (DNRM, 2000).

- (J) **SAR :** The SAR values observed were < 10 in all the soils examined, thus gives an impression that the soils could be categorized with no limitation. However, the soils associated with the pedon P₁₆ show severe limitations (SAR 17.85).

Thus, there is a wide range of soil physical and hydrological properties and processes have a strong modifying effect on soil physical quality, rooting condition and soil sustainability (Lal, 1994, Fig. 4.31). Similar to soil physical and hydrological properties, the soil chemical attributes and reactions have a strong impact on several soil modifying processes with strong influence on soil chemical and nutritional quality and sustainability under different land uses and farming system (Lal, 1994, Fig. 4.32).

After comparing different indications of soil sustainability with criteria and scoring proposed by Lal (1994), it is inferred that cumulative rating index (Table 4.55) was between 22 to 33 in all the pedons under study and thus the majority soils (pedon P₂ to P₄) of Hiran toposequence (T₁) were sustainable with high inputs (S₃) except P₁ (S₂ class) while in Shingoda toposequence, all the pedons P₆ to P₈ were found sustainable with high input (S₃). As far as, Machhundri toposequence is concerned the soils of pedons P₁₀ to P₁₂ were sustainable with high input (S₃) while P₉ was sustainable with alternate land use (S₄). In case of Rayadi toposequence the pedons P₁₃ and P₁₅ were sustainable with high input (S₃) while pedons P₁₄ and P₁₆ were sustainable with alternate land use (S₄) (Table 4.55).

In general, the soils of pedon P₁ were sustainable (S₂), while the soils associated with the pedons P₂ to P₈, P₁₀ to P₁₃ and P₁₅ were sustainable with high input (S₃). However, the soils of pedons P₉, P₁₄ and P₁₆ were sustainable with alternate land use (S₄) (Table 4.55).

Looking to the overall picture, the general mean score of weighted factors of four toposequence was found in order of Hiran toposequence (26) < Shingoda toposequence (27) < Machhundri toposequence (28) < Rayadi toposequence (29) (Table 4.55), which indicate that the soil constraints / limitations increased from west to east direction in the soils of southern Saurashtra.

4.9.2 Soil Constraints in Different Land Slopes

The soil constraints evaluation, their remedial measures and soil sustainability of different land slopes of southern Saurashtra are presented in Table 4.56.

Hill Slope : In general, the most favourable condition was found in west side of pedon P₁ (Sasan) except depth having sustainability (S₂) class. When traversing from west to east side of southern Saurashtra over the hill slope area are low O.C. and high pH of pedon P₁₃ (Dedan) have addition limitations which lead to places these soils in class S₃ i.e. sustainable with high input (Table 4.56).

Upper piedmont : The soils of western side of upper piedmont area (Pedons P₂ and P₅) were sustainable with high input (S₃) class whereas eastern side (Pedons P₉ and P₁₄) were sustainable with alternate land use (S₄) class (Table 4.56). Thus when we traverse from west to east side in upper piedmont area, the number of limitations were increased.

Lower piedmont, Piedmont plain and Coastal plain : The soils of the all the pedons situated in lower piedmont (P₃, P₆, P₁₀ and P₁₅), piedmont plain (P₄, P₇ and P₁₁) and coastal plain (P₈ and P₁₂) were sustainable with high input (S₃) class except pedon P₁₆ from coastal plain where it was sustainable with alternate land use (S₄) class indicating the soil constraints were increased from west to east (Table 4.56) except in lower piedmont (mean weighted factor score: 26) of southern Saurashtra. Thus, when we traverse from hill slope to

coastal plain, the number of limitations was increase except in piedmont plain. (Mean weighted factors score: 26) (Table 4.56)

The remedial measures to overcome the limitations in the soils of different land slopes are given in Table 4.56.

4.9.3 Water Resource Constraints

Water is one of the most important natural resources vital for economic development of a nation. Planning for judicious use of fresh quality and poor quality water in agriculture has to consider important factors for agriculture like nutrient value, soil salinity / sodicity, heavy metals in soils and plants, crop yield and quality aspects (DNRM, 2000). The water resource constraints of different land slopes in southern Saurashtra are presented in Table 4.57.

Hill slope : High runoff, low surface water resorviour condition and very deep water table were the major water resource constraints. However, the low availability of fresh ground water were observed in western part (Sasan) and eastern part (Dedan) of southern Saurashtra (Table 4.57).

Upper piedmont : The moderate runoff, moderate availability of ground water, moderate surface resorviour condition and deep water table were the major water resource constraints found in the land of upper piedmont area.

Lower piedmont : There was no any water resource constraints observed in lower piedmont area, except moderate availability of ground water.

Piedmont plain : The moderately saline water at eastern part of southern Saurashtra was observed the major soil water resource constraints (Table 4.57).

Coastal plain : Temporary water logging, saline and sodic ground water and tidle water intrusion at low lying sea coast were the major water constraints observed in coastal plain area (Table 4.57).

4.9.4 Climatic Constraints

Climatic change with global caused by the emission of green house gases have emerged as an important issue in the last two decades. The crucial requirement is to build up understanding of crop-weather relationship in a way that enables reliable crop yield and disease forecasting and also helps in developing crop-weather models to device efficient agricultural production system. Climate aberration in terms of temperature rise and ozone depletion have to be tackled by minimizing the emission of gree-house gas effects (Divisioin of Natural Resource Management, DNRM, 2000). The climatic constraint in different land slopes of southern Saurashtra are presented in Table 4.57.

Hill slope : The high rainfall intensity, warm winter for rabi crops and low humidity in summer were the important climatic constraints in hill slope of southern Saurashtra.

Upper piedmont : The high rainfall intensity, prolong, dry spell, inadequate and uneven distribution of rainfall, aberrant weather stuation and warm winter for rabi crops were the climatic constraints in the upper piedmont area.**Lower piedmont :** The inadequate and uneven distribution of rainfall, aberrant weather, dry spell, low relative humidity and warm winter for rabi crops were the major climatic constraints in the lower piedmont area (Table 4.57) of southern Saurashtra.

Piedmont plain : The inadequate and uneven distribution of rainfall, aberrant weather, prolonged dry spell and warm winter for rabi crops were the major climatic constraints identified in the piedmont plain area of southern Saurashtra (Table 4.57).

Coastal plain : The inadequate and uneven distributio of rainfall, prolonged dry spell, warm winter for rabi crops and high relative humidity for sesame and cotton crops were the major climatic constraints observed in the coastal plain area of southern Saurashtra (Table 4.57).

4.10 EVALUATION OF SOIL AND WATER RESOURCES

The natural soil and water resource management plays a key role not only in production and protection of crops but also in environmental quality. Strategies for natural soil and water resource management will enable to enhance the productivity and sustainability of land, arresting simultaneously the processes of land degradation and also for accelerating the rate of reclamation and restoration of productivity of natural resource (DNRM, 2000).

Soil degradation is a global threat (Lal and Steward, 1990), and it has strong impact on food and energy resources (Lal, 1988) and environmental (Lal, 1997), especially in relation to water quality (Lal and Steward, 1994).

4.10.1 Evaluation of Soil Resources

The data on reserve water and water balance based on annual rainfall, total WSC and total PAWC of profiles in the different land slopes of southern Saurashtra are presented in Table 4.58.

Hill slope : The minimum reserve water balance was observed between 0.116 to 0.156 m ha⁻¹ with a mean of 0.136 m ha⁻¹, respectively (Table 4.58). The water balance observed varied from 0.615 to 0.691 m ha⁻¹ with a mean of 0.653 m ha⁻¹, indicating that if intensity of rainfall is greater than infiltration rate in hill slope area, the positive water balance (0.653 m ha⁻¹, Table 4.58) observed might be due to runoff, which can be utilized as surface reservoir. If intensity of rainfall is less than infiltration rate then it percolates into the underground water in the studied area.

Upper piedmont : The reserve water and positive water balance varied from 0.118 to 0.242 and 0.500 to 0.665 m ha⁻¹ with the mean of 0.178 and 0.588 m ha⁻¹, respectively (Table 4.58) indicating that the positive water balance (0.588 m ha⁻¹) as observed in upper piedmont area might be percolated but when intensity of rainfall is less than infiltration rate then it could be percolate into

ground water. Soil and water conservation measures should be followed alongwith cover crops like groundnut, black gram and bean across the slopes.

Lower piedmont : The reserve water and water balance ranged from 0.126 to 0.505 and -0.037 to $+0.622 \text{ m ha}^{-1}$ with the mean of 0.249 and 0.276 m ha^{-1} (Table 4.58) indicating that the positive water balance observed in pedons P_3 , P_6 and P_{10} in lower piedmont area might be percolated when intensity of rainfall is less than infiltration rate and this percolating water can be utilize for ground water recharge. However, the negative water balance -0.037 m ha^{-1} observed in pedon P_{15} (Chotara) indicating deficit water balance and less availability of water result in the possibilities of water stress problems may occur in these area. Savalia and Gundalia (2005) found that the average reserve water and negative water balance (runoff/percolation loss) of the soils of Uben irrigation command area in Saurashtra region were 0.422 and -0.028 m ha^{-1} , respectively. The soil and water conservation measures should be followed alongwith cover crops like groundnut, black gram and bean across the slope. However, the lower and upper piedmont area have the intermediate hydrological problems hence management practices should be done accordingly.

Piedmont plain : The reserve water and water balance varied between 0.384 to 1.021 and -0.945 to $+0.147 \text{ m ha}^{-1}$ with the mean of 0.518 and -0.323 m ha^{-1} (Table 4.58) indicating that the percolation may be comparatively delay and less as soil depth is more and in association with very slow permeability, therefore the runoff will take place even moderate intensity of rainfall and water logged condition take place during the monsoon. As a corrective measure for this, the drainage provision should be done. An establishment of drainage network with the sowing of high water requirement crops like sugarcane and banana should be adopted.

Coastal plain : The reserve water and water balance ranged from 0.326 to 0.540 and -0.371 to $+0.078 \text{ m ha}^{-1}$ with the mean of 0.469 and -0.204 m ha^{-1} , respectively (Table 4.58). Due to the negative water balance (-0.204 m ha^{-1}) in

coastal area lead to ground water depletion year after year resulted in the ingress of seawater in to the ground water. This is the main reason for the poor quality of saline water observed in the coastal area. With the use of poor quality water, the soils also become saline and/or sodic due to secondary salinization in this area. It is inferred from the data (Table 4.58) tha the problem of coastal plain was more serious as compared to piedmont plain. In addition to this, the salinity problem also alarming in depression area as well as the tidal water inundated and mixed with fresh resorviour water thus the salinity spread over the coastal area. As a remedial measures, the use of soil amendmments and drainage provision should be done accordingly. The salt tolerant crops and varieties like perl millet, sorghum, cotton Var. Dhumad and paddy Kalarada can be grown in coastal plain area.

4.10.2 Evaluation and Suitability of Underground Water Resource

4.10.2.1 Evaluation of underground water resource

The evaluation of underground water was carried out based on EC classes, SAR classes and combined effect of EC and SAR classes (as per semi-logarithmic USSL diagram, Richard, 1954), which are presented in Table 4.59, 4.60 and 4.61, respectively. Out of 48 wells / tube wells water samples, 16.7, 50.0 and 33.3 per cent samples were facing the medium, high and very high salinity hazard problems (Table 4.59), respectively. While the 97.9 and 2.1 per cent water samples were facing the low and medium sodicity hazard problems (Table 4.60), respectively. The guideline for the management of different well/tube well water samples of respective EC classes and SAR classes are depicted in Table 4.59 and 4.60, respectively.

The percent distribution of underground water for irrigation of southern Saurashtra based on semi-logarithmic USSL diagram are presented in Table 4.61. The results reveals that out of 48 well/tube well water samples, 16.6, 47.9, 2.1, 6.3, 16.7, 8.3 and 2.1 per cent were placed in C_2S_1 , C_3S_1 , C_3S_2 , C_4S_1 ,

C_4S_2 , C_4S_3 and C_4S_4 water quality class, respectively. The guideline for its suitability and management are given in Table 4.61. The well No. 35 water associated in pedon P_{12} (Rampara) of coastal plain, the SAR value of 14.42 so far as sodium hazard (irrespective of salinity) is concerned, as an S_2 water (Table 4.60) but as per the semi-logarithmic USSL diagram for the classification of irrigation water, in which looking to the combined EC (6 dSm^{-1}) and SAR value (14) of the well No. 35 (Table 4.50), the water is rated S_4 sodicity class (Table 4.61). Hence, the guideline for the management of sodicity hazard for the well No.35 water is as per the S_4 class (Table 4.61) instead of S_2 class (Table 4.60).

4.10.2.2 Suitability of underground water resource

For ongoing discussion, the different quality of irrigation water was not suitable directly to the particular location. It is only just for guideline to use for as irrigation. The suitability of particular quality class of irrigation water is determined by prevailing the following five factors (f): $SI = f(QSPCM)$

Where,

SI = Suitability of irrigation water

Q = Quality of irrigation water : Water quality class, amount, nature and proportion of cations and anions presented in water.

S = Soil property : Depth of soil, texture, structure, drainage, permeability, hard pan, depth of water table, chemical composition of the soil pH, EC, ESP and CaCO_3 content will determine the suitability of irrigation.

P = Nature of plants to be grown : Water, which may not be suitable for sensitive crop, it may be suitable for tolerant crops. The information on salt tolerant crops and their varieties would decide the suitability of poor quality of underground water.

- C = Climatic condition : High temperature with less humidity will require more number of irrigation of prevailing water quality for irrigation to use in appropriate crop selection, considering the soil type and climate. e.g. High rainfall area (Mangrol and Junagah district) has the sufficient amount of rainfall to leach out the salts to use high saline water quality as compared to arid climatic condition in Jamnagar district at the same soil type. Thus, the climatic condition is looked into the suitability of poor quality of underground water.
- M = Management power of intellectual farmers are judge the suitability of poor quality of underground water, e.g. some of the farmers add the seashore sand in the soil which provide the high infiltration rate, a good soil physical environment and also act as a mulch which help in suitability even more poor quality ground water in addition to above mentioned factors.

4.10.3 Soil-site Suitability Evaluation for Different Crops of Southern Saurashtra

The soil-site suitability for different land uses is very important for alternate and suitable land use planning. The soils under study have been rated for horticultural crops, six field crops of kharif (groundnut, cotton, sesame, sorghum, maize and soybean) and five crops of rabi (wheat, sugarcane, mustard, pearl millet and sunflower). Land suitability for different crops and land quality ratings are those as suggested by Sys *et al.* (1991) and Natarajan and Gajbe (1983) for horticultural crops, FAO (1976) and Sys *et al.* (1991) for groundnut, sesame and sunflower and Sys *et al.* (1991) and NBSS & LUP (1994) for cotton sorghum, maize, soybean, wheat, sugarcane, mustard and pearl millet (Appendix-VI). The soil-site suitability evaluation based on comparison of land qualities and crop requirements for kharif and rabi crops and for horticultural crops for the area under present study are presented in Table 4.62, 4.63, respectively.

The overall suitability of land for the horticultural crops, kharif and rabi crops of the different toposequences and land slopes are presented in Table 4.64 and 4.65, respectively. The inferences drawn based on the land qualities and suitability ratings are described as per following sub heads:

4.10.3.1 Hiran toposequence

4.10.3.2 Shingoda toposequence

4.10.3.3 Machhundri toposequence

4.10.3.4 Rayadi toposequence

4.10.3.5 Land slopes

4.10.3.1 Hiran toposequence

The crop suitability evaluation of pedons P₁ to P₄ of Hiran toposequence are presented in Table 4.63 to 4.65.

Pedon-1 (Sasan (Gir)) from the Hill slope : The soils associated with the pedon P₁ were moderately suitable for mustard and pearl millet (Table 4.65). Satisfactory production could be achieved with soil conservation measures in hill slopes area of Sasan (Gir) range, as they have moderate slope and soil depth limitations for mustard and pearl millet. The soils were rated marginally suitable for horticultural crops and cotton on account of limitations imposed by rainfall, topography, stoniness, depth, pH and CEC (Table 4.63) for horticultural crops and topography and soil depth for cotton. Further, the soils were not suitable for groundnut, sesame, sorghum, maize, soybean, wheat, sugarcane and sunflower because of major limitations posed by topography (8-15 % slope) and soil depth (35 cm) (Table 4.64). The soil conservation measures were only the option to control the major limitation of erosion in the soils of hill slope area, and unable them to be upgraded from moderately sustainable to highly suitability class for mustard and pearl millet

and from marginally to moderately suitability class for horticultural crops and cotton.

Pedon-2 (Borvav) from the Upper piedmont : The soils of the pedon P₂ were highly suitable for sorghum, moderately suitable for groundnut, cotton, maize, sugarcane, pearl millet and mustard marginally suitable for horticultural crops (Table 4.63 to 4.65). Satisfactory production could be achieved with soil conservation measures to prevent from their truncation of soil depth (Kalyansundaram and Patil, 1995), if groundnut, maize, sugarcane and pearl millet are to be grown. Soil depth and texture are limitations for wheat, topography and soil depth are limitation for mustard and rainfall insufficiency, erosion, flooding, stoniness, soil depth, texture, pH, organic carbon and CEC are limitations for horticultural crops (Table 4.64 and 4.65), which need to be corrected to get satisfactory production.

These soils were found actually unsuitable but potentially suitable (N₁) for soybean and actually and potentially unsuitable (N₂) for sesame and sunflower on account of soil depth and sodicity limitations for soybean, rainfall, texture, soil depth and soil fertility (O.C.) for sesame and temperature, soil depth and soil fertility for sunflower (Table 4.64 and 4.65).

Pedon-3 (Maljinjava) from the Lower piedmont : The soils of pedon P₃ were highly suitable (Table 4.64 and 4.65) for pearl millet crop only. Tamgadge *et al.* (2000) also reported that millets were mostly suited under intermediate elevation. The soils of this area were moderately suitable for groundnut, sesame, sorghum, maize, soybean, wheat, sugarcane, mustard, pearl millet and sunflower (Table 4.64 and 4.65) on account of limitations like drainage, texture and soil depth for groundnut, rainfall, drainage, texture and soil depth for sesame, rainfall, drainage, soil depth and CaCO₃ for sorghum, drainage, soil depth and CaCO₃ for maize, rainfall, drainage, CaCO₃ and ESP for soybean, drainage and texture for wheat, drainage and soil depth for sugarcane, topography, drainage and soil depth for mustard, drainage for pearl millet and temperature, drainage, soil depth, CaCO₃ and O.C. for sunflower. On adoption of corrective measures, the suitability class for the

bove crops could be upgraded upto suitability class S_1 . Savalia and Gundalia (2004) have also indentified the drainage and texture as constraints for groundnut in medium black calcareous soils of Uben Irrigation command area of Saurashtra region. However, these soils were actually unsuitable but potentially suitable (N_1) for horticultural crops because of the limitations posed by low rainfall, erosion, drainage flooding, stoniness, soil depth, texture, pH and CEC (Table 4.63 and 4.65).

Pedon-4 (Kajali) from the Coastal plain : The soils of pedon P_4 were moderately suitable for sorghum, maize, wheat and mustard and marginally suitable for cotton only on account of limitations like low rainfall, poor drainage, high CaCO_3 , poor fertility (low O.C.) and high ESP for sorghum, poor drainage, high CaCO_3 and poor fertility (low O.C.) for maize, poor drainage, texture and salinity hazard (high E_{Ce}) for wheat (Rao *et al.*, 1998), drainage and CaCO_3 for mustard and rainfall, drainage, CaCO_3 , poor soil fertility (low O.C.), high E_{Ce} and ESP for cotton (Table 4.62, 4.65 and 4.65). Adoption of salt-tolerant cultivars and use of organic manures alongwith gypsum, ZnSO_4 and nitrogenous fertilizers can help to upgrade the sustainability class. However, the soils of this coastal area were actually and potentially not suitable for horticultural crops due to severe limitations of low rainfall, poor drainage, flooding, high salinity and low fertility (low O.C.). The soils of this area were actually unsuitable but potentially suitable (N_1) for groundnut on account of poor drainage, texture, low fertility (O.C.) and high ESP, insufficient rainfall, poor drainage, texture and low fertility (low O.C.) for sesame, insufficient rainfall, poor drainage, high CaCO_3 , poor fertility (low O.C.) for soybean, high salinity and alkalinity hazards, for sugarcane, poor drainage, poor fertility (low O.C.) and high ESP for pearl millet, warm temperature, poor drainage, high CaCO_3 and poor fertility (low O.C.) for sunflower.

4.10.3.2 Shingoda toposequence

The crop suitability of pedons P_5 to P_8 of Shingoda toposequence are presented in Table 4.63 to 4.65.

Pedon-5 (Jamwala) from the Upper piedmont : The soils of pedon P₅ were marginally suitable (S₃) for horticultural crops on account of limitations imposed by low rainfall, high erosion, high flooding, stoniness, shallow depth, high pH, low CEC (Table 4.63 & 4.65). The soils of this area were moderately suitable (S₂) for groundnut, cotton, sesame, soybean, wheat, sorghum, maize, sugarcane, mustard and pearl millet because of some limitations in which for groundnut texture, depth and high CaCO₃, for sorghum, maize and sugarcane, depth and high CaCO₃ for soybean; depth and high CaCO₃ and high ESP, for wheat; texture and high CaCO₃, for cotton, soil depth, CaCO₃ and poor soil fertility (low O.C.), for sesame, rainfall, texture, depth and low O.C., for mustard, topography, depth, CaCO₃ and for pearl millet, high CaCO₃ were the striking soil constraints for these crops (Table 4.64 & 4.65). however, suitability class of these soils could be raised after adopting proper management practices by providing optimum soil physical environment and proper selection of these varieties of above crops. The soils of this area were actually and potentially not suitable for sunflower on account of temperature, soil depth, high CaCO₃ and poor soil fertility (low O.C.) limitations (Table 4.64 & 4.65).

Pedon-6 (Kareda) from the Lower piedmont : The soils of this area were moderately suitable (S₂) for groundnut, sorghum, maize, soybean, wheat, sugarcane, mustard and pearl millet on account of limitations for groundnut; texture, soil depth, poor soil fertility (low O.C.) and high ESP, for maize; soil depth high CaCO₃ and poor soil fertility (low O.C.), for wheat; texture and soil depth, for sugarcane; soil depth, poor soil fertility (low O.C.), for wheat; texture and soil depth, for sugarcane; soil depth, poor soil fertility (low O.C.) and high ESP, for mustard topography and soil depth, for sorghum, soil depth, high CaCO₃, low CEC, poor soil fertility (low O.C.) and high ESP and for soybean, soil depth, high CaCO₃, low CEC, low O.C. and high ESP (Table 4.64 & 4.65). These soils were marginally suitable for cotton, sesame and horticultural crops on account of limitations for cotton; texture, soil depth, high CaCO₃, low CEC and soil fertility (low O.C.), for sesame; rainfall, texture, soil depth and poor soil fertility (low O.C.) and for horticultural crops; low rainfall, high erosion,

flooding, stoniness, soil depth, high pH, poor soil fertility (low O.C. and low CEC. On adoption of corrective measures, the suitability class for these crops could be corrected from S_3 to S_2 and S_2 to S_1 class. The soils of this area were actually and potentially unsuitable for sunflower on account of temperature, soil depth, high CaCO_3 and poor soil fertility (low O.C.) limitations.

Pedon-7 (Devali) from the Piedmont plain : The soils associated with the pedon P_7 were highly suitable for sorghum, sugarcane and mustard because of favorable soil-site characteristics of the studied area. However, these soils were moderately suitable for groundnut, cotton, maize, soybean, wheat, pearl millet and sunflower on account of the limitations of drainage and texture for groundnut, high CaCO_3 and poor fertility (low O.C.) for cotton, rainfall, texture, poor soil fertility (low O.C.) for sesame, high CaCO_3 for maize, high CaCO_3 and high ESP for soybean, texture for wheat and temperature, soil depth, high CaCO_3 and poor soil fertility (low O.C.) for sunflower (Table 4.63 to 4.65). On adoption of corrective measures like soil water conservation practices, use of organic manures / green manures improving the drainage conditions alongwith nitrogenous fertilizers, the suitability class of these crops could be raised from S_2 to S_1 class for these crops in this area.

Pedon-8 (Chauhani Khan) from the Coastal plain : The soils of the pedon P_8 were moderately suitable for the groundnut, cotton, sorghum, maize, soybean, wheat, sugarcane, mustard, pearl millet and sunflower on account of limitations of drainage, texture and poor soil fertility (low O.C.) for groundnut; rainfall, drainage, poor soil fertility (low O.C.) and salinity hazard (high E_{Ce}) for cotton, rainfall and drainage for sorghum; drainage for maize, mustard and pearl millet; rainfall, drainage and sodicity hazard (high ESP) for soybean; drainage and texture for wheat; drainage and poor fertility (low O.C.) for sugarcane and temperature, drainage and poor soil fertility (low O.C.) for sunflower (Table 4.64 & 4.65). On adoption of corrective measures like provision of subsurface drainage through lateral ditches (Giri *et al.*, 1999), adoption of salt tolerant varieties, use of organic manures alongwith gypsum and

nitrogenous fertilizers and soil and water conservation practices; the suitability class could be corrected. However, these soils were actually unsuitable but potentially suitable for horticultural crops on account of limitations of rainfall, drainage, flooding, stoniness, high pH, salinity, low soil fertility (low O.C.) and low CEC (Table 4.64 & 4.65).

4.10.3.3 Machhundri toposequence

The overall crop suitability evaluation of pedons P_9 to P_{12} of Machhundri toposequence are depicted in Table 4.63 to 4.65.

Pedon-9 (Fatsar) from the Upper piedmont : These soils were moderately (S_2) suitable for groundnut, cotton, sorghum, maize, wheat, sugarcane, mustard and pearl millet on account of limitations, for groundnut; texture and depth, for cotton, sorghum, maize, wheat, sugarcane and pearl millet; soil depth and for mustard; topography and soil depth (Table 4.64 and 4.65). However, suitability class of these soil could be raised after adopting proper remedial measures like practices for primary tillage, adequate plant population and following moisture conservation practices, selection of drought tolerant crops and varieties, provision of mulching and drip irrigation and adoption of soil conservation measures to protect the precious soil depth (Kalyansundaram and Patil, 1995); for increase soil depth/ rooting volume, conservation tillage and forage based crop rotations which reduce erosion and use of organic manures alongwith nitrogenous fertilizers. However, the soils of this pedon were marginally suitable (S_3) for horticultural crops on account of limitations of rainfall, erosion, flooding, stoniness, depth, texture, high pH and low CEC (Table 4.64 & 4.65). On adoption of corrective measures, the suitability class could be corrected from S_3 to S_2 class. The soils of these area were actually unsuitable but potentially suitable (N_1) for soybean on account of limitations of texture, soil depth and sodicity (high ESP). However these soils were actually and potentially unsuitable (N_2) for sesame and sunflower on account of limitations of rainfall, texture, soil depth, poor soil fertility (low O.C.) for

sesame and temperature, soil depth and poor soil fertility (low O.C.) for sunflower (Table 4.64 & 4.65).

Pedon-10 (Judavadali) from the Lower piedmont : The soils of pedon P₁₀ were moderately suitable (S₂) for groundnut, cotton, sorghum, maize, soybean, wheat, sugarcane and pearl millet on account of limitations of drainage, texture, soil depth and CaCO₃ for groundnut; soil depth, high CaCO₃ and poor soil fertility (low O.C.) for cotton, soil depth and high CaCO₃ for sorghum; maize and sugarcane soil depth, high CaCO₃ and sodicity hazard (high ESP) for soybean, texture, soil depth and CaCO₃ for wheat and poor drainage, soil depth and high CaCO₃ for pearl millet (Table 4.64 & 4.65). The suitability class of these soils could be updated after adopting proper remedial measures like soil conservation practices to protect the precious soil depth, use of improved drainage facilities, reclamation measures for high alkalinity, use of organic manures alongwith nitrogenous fertilization and better nutrient management practices. The soils of this area were marginally suitable (S₃) for horticultural crops, sesame and mustard on account of limitations of rainfall, erosion, drainage, flooding, stoniness, soil depth, high pH and low CEC for horticultural crops; rainfall, texture, soil depth and poor soil fertility (low O.C.) for sesame and topography soil depth and high CaCO₃ for mustard (Table 4.64 and 4.65). On adoption of proper corrective measures the suitability class of these crops could be raised from S₃ to S₂ class. However, the soils of this area were not suitable for sunflower because of temperature, soil depth, high CaCO₃ and poor soil fertility (low O.C.) were the major soil constraints for the production of sunflower.

Pedon-11 (Delawada) from the Piedmont plain : The soils of pedon P₁₁ were moderately suitable (S₃) for sorghum, maize, soybean, wheat and mustard on account of limitations of drainage and poor soil fertility (low O.C.) for maize and mustard, drainage, temperature and poor soil fertility (low O.C.) for wheat, rainfall, drainage, poor soil fertility (low O.C.) and sodicity (high ESP) for sorghum and soybean (Table 4.58 & 4.59). The soils of this area were

marginally suitable (S_3) for cotton on account of limitations of rainfall, drainage, poor soil fertility (low O.C.) and sodicity hazard (high ESP) (Table 4.64 & 4.65). The suitability class of these soils could be raised after improving the drainage conditions and adopting proper fertilization and management practices. However, the soils of this area were actually unsuitable but potentially suitable (N_1) for groundnut, sesame, sugarcane, pearl millet and sunflower; on account of limitations like poor drainage, texture, poor soil fertility (low O.C.) and sodicity hazard (high ESP) for groundnut, rainfall, poor drainage, texture, poor soil fertility (low O.C.) for sesame; poor drainage, poor soil fertility (low O.C.) and high sodicity for sugarcane; poor drainage and poor soil fertility (low O.C.) for pearl millet and temperature, poor drainage, soil depth and poor soil fertility (low O.C.) for sunflower (Table 4.64 & 4.65). The soils of this area were actually and potentially unsuitable (N_2) for horticultural crops on account of limitations like rainfall, erosion, poor drainage, flooding, stoniness, high pH, poor soil fertility (low O.C.) and low CEC (Table 4.63 & 4.65).

Pedon-12 (Rampara) from the Coastal plain : The soils of pedon P_{12} were moderately suitable (S_2) for cotton, sorghum, maize, wheat, sugarcane, mustard, pearl millet and sunflower on account of limitations like rainfall, drainage, high CaCO_3 , poor soil fertility (low O.C.) and sodicity hazard for cotton and sorghum, drainage and poor soil fertility (low O.C.) for maize, mustard, pearl millet, poor drainage, texture and poor soil fertility (low O.C.) for wheat, poor drainage, poor soil fertility (low O.C.) and sodicity hazard for sugarcane and temperature, poor drainage and poor soil fertility for sunflower (Table 4.64 & 4.65). The soils of this area were marginally suitable (S_3) for groundnut, sesame, soybean on account of poor drainage, texture, poor soil fertility (low O.C.) and high sodicity hazard for groundnut, rainfall poor drainage, texture and poor soil fertility (low O.C.) for sesame and rainfall, poor drainage, high CaCO_3 , poor soil fertility (low O.C.) and sodicity hazard for soybean (Table 4.64 & 4.65). The suitability class could be raised after adopting improved drainage facilities, reclamation measures for alkalinity, and providing better

management practices. The soils of this area were actually unsuitable but potentially suitable (N_1) for horticultural crops on account of limitations like rainfall, erosion, drainage, flooding, stoniness, high pH, poor soil fertility (low O.C.) and low CEC (Table 4.63 & 4.65).

4.10.3.4 Rayadi toposequence

The crop suitability evaluation of pedons P_{13} to P_{16} of Rayadi toposequence are given in Table 4.62 to 4.65.

Pedon-13 (Dedan) from the Hill slope : The soils associated with the pedon P_{13} from hill slope area were marginally suitable (S_3) for horticultural crops on account of limitations like rainfall, topography, erosion, stoniness, depth, high pH, poor soil fertility (low O.C.) and low CEC. These soils were moderately suitable (S_2) for pearl millet on account of limitations like topography and soil depth (Table 4.64 & 4.65). The soils of this area were actually unsuitable but potential suitable (N_1) for cotton, sorghum, soybean and mustard for limitations of topography, soil depth and poor soil fertility (low O.C.) for cotton; topography and soil depth for sorghum; topography, soil depth and sodicity hazard for soybean and topography, soil depth for mustard (Table 4.58 & 4.59). The soils of this area were actually and potentially unsuitable (N_2) for groundnut, sesame, maize, wheat, sugarcane and sunflower on account of limitations like topography, texture, soil depth and poor soil fertility (low O.C.) for groundnut and sesame; topography, soil depth for maize; topography, texture, soil depth for wheat; topography, soil depth and poor soil fertility (low O.C.) for sugarcane and topography, soil depth, poor soil fertility (low O.C.) for sunflower (Table 4.64 & 4.65).

Pedon-14 (Dedan) from the Upper piedmont : The soils of the pedon P_{14} were moderately suitable (S_2) for sorghum, maize, mustard and pearl millet on account of limitations like soil depth and poor soil fertility (low O.C.) for sorghum, topography and soil depth for maize, mustard and pearl millet (Table

4.63 to 4.65). These soils were marginally suitable (S_3) for horticultural crops, groundnut, cotton and sugarcane on account of limitations of rainfall, erosion, flooding, stoniness, soil depth, texture, high pH, poor soil fertility (low O.C.) and low CEC for horticultural crops, topography, soil depth, poor soil fertility (low O.C.) for cotton and topography, soil depth and poor soil fertility (low O.C.) for sugarcane (Table 4.63 & 4.65). On adoption of corrective measures, the suitability class for the above crops can be corrected. The soils of this area actually unsuitable but potentially suitable (N_1) for soybean only on account of limitations of topography, soil depth, poor soil fertility (low O.C.) and high ESP. While the soils of the pedon P_{14} were actually and potentially unsuitable (N_2) for sesame, wheat and sunflower on account of limitations of rainfall, topography, poor soil fertility (low O.C.) (Table 4.64 & 4.65)

Pedon-15 (Chotara) from the Lower piedmont : The soils of this area were moderately suitable (S_2) for groundnut, cotton, sesame, sorghum, maize, soybean, wheat, sugarcane, mustard and sunflower on account of limitations like drainage, texture, soil depth, and sodicity (high ESP) for groundnut, rainfall, drainage, soil depth, poor soil fertility (low O.C.) and sodicity (high ESP) for cotton, rainfall, drainage, texture, soil depth, poor soil fertility (low O.C.) and sodicity (high ESP) for sesame, rainfall, drainage, soil depth and sodicity (high ESP) for sorghum, poor drainage for maize, rainfall, drainage and sodicity (high ESP) for soybean, drainage and texture for wheat; drainage, soil depth and sodicity (high ESP) for sugarcane; topography, drainage and soil depth for mustard and temperature, drainage, soil depth, poor soil fertility (low O.C.) for sunflower. However, these soils were actually unsuitable but potentially suitable (N_1) for horticultural crops on account of limitations like rainfall, erosion, drainage, flooding, stoniness, depth, texture, high pH and low CEC (Table 4.64 & 4.65) on adoption of corrective measures like provision of subsurface drainage through lateral ditches adoption of salt tolerant varieties use of organic manures alongwith gypsum and nitrogenous fertilizer the suitability class can be corrected.

Pedon-16 (Kadiyali) from the Hill slope : The soils of the pedon P₁₆ were moderately suitable (S₂) for sorghum and wheat on account of limitations like rainfall, poor drainage, soil depth, high CaCO₃ and sodicity hazard for sorghum and poor drainage, texture, CaCO₃ and salinity hazard for wheat. However, the soils of pedon P₁₆ were marginally suitable (S₃) for cotton and soybean on account of limitations like rainfall, drainage, soil depth, CaCO₃, poor soil fertility (low O.C.), salinity and sodicity for cotton, rainfall, drainage, CaCO₃, salinity and sodicity for soybean. However, these soils were actually unsuitable but potentially suitable (N₁) for horticultural crops, groundnut, sesame, mustard and pearl millet, on account of limitations like rainfall, erosion, drainage, flooding, stoniness, high pH, high EC, poor soil fertility (low O.C.) and low CEC for horticultural crops, drainage texture, soil depth, CaCO₃, low O.C. and high ESP for groundnut; topography drainage, soil depth and high CaCO₃ for mustard and poor drainage and high CaCO₃ for pearl millet (Table 4.63 & 4.65). The soils were actually and potentially unsuitable for maize, sugarcane and sunflower on account of limitations of poor drainage and high CaCO₃ for maize; poor drainage, soil depth, high CaCO₃, poor soil fertility (low O.C.) and high sodicity for sugarcane and temperature, poor drainage, soil depth, high CaCO₃ for sunflower (Table 4.64 and 4.65). The suitability class can be raised after adopting improved drainage, fertilizers, reclamation measures for salinity / sodicity, providing better management practices and addition of FYM, gypsum alongwith nitrogenous fertilizers.

4.10.3.5 Land slopes

The crop suitability of soils of different land slopes and existing crops grown in the studied area are presented in Table 4.66. The limitations of different crops of individual pedons were discussed in this text in 4.10.3.1 to 4.10.3.4 hence not discussed here.

LS-1 : Hill slope : The soils of western hill slope (P₁, Sasan) were moderately suitable (S₂) for mustard and pearl millet and marginally suitable (S₃) for

horticultural crops and cotton while eastern hill slope (P₁₃, Dedan) were moderately suitable (S₂) for pearl millet only and marginally suitable (S₃) for horticultural crops only (Table 4.66).

LS-2 : Upper piedmont : The soils of pedons P₂, P₅, P₉ and P₁₄ were marginally suitable (S₃) for horticultural crops, while the pedons P₂, P₅ and P₉ were moderately suitable (S₂) for groundnut, cotton, wheat and sugarcane and pedon P₁₄ was marginally suitable (S₃) for groundnut and cotton. The soils of pedon P₅ were moderately suitable (S₂) for sesame and soybean. The soils of all the pedons of upper piedmont area were moderately suitable (S₂) for maize, mustard and pearl millet. The soils of pedon P₂ were highly suitable (S₁) for sorghum, pedons P₅, P₉ and P₁₄ were moderately (S₂) suitable for sorghum. The soils of P₂, P₅ and P₉ were moderately suitable (S₂) for wheat and sugarcane and pedon P₁₄ were marginally suitable (S₃) for sugarcane. However, the soils of all the pedons were actually and potentially unsuitable (N₂) for sunflower.

The farmers of Borvav (Pedon P₂) upper piedmont area could be grown cotton, sorghum, maize and mustard beside the existing crops of groundnut, sugarcane, blackgram, pigeonpea and banana. The sesame and soybean as a new crops cotton, sorghum, maize as a sweetcorn and mustard could be introduce besides the existing crops like groundnut, pearl millet, sugarcane and wheat in the soils associate with the pedon P₅ of Jamwala region which were moderately suitable (S₂).

LS-3 : Lower piedmont : The soils of land slopes were marginally suitable (S₃) for horticultural crops (Table 4.66). The soils of all the pedons P₃, P₆, P₁₀ and P₁₅ were moderately suitable (S₂) for groundnut, sorghum, maize, soybean, wheat, sugarcane and pearl millet. The soils of pedons P₁₀ and P₁₅ were moderately suitable (S₂) and pedons P₃ and P₆ were marginally suitable (S₃) for cotton. The soils of the pedons P₃ and P₁₅ of lower piedmont area were moderately suitable (S₂) and P₆ and P₁₀ were marginally suitable (S₃) for

sesame. The soils of pedons P₃, P₆ and P₁₅ were moderately suitable (S₂) and P₁₀ were marginally suitable (S₃) for mustard crop.

The soils of pedon P₃ (Maljinjava) and P₁₅ (Chotara) were moderately suitable (S₂) for sunflower as a new crop (Table 4.66). Thus, it can be inferred from the Table 4.66, the farmers around the Maljinjava (Pedon P₃) could be grow sesame, pearl millet, maize, wheat, pearl millet and mustard beside the existing crops of groundnut, sorghum, cotton and sugarcane. The soybean and sunflower as new crops can be moderately suitable (S₂) in the Maljinjava (P₃). The farmers of the Kareda village can adopt maize as a sweetcorn, soybean and mustard in addition of existing crops of groundnut, pearl millet, cotton, sorghum, sesame, sugarcane and wheat. The farmers around the Judavadali (Pedon P₁₀) could be grow maize as a sweetcorn and soybean (new crop). The farmers of Chotara village (Pedon P₁₅) could be adopt maize as a sweetcorn, soybean, sunflower, sugarcane and mustard in addition to the existing crops of groundnut, pearl millet, cotton, sesame, sorghum and wheat (Table 4.66).

LS-4 : Piedmont plain : The soils of Devali (Pedon P₇) which was middle portion of piedmont plain area were found highly suitable (S₁) for sorghum, sugarcane and mustard crops, moderately suitable (S₂) for groundnut, sesame, soybean, pearl millet and sunflower and marginally suitable (S₃) for horticultural crops. The soils of all the pedons (P₄, P₇ and P₁₁) were moderately suitable (S₂) for maize and wheat. The soils of pedon P₇ were moderately suitable (S₂) and pedon P₁₁ were marginally suitable (S₃) for cotton. The soils of pedons P₄ and P₁₁ were moderately suitable (S₂) for sorghum.

The farmers of Kajali village (Pedon P₄) could be introduce sorghum, maize as a sweetcorn and mustard as a new crops in addition to the existing crops of groundnut, wheat, black gram, green gram and vegetables. However, groundnut was found actually unsuitable but potentially suitable (N₁) in this region.

The farmers of Devali village (Pedon P₇) could be adopt cotton, sesame, sorghum, maize as a sweetcorn, soybean and sunflower as a new crops, and mustard in addition to the existing crops of groundnut, pearl millet, sugarcane and wheat.

The farmers of Delawada village (Pedon P₁₁) could be select sorghum, soybean (as a new crop), wheat and mustard in addition to the existing crops of groundnut, pearl millet, cotton, maize and banana (Table 4.66).

LS-5 : Coastal plain : The soils of pedon P₈, P₁₂ and P₁₆ were actually unsuitable but potentially suitable (N₁) for horticultural crops. The soils of pedon P₈ were moderately suitable (S₂) and pedon P₁₂ (Rampara) were marginally suitable (S₃) for groundnut and soybean. The soils of pedon P₈ and P₁₂ were moderately suitable (S₂) and pedon P₁₆ were marginally suitable (S₃) for cotton. The soils of all the pedons of this area were moderately suitable (S₂) for sorghum and wheat. While the soils of pedons P₈ and P₁₂ were moderately suitable for sugarcane, mustard, pearl millet and sunflower.

Thus, the farmers around the Chauhani Khan (Pedon P₈) could be grow cotton, sorghum, maize as a sweetcorn, mustard and soybean as well as sunflower as new crops in addition to existing crops like groundnut, wheat, sugarcane and pearl millet. While the farmers of Rampara village (Pedon P₁₂) could be adopt sorghum, maize as a sweetcorn, sugarcane, mustard and sunflower (new crop) in addition to existing crop like groundnut, pearl millet, cotton, wheat, sesame and banana.

The farmers of Kadiyali village (Pedon P₁₆) were continuously growing existing crops like groundnut, pearl millet, and sesame were actually not suitable but potentially suitable (N₁) class. The farmers of Kadiyali village, Tal. Jafraabad (Pedon P₁₆) of coastal area could be adopt cotton and soybean as marginally suitable (S₃) crops instead of groundnut, pearl millet, sesame as an existing crops which were actually unsuitable but potentially suitable class (N₁). However, the existing crops like

sorghum and wheat which were moderately suitable (S₂) class could be continued to be grown in this coastal area.

It is noted that the soils of southern Saurashtra might be sustainable for existing crops like castor, pigeonpea, black gram and banana, but due to lack of basic information available for computing suitability class, it was not possible to include in the text. However, the following crops might be suitable (suggested crop suitability options) in different land slopes of southern Saurashtra (Table 4.67).

Table 4.67 Suggested soil suitability for different crop options in different land slopes of southern Saurashtra.

Sr. No.	Land slopes	Suggested crops suitability options
1	Hill slope & Upper piedmont	Black gram and isabgul for field crops and lemon, custard apple and pineapple for horticultural crops.
2	Lower piedmont & Piedmont plain	Castor and pigeonpea as a field crops and hybrid aonla and orange as a horticultural crops.
3	Coastal plain	Safflower as a field crop and fig, sugarbeat as horticultural crops.

Thus, the above field crops and horticultural crops would be introduced as remunerative crops in the respective land slopes area of southern Saurashtra.

Thus, the above foregoing information provides guide lines for the appropriate management, effective use of natural resources to achieve the sustainable agricultural production in the soils of southern Saurashtra region.

CHAPTER – V

SUMMARY AND CONCLUSIONS

Four toposequences viz., Hiran, Shingoda, Machhundri and Rayadi were studied across the five land slopes namely hill slope, upper piedmont, lower piedmont, piedmont plain and coastal plain of the southern Saurashtra. The sixteen representative pedons in four toposequences across the land slopes were excavated to study the profile-site, morphological, mineralogical, physico-chemical properties, taxonomic classification of soils and to evaluate their sustainability and soil-site suitability for different important crops. Simultaneously, underground water samples from existing wells/tube wells in the vicinity of the pedons of the study area were also collected for laboratory analysis and characterization. The summary of the salient findings and conclusions are presented as follows.

5.1 MORPHOLOGICAL CHARACTERISTICS

The soils of the hill slope area were shallow, in upper piedmont area were moderately deep to deep, in lower piedmont area were deep and in piedmont plain and coastal plain area were very deep. The soils situated at higher elevations, i.e. hill side slope, upper and lower piedmont area have well developed over partially weathered trap, while those in the piedmont plain and coastal plain were developed from the deposition of alluvial parent materials over Gajbed and milliolitic lime stone. The soil colour exhibited varying from very dark grayish (10 YR 3/1 M) to brown (10 YR 5/3 M). The texture varied from loam to clayey, while structure was moderate to strong subangular blocky. Further, the soils produced slight to strong effervescence with dilute HCl. However, in some horizons of pedons becomes violent as one move down the depth.

5.2 SOIL MINERALOGICAL COMPOSITION

5.2.1 Mineralogical Composition of selected Toposequences :

The plagioclase was identified as a dominant mineral in sand and silt fractions in hill slope and upper piedmont while the quartz in the lower piedmont in Hiran and Rayadi toposequences. Both quartz and plagioclase were predominant minerals in sand and silt fractions in piedmont plain in Hiran toposequence, while the quartz was dominant in coastal plain of Rayadi toposequence. Smectite was the dominant mineral in clay fraction in all the land slopes of Hiran and Rayadi toposequences.

5.2.2 Mineralogical Composition of different Land Slopes

Sand mineralogy : The dominant sand minerals such as plagioclase > vermiculite > quartz were identified in hill slope, plagioclase “=” quartz > vermiculite in upper piedmont, quartz > calcite > vermiculite in lower piedmont and plagioclase > quartz > vermiculite in piedmont plain and coastal plain. In general, plagioclase and quartz were the dominant minerals in sand fractions in the soils of southern Saurashtra.

Silt mineralogy : The dominant silt minerals followed the sequence of plagioclase > quartz “=” augite > vermiculite, plagioclase > quartz > vermiculite in hill slopes and upper piedmont area, respectively. The dominant silt minerals in lower piedmont and piedmont plain were in the order of quartz > plagioclase > vermiculite, while those in the coastal plain followed the sequence of plagioclase > quartz > vermiculite = calcite.

Clay mineralogy : The dominant clay minerals followed the sequence of smectite > kaolinite = illite > mixed layer in hill slope while that of smectite > chlorite in upper piedmont. The smectite was the dominant mineral identified in lower piedmont and piedmont plain. The dominant clay minerals identified in coastal plain were in the order of smectite > chlorite.

5.3 SOIL PHYSICAL CHARACTERISTICS

5.3.1 Mechanical Composition and other Physical Characteristics

Toposequences : A decrease in clay content with the depth was observed in pedons P_2 and P_3 in Hiran toposequences, pedon P_{10} in Machhundri toposequence and pedon P_{13} in Rayadi toposequence. The soil texture varied from silty clay loam to silty clay, silty to silty clay loam, clay loam to clay and silty loam to silty clay in Hiran, Shingoda, Machhundri and Rayadi toposequences, respectively. The particle density was decreased along with depth in pedon P_1 in Hiran toposequences and P_{13} in Rayadi toposequence, while the reverse trend was observed in pedon P_9 in Machhundri toposequence. The bulk density was increased while pore space was decreased with depth in all the pedons of four toposequences. The expansion of soils ranged from 8.32 to 23.40, 4.87 to 17.60, 7.45 to 16.85 and 9.35 to 25.10 per cent in Hiran, Shingoda, Machhundri and Rayadi toposequences, respectively.

Land slopes : The total sand, silt and clay content varied from 20.56 to 51.57, 16.26 to 43.98 and 16.40 to 49.45 per cent with the mean values of 35.27, 32.44 and 32.29 per cent, respectively in the soils at the different land slopes of southern Saurashtra. The proportion of silt content in soil separate was increase with decreasing of an elevation. The proportion of clay content was observed in descending order viz., upper piedmont > lower piedmont > piedmont plain > hill slope > coastal plain. When traverse from West to East in upper piedmont area the proportion of fineness of soil particles were increased. About equal proportion of total sand, silt and clay fractions were observed in upper piedmont, lower piedmont and piedmont plain area. The particle density and bulk density varied from 2.40 to 2.55 and 1.28 to 1.57 Mg m^{-3} with the mean value of 2.46 and 1.41 Mg m^{-3} , respectively in different land slopes. The higher bulk density was observed from lower piedmont to the coastal plain may cause the mechanical impedance to the roots at the lower depth. While the soils of hill slope and upper piedmont area have to the low value of bulk density indicating easy penetration of roots to the lower depths. The pore space of soil were observed in the decreasing order of hill slope > upper piedmont > coastal

plain > piedmont plain > lower piedmont. whereas, the expansion of soils were found in the decreasing sequence of upper piedmont > lower piedmont > piedmont plain > coastal plain > hill slope, respectively, indicating the soils of upper piedmont were highly expansible as compared to other land slopes area.

5.3.2 Hydrological Characteristics

Toposequences : The MWHC was decreased with increasing depth throughout the profile in pedon P₃ of Hiran and upto in solum of the pedons P₅, P₆ and P₇ of Shingoda toposequences. The saturated hydraulic conductivity was recorded slow in pedons P₁ and P₂, P₅ to P₇ and P₁₃ of Hiran, Shingoda and Rayadi toposequences, respectively. While it was found very slow in pedons P₃, P₄, P₈, P₉ to P₁₂, and P₁₄ to P₁₆ of Hiran, Shingoda, Machhundri and Rayadi toposequences, respectively. The rate of saturated hydraulic conductivity was decreased with an increase the depth in pedons P₁ and P₂ of Hiran toposequence, while the reverse trend was observed in pedon P₃ of Hiran toposequence and P₆ and P₇ in Shingoda toposequence. However, the saturated hydraulic conductivity was noted almost absent in pedon P₁₆ of Rayadi toposequence due to dominance of smectite clay, high ESP and SAR. The infiltration rate was moderately slow in most of the pedons in all the toposequences except some pedons in Rayadi toposequence where it was found slow and very slow in pedon P₁₅ and P₁₆, respectively. The available water capacity (AWC) was increased along with the depth in the solum of the pedons P₁, P₂ and P₄ in Hiran toposequence, P₈ in Shingoda toposequence, P₁₂ in Machhundri toposequence and P₁₄ in Rayadi toposequence, while it was decreased with the depth throughout the profile in pedons P₅ and P₆ in Shingoda toposequence and P₁₃ in Rayadi toposequence. However, the vertical distribution of PAWC was found in a irregular manner along with the depth in all the pedons of four toposequences. The total water storage capacity (WSC) were increased with decreasing of an elevation in Hiran and Machhundri

toposequence. The PAWC/WSC ratio was increased with decrease in elevation in Shingoda toposequence only.

Land Slopes : The MWHC ranged from 32.77 to 53.15 per cent with the mean value of 43.62 per cent in the soils of different land slope. The saturated hydraulic conductivity and infiltration rate ranged from 0.00 to 0.30 and 0.09 to 1.23 (m hr^{-1}) with the mean of 0.10 and 0.70 cm hr^{-1} in the soils of different land slopes. The MWHC, saturated hydraulic conductivity and infiltration rate in the soils of different land slopes were in decreasing order of hill slope > upper piedmont > lower piedmont > piedmont plain > coastal plain. The moisture held at 0.03 (FC) and 1.5 MPa (PWP) were ranged from 0.30 to 0.54 and 0.11 to 0.22 $\text{m}^3 \text{m}^{-3}$ with the mean of 0.44 and 0.19 $\text{m}^3 \text{m}^{-3}$, respectively, in the soils of different land slopes. The AWC ranged between 0.19 and 0.33 $\text{m}^3 \text{m}^{-3}$ with the mean of 0.25 $\text{m}^3 \text{m}^{-3}$ in different land slopes. The AWC was identified in the decreasing order (0.33 to 0.19 $\text{m}^3 \text{m}^{-3}$) of piedmont plain > lower piedmont > coastal plain = upper piedmont > hill slope. The total PAWC and water storage capacity of the soils associated in different land slopes were ranged from 0.063 to 0.767 and 0.179 to 1.539 m ha^{-1} with the mean of 0.229 and 0.537 m ha^{-1} , respectively. The total PAWC and WSC were found in the decreasing order of piedmont plain > coastal plain > lower piedmont > upper piedmont > hill slope in the soils. The PAWC / WSC ratio were ranged from 0.346 to 0.498 with the mean of 0.407 indicating 41 per cent water is available for plant from total water storage capacity of the soils of 0.537 m ha^{-1} .

5.4 CHEMICAL CHARACTERISTICS

5.4.1 Important Chemical Characteristics

Toposequence : The soils of all the pedons of four toposequences were moderately alkaline in reaction except pedon P_1 (Sasan) from hill slope of Hiran toposequence which was slightly alkaline. The pH was decreased with increasing depth in pedons P_1 of Hiran, P_{10} of Machhundri and P_{13} , P_{15} and P_{16} in Rayadi toposequences, while reverse trend was observed in pedons P_5 , P_9

and P₁₄ in the soils of Shingoda, Machhundri and Rayadi toposequences, respectively. The EC was decreased with an increase in soil depth in pedon P₂ in Hiran and P₁₃ in Rayadi toposequences. The pH and EC were increased with decreasing an elevation in the soils of four toposequences. The organic carbon was decreased with increasing the depth in pedons P₁ and P₂ in Hiran toposequences, P₅ in Shingoda toposequence, P₉ and P₁₀ in Machhundri toposequence and P₁₃, P₁₄ and P₁₆ in Rayadi toposequence. However, the vertical distribution of organic carbon was irregular manner in pedons P₄, P₈, P₁₁ to P₁₂ and P₁₅ in Hiran, Shingoda, Machhundri and Rayadi toposequence, respectively indicating these soils corroborated their Fluventic nature. The CaCO₃ content increased with an increase in depth in pedons P₄ in Hiran toposequence, P₅ and P₆ in Shingoda toposequence, P₉ and P₁₀ in Machhundri toposequence and P₁₃, P₁₄ and P₁₆ in Rayadi toposequence, while the opposite trend was observed in pedons P₁, P₈, P₁₁ and P₁₅ in the soils of Hiran, Shingoda, Machhundri and Rayadi toposequences, respectively. The CEC was decreased with increasing the depth in pedons P₃ in Hiran toposequence, P₅ and P₆ in Shingoda toposequence, P₉ and P₁₀ in Machhundri toposequence and P₁₃, P₁₅ and P₁₆ in Rayadi toposequence, while the reverse trend was observed in pedon P₁ in Hiran toposequence. The CEC was decreased from the hill slope to piedmont plain with decrease of an elevation in Machhundri toposequence only. The proportion of exchangeable cations was found in the decreasing order of $\text{Ca}^{2+} > \text{Mg}^{2+} > \text{Na}^+ > \text{K}^+$ in the soils of all the pedons of four toposequences of southern Saurashtra. The ESP was increased with lower the depth in pedons P₃, P₈ and P₉ in Hiran, Shingoda and Machhundri toposequences, respectively, while the reverse trend was observed in ESP in the pedons P₁ and P₁₃ in Hiran and Rayadi toposequences, respectively. Slightly higher ESP content was assessed in pedons P₄ (13.73 to 18.13) in Hiran toposequence, P₆ (9.17 to 16.89) in Shingoda toposequence, P₁₁ and P₁₂ (9.78 to 17.00) of Machhundri toposequence and P₁₅ and P₁₆ (8.52 to 14.56) in Rayadi toposequence which project the possibility of an alkalinity hazard in the

near future and a caution to take adequate amending measures and drainage improvement efforts.

Land Slopes : The pH, EC, organic carbon and CaCO_3 ranged from 7.70 to 8.59, 0.18 to 1.06 dSm^{-1} , 0.12 to 0.93 per cent and 1.96 to 47.05 per cent with the overall mean of 8.13, 0.36 dSm^{-1} , 0.49 per cent and 17.24 percent, respectively, in the soils of different land slopes which indicate the soils were moderately alkaline in reaction, low in organic carbon status and highly calcareous in nature. The pH and EC were found in the order of hill slope < upper piedmont < lower piedmont < piedmont plain < coastal plain, which might be due to the continuous flow of bases and salts from higher to lower topography, respectively.

The organic carbon content of the soils was observed in the sequence of coastal plain < piedmont plain < upper piedmont < lower piedmont < hill slope. The CaCO_3 content was found in the order of hill slope < upper piedmont < piedmont plain < lower piedmont < coastal plain.

The CEC, BSP and ESP ranged from 16.11 to 28.80 $\text{cmol (p}^+) \text{ kg}^{-1}$, 90.15 to 93.50 and 6.38 to 14.90 with the mean of 24.39 $\text{cmol (p}^+) \text{ kg}^{-1}$, 92.47 and 9.67, respectively in the soils of different land slopes. The exchangeable Ca^{2+} was the dominant cation followed by Mg^{2+} , Na^+ and K^+ in the soils of different land slopes. The ESP was found in the sequence of upper piedmont < hill slope < lower piedmont < coastal plain < piedmont plain. The ESP of more than 10.00 from lower piedmont to coastal plain is a cause for an alarm situation and need to be closely monitored.

5.4.2 Composition of Saturation Extracts

Toposequences : The pHs decreased with increasing depth in pedons P_4 , P_5 , P_9 and P_{13} to P_{14} in the soils of Hiran, Shingoda, Machhundri and Rayadi toposequence, respectively. The ECe decreased with increasing depth in pedon P_4 in Hiran toposequence, while the reverse trend was observed in pedon P_{13} of Rayadi toposequence. The ECe was increased with decreasing elevation in the soils of Hiran and Rayadi toposequence.

The proportion of water soluble cations in saturation extracts observed in decreasing order of $Mg^{2+} > Ca^{2+} > Na^+ > K^+$ in pedons P_1 and P_2 and $Mg^{2+} > Na^+ > Ca^{2+} > K^+$ in P_3 and P_4 of Hiran toposequence, while that of $Mg^{2+} > Na^+ > Ca^{2+}$ in pedons P_5 , P_9 and P_{13} in Shingoda, Machhundri and Rayadi toposequences, respectively. However, the proportion of cations was identified in decreasing sequence of $Na^+ > Mg^{2+} > Ca^{2+} > K^+$ in pedons P_6 to P_8 , P_{10} to P_{12} and P_{14} to P_{16} in Shingoda, Machhundri and Rayadi toposequence, respectively. Among the anions, HCO_3^- was dominant followed by Cl^- in pedons P_5 to P_7 in Shingoda toposequence, P_9 to P_{12} in Machhundri toposequence and P_{13} in Rayadi toposequence, while the Cl^- was dominant followed by HCO_3^- in pedons P_1 to P_4 in Hiran toposequence, P_8 in Shingoda toposequence and P_{14} to P_{16} in Rayadi toposequence. The CO_3^{2-} was found absent in the saturation extracts in the soils of four toposequences. The SAR ranged from 0.71 to 4.81, 1.24 to 6.21, 0.75 to 3.53 and 9.69 to 29.25 in the soils of Hiran, Shingoda, Machhundri and Rayadi toposequence, respectively.

Land Slopes : The saturation percentage ranged from 34.17 to 63.21 with the mean of 51.38 in the soils of different land slopes. The pHs and ECe ranged from 7.79 to 8.16 and 0.75 to 3.66 dSm^{-1} with the mean of 7.96 and 1.32 dSm^{-1} , respectively, in the soils of different land slopes indicating the soils were generally non-sodic and non-saline. The distribution of pHs in different land slopes were in the decreasing order of coastal plain = piedmont plain > lower piedmont > upper piedmont > hill slope, while in case of ECe, it was in decreasing order of coastal plain > piedmont plain > lower piedmont > upper piedmont > hill slope which indicate that the distribution of pHs increase with decrease an elevation.

The water soluble Ca^{2+} , Mg^{2+} , Na^+ and K^+ ranged from 0.90 to 6.15, 2.37 to 19.33, 1.54 to 30.63 and 0.00 to 0.32 $me\ l^{-1}$ with the mean of 2.21, 5.11, 6.08 and 0.04 $me\ l^{-1}$, respectively in the soils of different land slopes. The proportion of water soluble Na^+ was dominant followed by Mg^{2+} , Ca^{2+} and K^+ . Among the water soluble anions, CO_3^{2-} was absent, while HCO_3^- and Cl^- ranged from 2.66 to 4.75 and 2.19 to 28.11 $me\ l^{-1}$ with the mean of 3.60 and 7.38 $me\ l^{-1}$, respectively, indicating the dominance of Cl^- followed by HCO_3^- . The distribution of HCO_3^- and Cl^- was increased with decreasing elevation from hill slope to piedmont plain and hill slope to coastal plain, respectively. The SAR was ranged from 0.88 to 17.85 with the mean of 3.32, which was increased gradually with decreasing elevation from hill slope to coastal plain.

5.5 AVAILABLE NUTRIENT STATUS

Toposequences : The soils of all the pedons of Hiran and Shingoda toposequences were low in available nitrogen, medium in available phosphorus and high in available potash, while the soils of Machhundri toposequence were low in available nitrogen and phosphorus and medium in available potash. Whereas, the soils of all the pedons of Rayadi toposequence were showed low in available nitrogen, phosphorus and potash. The soils of all the pedons of Hiran, Shingoda, Machhundri and Rayadi toposequences have high status of available Fe, Mn, Zn and Cu, except available Zn in Rayadi toposequence where it was in medium status.

Land Slopes : The soils of the Western part of hill slope (Pedon P₁, Sasan (Gir)) contained high status of available nitrogen and potash as compared to Eastern part (Pedon P₁₃, Dedan). The soils of different land slopes across the toposequences of southern Saurashtra were low in available nitrogen and phosphorus, medium in available potash and high in available Fe, Mn, Zn and Cu. The available N was decreased with decreasing elevation, while the opposite trend was observed in case of available phosphorus. The available potash was decreased from the piedmont plain to hill slope. The available Fe and Mn decreased with decrease in elevation from hill slope to piedmont plain.

5.6 SOIL TAXONOMIC CLASSIFICATION

According to the criteria of soil Taxonomy (Soil Survey Staff, 1998). The soils of the pedons P₁ and P₁₃ from the hill slopes and P₂, P₉ and P₁₄ from the upper piedmont were classified as Lithic Ustorthents at sub group level. Whereas P₆ from the lower piedmont belonged to Typic Ustorthents. The soils of pedons P₅ from upper piedmont and P₁₀ from the lower piedmont were placed in Typic Ustochrepts whereas P₃ and P₁₅ from lower piedmont were classified as Vertic Ustochrepts (Now, Haplustepts modified from Ustochrepts as per the Soil Survey Staff, 2003). The soils of pedon P₇ from the piedmont plain were placed in Typic Ustropepts (Now, Haplustepts isohyperthermic modified from Ustopepts as per Soil Survey Staff, 2003). The soils of pedon P₁₁ from piedmont plain and P₈ and P₁₂ from the coastal plain were placed in Fluventic Ustropepts. The soils of pedon P₄ from the piedmont plain and P₁₆ from the coastal plain were classified as Fluventic Calcistepes and Calcic Ustropepts, respectively.

5.7 CHARACTERISTICS OF WATER RESOURCES

Toposequences : The pH of water for wells/tube wells for irrigation increased with decreasing elevation in the different toposequences except Rayadi toposequence. Similarly, the EC also increased with decrease of elevation in all the pedons of four toposequences. The proportion of water soluble cations was detected in order of $\text{Ca}^{2+} > \text{Mg}^{2+} > \text{Na}^+ > \text{K}^+$, $\text{Mg}^{2+} > \text{Ca}^{2+} > \text{Na}^+ > \text{K}^+$, $\text{Na}^+ > \text{Mg}^{2+} > \text{Ca}^{2+} > \text{K}^+$, and $\text{Ca}^{2+} > \text{Na}^+ > \text{Mg}^{2+} > \text{K}^+$ in Hiran,

Shingoda, Machhundri and Rayadi toposequences, respectively. Among the anions, Cl^- was dominant followed by HCO_3^- in water samples adjoining to pedons P_4 of Hiran toposequence, P_6 , P_7 and P_8 of Shingoda toposequence, P_{11} and P_{12} of Machhundri toposequence and P_{14} , P_{15} and P_{16} of Rayadi toposequence. While the HCO_3^- was dominant followed by Cl^- in water samples from wells/tube wells adjoining to pedons P_1 , P_2 and P_3 of Hiran toposequence, P_5 of Shingoda toposequence, P_9 and P_{10} of Machhundri toposequence and P_{13} of Rayadi toposequence. The concentration of Na^+ increased with increase in EC in Hiran toposequence. The CO_3^{2-} and Cl^- increased with decreasing elevation in Shingoda toposequence. The SSP increased with decrease in elevation from higher topography to piedmont plain in Hiran and Machhundri toposequence, while, the SAR also increased with increasing EC in Hiran toposequence. The SAR values were below 10 in all water samples of four toposequences except water samples No. 35 of Machhundri toposequence where it was noted of 14.42 and a cause for alarm.

Land Slope : In general, the depth of water table ranged from 5 to 26 m with mean of 17 m. There was an inverse relationship between depth of water table and elevation. The pH and EC of irrigation water increased with decreasing elevation. It was interesting to note that the pH of underground water increased with increase in EC. The SSP and SAR increased with decreasing elevation from hill slope to coastal plain. The RSC was found absent in all the 48 collected water samples.

5.8 CLIMATIC CONDITION OF SOUTHERN SAURASHTRA

The rainfall varies from low to very high in different toposequences and land slopes. The hyperthermic temperature regime was identified in hill slope to lower piedmont, while the isohyperthermic temperature regime was found in piedmont plain and coastal plain of southern Saurashtra.

5.9 NATURAL SOIL, WATER AND CLIMATIC CONSTRAINTS

5.9.1 Constraints Analysis for Soil Sustainability

In general, the soils of pedon P_1 (Sasan) were placed in sustainable class S_2 , while the soils associated with the pedons P_2 to P_8 , P_{10} to P_{13} and P_{15} were placed in sustainable with high input class S_3 . Whereas, the soils of pedons P_9 , P_{14} and P_{16} were placed in sustainable with alternate land use class S_4 .

The general mean score of weight factors of four toposequences was found in order of Hiran (26) < Shingoda (27) < Machhundri (28) < Rayadi (29) indicating the soils constraints / limitations were increase from west to east direction in the soils of southern Saurashtra.

In addition this, the general mean score of weight factors of five land slopes was found in the order of hill slope (24) < piedmont plain (26) < upper piedmont (29), lower piedmont (29) and coastal plain (29) indicating the soils of hill slope and piedmont plain area were facing less soil constraints as compared to upper piedmont, lower piedmont and coastal plain area. The remedial measures were discussed to overcome the soil and water constraints in different land slopes for soil sustainability, productivity and soil health.

5.9.2 Water Resource Constraints

The high runoff, high erosion and very deep water table were the moderate water resource constraints in hill slopes, while the moderate runoff, moderate availability of underground water and deep water table were the major constraints identified in the upper piedmont area. The moderately saline water was the major water constraint observed in the eastern part of piedmont plain area. While the temporary water logging, saline and sodic water and seawater intrusion were the major constraints observed in coastal plain area of southern Saurashtra.

5.9.3 Climatic Constraints

The inadequate and uneven distribution of rainfall, aberrant weather situation, prolonged dry spell and warm winter for rabi crops were the major climatic constraints observed in the soils of southern Saurashtra. When traverse from western to eastern side in hill slope of southern Saurashtra, the rainfall intensity gradually decreased. The high relative humidity for sesame and cotton crops was the major climatic constraint identified in coastal plain area.

5.10 EVALUATION OF SOIL AND WATER RESOURCES

5.10.1 Evaluation of Soil Resources

The evaluation of soil resource plays an important role in soil sustainability and environmental quality. The mean reserve water of 0.136, 0.178, 0.249, 0.518 and 0.469 m ha⁻¹ was found in the soils of hill slope, upper piedmont, lower piedmont, piedmont plain and coastal plain area, respectively. The overall average reserve water in the soils of southern Saurashtra region was found to be 0.308 m ha⁻¹. The mean water balance was found to be +0.653, +0.588, +0.276, -0.323 and -0.204 m ha⁻¹, in the soils of hill slope, upper piedmont, lower piedmont, piedmont plain and coastal plain area, respectively. The overall water balance of the soils of southern Saurashtra was +0.253 m ha⁻¹. The positive water balance in hill slope area indicating the possibilities of runoff water which can be collected in surface resourvier / farm pond and it can be utilize as life saving irrigation. While the positive water balance in upper piedmont and lower piedmont area indicating the possibilities of percolation of water (when intensity of rainfall < I.R.) which can recharge in the ground water. The negative water balance observed in piedmont plain area shows that whichever the quantity of rain water is available will be utilized in saturating the profile and no additional water will be available for its alternate uses. The negative water balance in coastal region lead to ground water depletion every year and ingress of sea water, which is the main cause for the poor quality of water as observed in coastal area.

5.10.2 Evaluation and Suitability of Underground Water Resource

Based on the semi-logarithmic USSL diagram, out of 48 well/bore wells water samples, 16.7, 50.0 and 33.3 per cent samples were placed in medium (C₂), high (C₃) and very high (C₄) salinity water class, respectively. The well/tube well associated with the pedons P₄, P₇, P₈, P₁₁, P₁₂ and P₁₆ of piedmont plain / coastal plain area of southern Saurashtra have very high salinity water (C₄) due to sea water encroachment near the seacoast.

As per the SAR value only, out of 48 well/tube well water samples, 97.9 per cent (47 samples) samples have SAR value < 10 irrespective of salinity, which can be placed in low sodicity class (S₁). The per cent distribution of underground water for irrigation of southern Saurashtra based on semi-logarithmic USSL diagram, 16.6, 47.9, 2.1, 6.3, 16.7, 8.3 and 2.1 per cent were placed in C₂S₁, C₃S₁, C₃S₂, C₄S₁, C₄S₂, C₄S₃ and C₄S₄ water quality class, indicating the majority of water samples fall in C₃S₁ class. The strategies for its suitability and management were discussed in the text.

5.10.3 Soil-site Suitability Evaluation for Different Crops

The crop suitability evaluation of soils of different toposequences across the land slopes in southern Saurashtra were found as under :

Hiran toposequence : The soils of pedon P₂ (Borvav) from the upper piedmont were highly suitable (S₁) for sorghum only. The soils of pedon P₁ (Sasan) from hill slope were moderately suitable (S₂) for mustard and pearl millet whereas the P₂ (Borvav) from upper piedmont were moderately suitable for groundnut, cotton, maize, wheat, mustard and pearl millet. The soils of pedon P₃ (Maljinjava) from lower piedmont were moderately suitable for groundnut, sesame, sorghum, maize, soybean, wheat, sugarcane, mustard and sunflower whereas the P₄ (Kajali) from piedmont plain were moderately suitable for sorghum, maize, wheat and mustard.

Shingoda toposequence : The soils of pedon P₇ (Devali) from piedmont plain were highly suitable (S₁) for sorghum, sugarcane and mustard. The soils of pedon P₅ (Jamwala) from upper piedmont were found better (S₂ class) for groundnut, cotton, sesame, sorghum, maize, soybean, wheat, sugarcane, mustard and pearl millet, whereas P₆ (Kareda) from lower piedmont were better for groundnut, sorghum, maize, soybean, wheat, sugarcane, mustard and pearl millet. The soils of pedon P₇ (Devali) from piedmont plain were found better for groundnut, cotton, sesame, maize, soybean, wheat pearl millet and sunflower whereas P₈ (Chauhani Khan) from coastal plain for groundnut, cotton, sorghum, maize, soybean, wheat, sugarcane, mustard, pearl millet and sunflower.

Machhundri toposequence : The soils of pedon P₉ (Fatsar) over upper piedmont were moderately suitable for crops like groundnut, cotton, sorghum, maize, wheat, sorghum, mustard and pearl millet, whereas soils of P₁₀ (Judavadali) over lower piedmont were moderately suitable for crops like groundnut, cotton, sorghum, maize, soybean, wheat, sugarcane and pearl millet. The soils of pedon P₁₁ (Delawada) from piedmont plain were moderately suitable for crops like sorghum, maize, soybean, wheat and mustard, whereas soils in P₁₂ (Rampara) from coastal plain were moderately suitable for crops like sorghum, maize, wheat, sugarcane, mustard, pearl millet and sunflower.

Rayadi toposequence : The soils in pedon P₁₃ (Dedan) from hill slope for pearl millet, the soils of pedon P₁₄ (Dedan) from the upper piedmont sorghum, maize, mustard and pearl millet, the soils of P₁₅ (Chotara) from the lower piedmont for groundnut, cotton, sesame, sorghum, maize, soybean, wheat, sugarcane, mustard and sunflower and P₁₆ (Kadiyali) from the costal plain for sorghum and wheat were moderately suitable (S₂) in this toposequence.

CONCLUSION :

From the above discussion, it can be concluded that the soils of southern Saurashtra were shallow to very deep, with a very dark grayish to brown in colour, clay loam to clayey in texture and moderate to strong subangular blocky structure. Smectite was the dominant mineral in clay fractions whereas plagioclase and quartz were dominant in silt and sand fraction. The soils were calcareous in nature (CaCO₃, 1.96 to 47.05 per cent), moderately alkaline in reaction, non-sodic and non-saline except pedon P₆ (Kadiyali). The

soils were low in available nitrogen and P_2O_5 , medium in available K_2O and high in available Fe, Mn, Zn and Cu. The infiltration rate and saturated hydraulic conductivity of the soils were moderate and slow, respectively except pedon P₁₆. The hydrological properties have been discussed thoroughly. Taxonomically the Ustorthents, Ustochrepts (Haplustepts modified from Ustochrepts), Ustropepts (Haplustepts iso-hyperthermic modified from Ustropepts), Calciustepts and Ustifluvents great groups have been identified.

Only 2.1 per cent underground water samples are of poor quality class (C₄S₄), which generally not suitable for irrigation. The soil, water and climatic constraints have been identified and evaluated accordingly. The reserve water and water balance in respect to land slopes have been worked out. Considering the present land use, soil and climatic information, the soil-site suitability evaluation for different crops have been suggested.

FUTURE RESEARCH NEEDS :

The following suggestions are made for future line of research in the soils of southern Saurashtra.

- 1) Conducting soil series based fertility trials for confirmation and adoption of suitable agronomic technology by farmers.
- 2) Field experiment have to be conducted to verify adoptability, suitability and choice of the new crops/varieties in each soil series.
- 3) Clay mineralogical information may be helpful to characterize the clay minerals according soil series.
- 4) Use of remote sensing techniques and soil hydraulic properties in predicting soil water storage and length of growing period over large areas hold great promise.
- 5) An integrated approach is needed to study the inter relationship of soil physical properties, water and fertilizer application amounts and methods for the targeted yield, plant and nutrient, root growth and water extraction by plants for an efficient use of limited water resources to sustain crop productivity and profitability.
- 6) Evaluation of land qualities and soil-site suitability of different crops in the all the soil series of the Saurashtra region is highly needed.

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APPENDIX – I
Monthwise maximum, minimum and mean temperature recorded from
observations nearest to study sites

Month/ Location	Pedons P ₁ to P ₁₂ of Junagadh district			Pedons P ₁₃ to P ₁₆ of Amreli district			Mean temp. of Junagadh & Amreli (°C)
	Max. Temp. (°C)	Min. Temp. (°C)	Mean Temp. (°C)	Max. Temp. (°C)	Min. Temp. (°C)	Mean Temp. (°C)	
January	29.8	11.0	20.4	28.1	11.2	19.7	20.1
February	32.1	13.4	22.8	31.8	13.8	22.8	22.8
March	36.0	18.4	27.2	36.6	19.1	27.9	27.6
April	38.7	21.9	30.3	38.8	22.3	30.6	30.5
May	39.3	25.3	32.2	40.6	25.3	33.0	32.6
June	36.3	26.6	31.5	37.3	26.2	31.8	31.7
July	29.1	23.4	26.3	33.0	25.6	29.3	27.8
August	30.8	24.6	27.7	31.6	24.6	28.1	27.9
September	32.4	23.5	28.0	31.9	23.3	27.5	27.8
October	35.7	20.9	28.3	35.2	21.8	28.5	28.4
November	34.0	16.6	25.1	33.2	17.4	25.3	25.2
December	30.9	12.1	21.5	30.1	13.6	21.9	21.7

Nearest observatory at
(2000)
Junagadh

Source: SWMR & NBSS & LUP
& Amreli

APPENDIX – II

Monthwise climatic water balance of the studied area of southern Saurashtra.

(a) Sasan (Gir) (P_1), Borvav (P_2), Jamwala (Gir) (P_5), Fatsar (P_9), Judavdali (P_{10}) and Dedan (P_{13} & P_{14}).

[illegible]

(b) Maljinjava (P_3), Kajali (P_4), Chauhani Khan (P_8), Delawada (P_{11}) and Rampara (P_{12}).

[illegible]

(c) Devali (P₇) and Kareda (P₆) and Devali (P₇).

Param-eters	Jan	Feb	Mar	April	May	June	July	Aug	Sep	Oct	Nov	Dec	Total
P	0.00	0.00	1.00	0.00	0.30	156.00	402.00	100.00	93.00	17.00	0.00	0.50	769.80
PE	115.30	124.00	167.50	181.30	183.40	159.60	123.10	114.40	128.30	148.90	126.00	113.20	1685.00
P-PE	-115.30	-124.00	-166.50	-181.30	-183.10	-3.60	278.90	-14.40	-35.30	-131.90	-126.00	-112.70	-915.20
APWL	-535.60	-659.60	-826.10	-1007.40	-1190.50	-1194.10	0.00	-14.40	-49.70	-181.60	307.60	-420.30	-6386.90
STOR	4.22	1.85	0.61	0.18	0.05	0.05	150.00	136.27	107.69	44.70	19.30	9.10	474.02
S	-4.88	-2.37	-1.24	-0.43	-0.13	0.00	149.95	-13.73	-28.58	-62.99	-25.40	-10.20	0.00
AE	4.88	2.37	2.24	0.43	0.43	156.00	123.10	113.73	121.58	79.99	25.40	10.70	640.85
WD	110.42	121.63	165.26	180.87	182.97	3.60	0.00	0.67	6.72	68.91	100.60	102.50	1044.15
WS	0.00	0.00	0.00	0.00	0.00	0.00	128.95	0.00	0.00	0.00	0.00	0.00	128.95
AWC	150	Nearest observatory : Kodinar											
LGP	90-105												

(d) Chotara (P₁₄) and Kadiyali (P₁₆)

Param-eters	Jan	Feb	Mar	April	May	June	July	Aug	Sep	Oct	Nov	Dec	Total
			Nearest observatory : Maliya										
P	1.00	1.10	1.00	3.70	5.70	115.90	218.70	111.70	94.00	28.50	6.30	1.20	588.80
PE	115.30	124.00	167.50	181.30	183.40	159.60	123.10	114.40	128.30	148.90	126.00	113.20	1685.00
P-PE	-114.30	-122.90	-166.50	-177.60	-177.70	-43.70	95.60	-2.70	-34.30	-120.40	-119.70	-112.00	-1096.20
APWL	-503.40	-626.30	-792.80	-970.40	-1148.10	-1191.80	0.00	-2.70	-37.00	-157.40	-277.10	-389.10	-6096.10
STOR	0.00	0.00	0.00	0.00	0.00	0.00	50.00	47.37	23.86	2.15	0.20	0.02	123.60
S	-0.02	0.00	0.00	0.00	0.00	0.00	50.00	-2.63	-23.51	-21.71	-1.95	-0.18	0.00
AE	1.02	1.10	1.00	3.70	5.70	115.90	123.10	114.33	117.51	50.21	8.25	1.38	543.20
WD	114.28	122.90	166.50	177.60	177.70	43.70	0.00	0.07	10.79	98.69	117.75	111.82	1141.80
WS	0.00	0.00	0.00	0.00	0.00	0.00	45.60	0.00	0.00	0.00	0.00	0.00	45.60
AWC	50	Nearest observatory : Mahuva											
LGP	90-105												

Source : SWMR and NBSS & LUP (2000)

** P = Precipitation (Rainfall) (mm); PE = Potential evaporation (mm); APWL = Accumulative potential water loss (mm);
 STOR= Actual storage of soil moisture (mm); S=Change in storage (mm); WD=Water deficit (mm); WS=Water surplus (mm)
 AWC = Available water capacity (mm); LGP = Length of growing period (days) AE=Actual evapotranspiration (mm)

APPENDIX – III

Common vegetation occurring in study area.

Sr. No.	Local name	Botanical name
1	Deshi Baval	<u>Acaccia nilotica</u>
2	Limdo, Neem	<i>Azadirachta indica</i>
3	Tad	<i>Borassus flabellifer</i>
4	Khakharo, Palas	<i>Butea monosperma</i>
5	Gunda	<i>Gordia dichotoma</i>
6	Timru	<i>Diopyros melanoxydon</i>
7	Papal, Vad	<i>Ficus species (Benghalensis religiosa)</i>
8	Khijado	<i>Prasopis juliflora</i>
9	Amli	<i>Tamarindus indica</i>
10	Sag	<i>Tectona grandis</i>
11	Coconut	<i>Coconus nucefera</i>
12	Bor, Bordi	<i>Zizyphus mauritiana</i>
13	Mango	<i>Manjifera indica</i>
14	Akado	<i>Calotropis gigantean</i>
15	Karmada	<i>Carissa carandas</i>
16	Aval	<i>Cassia auriculata</i>
17	Vikro	<i>Gymnosporia Montana</i>
18	Chaniber	<i>Zizyphus nummularia</i>
19	Dharo	<i>Cynoden dectylon</i>
20	Zinjavo	<i>Dichanthium annulatum</i>
21	Chidho	<i>Cyperus rotundus L.</i>
22	Cactus	<i>Agava arabica</i>

APPENDIX - IV
Taxonomic classification of the soils of different toposequences of southern Saurashtra

Pedon No.	Location	Order	Sub order	Great group	Sub group	Soil family
1	2	3	4	5	6	7
T₁	Hiran toposequence					
P ₁	Sasan (Gir) Tal: Talala	Entisols	Orthents	Ustorthents	Lithic Ustorthents	Fine loamy, (calcareous), hyperthermic of Lithic Ustorthents
P ₂	Borvav (Gir) Tal: Talala	Entisols	Orthents	Ustorthents	Lithic Ustorthents	Fine, mixed (calcareous), hyperthermic of Lithic Ustorthents
P ₃	Mavjinjava Tal: Talala	Inceptisols	Ochrepts	Ustochrepts*	Vertic Ustochrepts*	Fine, smectitic (calcareous), hyperthermic of Vertic Ustochrepts*
P ₄	Kajali Tal: Talala	Inceptisols	Ustepts	Calciustepts	Fluventic Calciustepts	Fine, smectitic (calcareous), isohyperthermic of Fluventic Calciustepts
T₂	Shingoda toposequence					
P ₅	Jamwala (Gir) Tal: Una	Inceptisols	Ochrepts	Ustochrepts*	Typic Ustochrepts*	Fine loamy, smectitic (calcareous), hyperthermic of Typic Ustochrepts*
P ₆	Kareda Tal: Kodinar	Entisols	Orthents	Ustorthents	Typic Ustorthents	Coarse loamy, smectitic (calcareous), hyperthermic of Typic Ustorthents
P ₇	Davali Tal: Kodinar	Inceptisols	Opepts	Ustropepts**	Typic Ustropepts**	Fine loamy, smectitic (calcareous), isohyperthermic of Typic Ustropepts**

1	2	3	4	5	6	7
P ₈	Chauhani khan Tal: Kodinar	Inceptisols	Opepts	Ustropepts**	Fluventic Ustropepts**	Fine loamy, smectitic (calcareous), isohyperthermic of Fluventic Ustropepts**
T₃	Machhundri toposequence					
P ₉	Fatsar Tal: Una	Entisols	Orthents	Ustrothents	Lithic Ustorthents	Fine, clayey, smectitic (calcareous), hyperthermic of Lithic Ustorthents
P ₁₀	Judavadali Tal: Una	Inceptisols	Ochrepts	Ustochrepts*	Typic Ustochrepts*	Fine loamy, smectitic (calcareous) hyperthermic of Typic Ustochrepts*
P ₁₁	Delawada Tal: Una	Inceptisols	Opepts	Ustropepts**	Fluventic Ustropepts**	Fine loamy, smectitic (calcareous) isohyperthermic of Fluventic Ustropepts**
P ₁₂	Rampara Tal: Una	Inceptisols	Opepts	Ustropepts**	Fluventic Ustropepts**	Fine loamy, smectitic (calcareous) isohyperthermic of Fluventic Ustropepts**
T₄	Rayadi toposequence					
P ₁₃	Dedan Tal: Khamba	Entisols	Orthents	Ustrothents	Lithic Ustorthents	Fine loamy, skeletal, mixed, hyperthermic of Lithic Ustorthents
P ₁₄	Dedan Tal: Khamba	Entisols	Orthents	Ustrothents	Lithic Ustorthents	Fine, clayey, smectitic (calcareous), hyperthermic of Lithic Ustorthents
P ₁₅	Chotara Tal: Rajula	Inceptisols	Ochrepts	Ustochrepts*	Vertic Ustochrepts*	Fine, smectitic (calcareous) hyperthermic of Vertic Ustochrepts*
P ₁₆	Kadiyali Tal: Jafrabad	Inceptisols	Opepts	Ustropepts**	Calcic Ustropepts**	Fine loamy, smectitic (calcareous) isophperthermic of Calcic Ustropepts**

* Haplustepts and ** Haplustepts iso-hyperthermic modified from Ustochrepts and Ustropepts, respectively. (Soil Survey Staff, 2003)

APPENDIX – V

Critical levels of key indicators for soil constraints evaluation and soil sustainability according to Lal (1994)

Limitations	Weighting factors	Effective rooting depths (cm)	Bulk density (Mg/m ³)	Consistency	Texture	Available water capacity (cm/m)	Structure	Sat. hydraulic conductivity (cm hr ⁻¹)
None	1	> 150	< 1.2	Loose	Loam	> 30	Strong sub angular blocky to crumb	> 2.0
Slight	2	100-150	1.2-1.3	Very friable	Silt-loam, silt, silty clay loam	20-30	Sub angular blocky	0.2-2.0
Moderate	3	50-100	1.3-1.4	Friable	Clay loam, sandy loam	8-20	Moderate sub angular blocky	0.02-0.2
Severe	4	25-50	1.4-1.5	Hard	Silty clay, loamy sand	2-8	Weak sub angular blocky	0.002-0.02
Extreme	5	< 25	> 1.5	Hard to extremely hard	Clay, sand	< 2	Massive or single grain	< 0.002

Limitation	Weighting factors	pH	EC (dSm ⁻¹)	Org. C. (%)	ESP	SAR
None	1	6.0 - 7.0	< 3	5-10	< 15	< 10
Slight	2	7.0 - 7.4	3-5	3-5	15-30	10-12
Moderate	3	7.4 - 7.8	5-7	1-3	30-50	12-15
Severe	4	7.8 - 8.2	7-10	0.5-1.0	50-70	15-20
Extreme	5	> 8.2	> 10	< 0.5	> 70	> 20

Sustainability	Cumulative rating index
S ₁ : Highly sustainable	< 20
S ₂ : Sustainable	20 – 25
S ₃ : Sustainable with high input	25 – 30
S ₄ : Sustainable with alternate land use	30 – 40
S ₅ : Unsustainable	> 40

APPENDIX – VI
Climatic and soil-site sustainability criteria.

(a) Horticultural crops (Sys *et al.*, 1991; FAO, 1976 and Natarajan and Gajbe, 1983)

Land characteristics	Rating class*				
	S ₁	S ₂	S ₃	N ₁	N ₂
1	2	3	4	5	6
Rainfall (mm)	Greater than 1000	800-1000	600-800	400-600	Less than 600
Land slope (%)	Level to gently sloping	Undulating	Steep, rolling	Very deep	Very very deep
Erosion	Very slighter	Very slight	Moderate	Gully erosion	Gully erosion
Drainage	Well	Moderately well	Excessive	Imperfectly	Poor
Flooding	Very low	Low	Moderate	High	Very high
Stoniness (%)	Less than 1	1-3	3-15	60-90	Greater than 90
Soil depth (cm)	Very deep	Moderately deep to deep	Shallow	Very shallow	Very shallow
Texture	Fine loamy, coarse loamy	Loamy skeletal	Clayey sand	Fragmental	Fragmental
pH	5.5 – 7.5	7.5-8.0	8.0-8.5	8.5-9.0	Greater than 9
EC (dSm ⁻¹)	Less than 2	2-3	3-4	Greater than 4	--
CEC(cmol(p+) kg ⁻¹)	High	Medium	Low	Very low	--
Organic carbon (%)	High	Medium	Low	Very low	--

* S₁ – Highly suitable, S₂ – Moderately suitable, S₃–Marginally suitable

N₁–Actually unsuitable but potentially suitable, N₂–Actually and potentially unsuitable

(b) Groundnut (FAO, 1976 & Sys *et al.*, 1991)

1	2	3	4	5	6
Climatic (C)					
Precipitation (mm)	700-400	400-300	300-200	--	< 200
Mean precipitation of I st month (mm)	165-70	70-60	60-50	--	< 50
II nd month (mm)	175-100	100-75	75-50	--	< 50
III rd month (mm)	175-100	100-75	75-50	--	< 50
IV month (mm)	145-275	275-400	400-475	--	> 475
Mean temperature (°C)	24-18	18-14	14-10	--	< 10
Mean maximum temperature of growing cycle (°C)	35-38	38-40	40-42	--	> 40
Mean minimum temperature of growing cycle (°C)	19-14	14-10	10-6	--	< 6
Topography (t)					
Slope (%)	0-2	2-4	4-6	--	> 6
Wetness (w)					
Drainage	Good	Moderate	Imperfect	Poor drain-ability	Poor not drainable
Physical characteristics (s)					
Texture / structure	L	c<60s	c>60v	--	cm, sicm
Coarse fragments (%)	0-3	3-15	15-35	--	> 35
Soil depth (cm)	> 75	75-50	50-25	--	< 25

CaCO ₃ (%)	0-25	25-35	35-50		
Gypsum (%)	0-4	4-10	10-20		
1	2	3	4	5	6
Soil fertility characteristics (f)					
CEC (cmol (P ⁺) kg ⁻¹)	> 16	> 16(-)	C16(+)	--	--
B.S. (%)	35	< 35	--	--	--
pH, H ₂ O	6.8-7.5	7.5-8.0	8.0-8.2	--	--
Organic carbon (%)	> 0.8	0.8-0.4	< 0.4	--	--
Salinity alkalinity (n)					
ECe (dSm ⁻¹)	0-4	4-6	6-8	8-12	> 12
ESP (%)	0-10	10-15	15-20	--	> 20

(c) Cotton (Sys *et al.*, 1991 & NBSS & LUP, 1994)

1	2	3	4	5	6
Climatic characteristics					
Total rainfall (mm)	700-1050	550-700	< 550	--	--
Rainfall growing season (mm)	600-950	450-600	< 450	--	--
Rainfall during critical period (soil development)	100-120	-	-	--	--
Length growing period (days)	> 135	120-135	< 120	--	--
Mean temp. growing season (°C)	22.32	> 32	-	--	--
Mean max. temp grow. Season (°C)	-	-	> 36	--	--
Mean min. temp grow. Season (°C)	-	-	< 19	-	-
Mean R.H. in growing season	60-90	-	< 50	-	-
Length of dry spells (weeks)					-
July (beginning)	< 1	-	> 1	-	-
August (end)	< 2	-	> 2	-	-
Site characteristics					
Slope (%)	< 3	3-5	> 5	-	-
Erosion	e ₁	e ₂	e ₃	-	-
Drainage	Well to mod.	Imperfect	Poor & excessive	-	-
Water stagnation (days AWC (mm/m))	< 2	2-3	3-5	> 5	-
Stoniness (surface)	> 150	100-150	50-100	-	-
Soil characteristics texture	< 15	15-40	> 40	-	-
Texture	sic, sicl, c, cl	sci, sicl, l, sc	si	s, ls	-
Coarse fragments (vol. %)					
within 50 cm	< 15	15-35	> 35	-	-
Below 50 cm	5-35	35-50	> 50	-	-
Depth (cm)	> 75	50-75	25-50	< 25	-
CaCO ₃ (%)	< 10	10-20	> 20	-	-
Gypsum (%)	-	-	-	-	-
Soil fertility					
CEC (cmol (p ⁺) kg ⁻¹)	> 20	< 20	-	-	-
BS (%)	> 50	35-50	<35	-	-
O.M. (%) (0-15 cm)	> 0.75	0.5-0.75	< 0.50	-	-
ECe (dSm ⁻¹)	< 2	2-4	> 4	-	-
ESP	< 10	10-15	> 15	-	-
PH (1:2.5)	8.0-8.5	8.5-9.5	> 9.0	-	-

Appendix-VI Contd...

(d) Sesame (FAO, 1976 & Sys *et al.*, 1991)

1	2	3	4	5	6
Climatic (c)					
Precipitation (mm)					
I st month	100-300	300-475	> 475	-	-
II nd month	175-100	100-50	50-25	-	< 25
III rd month	< 200	> 200	-	-	-
Mean maximum temperature (°C)	35-38	38-40	40-42	-	> 42
Mean maximum temperature (°C)	19-16	16-14	14-12	-	> 12
Topography (t)					
Slope (%)	0-2	2-4	4-6	-	> 6
Wetness (w)					
Drainage	Well to good	Imperfect	Poor & aenc	Poor but drainable	Poor not drainable
Physical characteristics					
Texture / structure	1	Cs, co	C > 50 s	-	Cm , sicm
Coarse fragments (%)	0-15	15-35	35-55	-	> 55
Soil depth (cm)	> 75	75-50	50-35	-	< 30
CaCO ₃	-	-	-	-	-
Gypsum (%)	-	-	-	-	-
Soil fertility characteristics					
CEC cmol (p ⁺) kg ⁻¹	> 16	< 16 (+)	< 16(+)	-	-
B.S. (%)	> 50	50-55	< 35	-	-
pH, H ₂ O	6.3-7.0	7.0-7.5	7.5 8.2	-	> 8.2
Organic carbon (%)	> 1.2	1.2-0.3	< 0.8	-	-
Salinity/alkalinity (n)					
ECe (dSm ⁻¹)	0-4	4-6	6-5	-	> 8

(e) Sorghum (Sys, *et al*, 1991 NBSS and LUP, 1994)

1	2	3	4	5	6
Climatic Characteristics					
Total rainfall (mm)	750-650	650-550	450-550	< 450	-
Rainfall growing season (mm)	700-500	400-500	300-400	< 300	-
Rainfall during critical period	-	-	-	-	-
Length growing period (days)	150-105	105-90	< 90	-	-
Mean temp. growing season (°C)	32-24	24-22	22-20	< 20	-
Mean max. temp grow (°C)	< 18	18.15	< 15	-	-
Mean R.H. in growing season	70-50	50-40	< 40	-	-
Length of dry spells (days)					
After sowing & during flowering	< 10	10-15	15-21	> 21	-
Site characteristics					
Slope (%)	< 3	3-5	5-8	> 8	-
Erosion	01	02	03	-	-
Drainage	Well to mod.well	Imperfect & somewhat excessive	Poor & excessive	-	-
Water stagnation (days)	< 3	4	5	> 5	-
AWC (mm m ⁻¹)	> 150	100-150	50-100	< 50	-
Stoniness % (surface)	< 15	15-40	40-60	> 60	-

Appendix-VI Contd...

1	2	3	4	5	6
Soil characteristics					
Texture (clay %)	sic, sicl, cl, sc	sil sci	sl cm	s ls	-
Coarse fragments (vol. %)					
Within 50 cm	< 15	15-35	35-50	> 50	-
Below 50 cm	5-40	40-75	> 75	-	-
Depth (cm)	> 75	50-75	< 50	-	-
CaCO ₃ (%) (with in 50 cm)	< 10	10-25	> 25	-	-
Soil fertility					
CEC (cmol (p ⁺) kg ⁻¹)	> 20	20-10	< 10	-	-
BS (%)	> 50	50-35	< 35	-	-
O.C. (%) (0.15 cm)	> 0.50	0.5-0.2	< 0.20	-	-
ECe (dSm ⁻¹)	< 4	4-8	8-10	> 10	-
ESP	< 10	10-15	> 15	-	-
pH (1:2.5)	6.5-5.50 7.5-8.0	5.5-5.0 8.0-8.5	< 5.0 8.5-9.0	> 9.0 -	- -

(f) Maize (Sys, *et al*, 1991, NBSS and LUP : 1994)

1	2	3	4	5	6
Climatic (c)					
Precipitation growing cycle (mm)	750-500	500-400	400-300	-	< 300
I st month	175-100	100-75	75-60		60
II nd month	200-150	150-120	120-70	-	< 70
III rd month	165-100	100-80	60-80	-	< 60
IV th month					
Mean temperature growing cycle (°C)	24-32	32-35	35-40	-	> 40
Mean maximum temperature growing cycle (°C)	17-24	24-28	28-30	-	> 30
Topography (t)					
Slope (%)	0-2	2-4	4-6	-	> 6
Wetness (w)					
Drainage	Good to moderate	Imperfect	Poor	Poor but drain-able	Poor not drain-able
Physical characteristics (s)					
Texture/structure	c	cl, scl	fs, s,<cs	-	cm, sicm
Coarse fragments (%)	0-15	15-35	35-55	-	> 55
Soil depth (cm)	> 75	75-50	50-20	-	> 20
CaCO ₃ (%)	0-15	15-25	25-35	-	> 35
Gypsum (%)	0-4	4-10	10-20	-	> 20
Soil fertility characteristics (f)					
CEC cmol (p ⁺) kg ⁻¹	> 16	< 16 (-)	< 16 (+)	-	-
B.S. (%)	> 50	50-35	35-20	< 20	
pH, H ₂ O	6.6-7.8	7.8-8.2	8.2-8.5	-	> 8.5
Organic carbon (%)	> 0.6	0.4-0.6	< 0.4	-	-
Salinity alkalinity (u)					
ECe (dSm ⁻¹)	0-4	4-6	6-8	8-12	> 12
ESP (%)	0-15	15-20	20-25	-	> 25

Appendix-VI Contd...

(g) Soybean (Sys, *et al*, 1991, NBSS & LUP, 1994)

1	2	3	4	5	6
Climatic characteristics					
Total rainfall (mm)	> 750	650-750	550-650	< 550	-
Rainfall growing seasons (mm)	> 600	500-600	500-400	< 400	-
Rainfall during critical period	-	-	-	-	-
Length growing period (days)	> 110	110-100	90-100	< 90	-
Mean temp. growing season ($^{\circ}\text{C}$)	25-28	28-30	30-34	> 34	-
Mean max. temp. grow. Season ($^{\circ}\text{C}$)	-	-	-	-	-
Mean min. temp. grow. Season ($^{\circ}\text{C}$)	-	-	< 20	-	-
Mean R.H. in growing season	> 70	50-70	< 50	-	-
Length of dry spells (days)	Flowering to pod filling is critical				
	< 4	4-8	8-12	> 12	-
Site characteristics					
Slope (%)	< 3	3-5	5-8	> 8	-
Erosion	-	-	-	-	-
Drainage	Well to mod. Well	Poor/ excessive	-	-	-
AWC (mm/m)	> 200	150-200	100-150	50-100	< 50
Stoniness % (surface)	5-10	10-15	15-25	> 25	-
Soil characteristics					
Texture	cl, sicl, l, sil, scl	sl, c	cm, ls	s	-
Coarse fragments (vol. %)					
Within 50 cm	< 15	15-25	25-35	> 35	-
Depth (cm)	> 60	50-60	40-50	< 40	-
CaCO ₃ (%)	< 10	10-20	> 20	-	-
Soils fertility					
CEC cmol(p ⁺) kg ⁻¹	> 20	20-10	< 10	-	-
B.S. (%)	> 50	50-35	< 35	-	-
Sat. H.C. (0-15 cm)	> 0.5	0.5-0.2	< 0.2	-	-
pH (1:2.5)	6.5-7.5	7.5-8.5	> 8.5	-	-
ECe (dSm ⁻¹)	< 2	2-3	3-4	> 4	-
ESP	< 5	5-10	10-15	> 15	-

(h) Wheat (Sys *et al.*, 1991 & NBSS & LUP, 1994)

1	2	3	4	5	6
Climatic (c)					
Precipitation	700-350	350-250	250-200	-	< 200
Monthly rainfall veg. stage	65-20	20-12	12-8	-	< 8
Monthly rainfall flowering stage	75-30	30-15	15-10	-	< 10
Monthly rainfall ripening stage	60-30	30-10	< 10	-	-
Mean temperature ($^{\circ}\text{C}$)					
Mean temp. vegetative stage	10-6	6-4	4-2	-	< 2
Flowering stage	18-12	12-10	10-8	-	< 8
Ripening stage	20-14	14-12	12-10	-	< 10
Topography (t)					
Slope (%)	0-2	2-4	4-6	-	> 6

Appendix-VI Contd...

1	2	3	4	5	6
Wetness					
Drainage	Good to moderate	Imperfect	Poor & acric	Poor but drain able	Poor, but not drainable
Physical characteristics (s)					
Texture	c, l	scl	sl, lfs	-	cm, sicm
Coarse fragments (%)	0-15	15-35	35-55	-	> 55
Soil depth (cm)	> 50	50-20	20-10	-	< 10
CaCO ₃ (%)	3-30	30-40	40-60	-	> 60
Gypsum (%)	0-5	5-10	10-20	-	> 20
Soil fertility characteristics (f)					
CEC cmol (p ⁺) kg ⁻¹	> 16	< 16 (-)	< 16 (+)	-	-
BS (%)	> 50	50-35	< 35	-	-
pH, H ₂ O	7.0-8.2	8.2-8.3	8.3-8.5	-	> 8.5
Organic carbon (%)	> 0.4	< 0.4	-	-	-
Salinity alkalinity (n)					
ECe (dsm ⁻¹)	0-3	3-5	5-6	6-10	> 10
ESP (%)	0-20	20-30	30-45	-	> 45

(i) Sugarcane (Sys *et al.*, 1991 & NBSS & LUP, 1994)

1	2	3	4	5	6
Climatic (c)					
Mean day temp. at germination (°C)	28-32	32-34	34-35	-	> 35
Mean day temp. for tillage stage (°C)	27-32	32-35	> 35	-	-
Mean day temp. for veg. stage (°C)	26-32	32-35	> 35	-	-
(T _{max} -T _{min} /T _{mean}) at maturation stage	> 0.45	0.45-0.4	0.4-0.3	-	< 0.3
10 days rainfall (mm)	> 60	60-50	50-30	-	< 30
Topography (t)					
Slope (%)	0-2	2-4	4-6	-	> 6
Wetness					
Drainage	Good to moderate	Imperfect	Poor & aeric	Poor but drainable	Poor not drainable
Physical characteristics (s)					
Texture / structure	c, cl, l	sl, s, fs	s, fs	-	> 55
Coarse fragments (%)	0-15	15-35	35-55	-	> 55
Soil depth (cm)	> 80	80-50	50-25	-	< 25
CaCO ₃ (%)	0-25	25-35	35-50	-	> 50
Gypsum (%)	0-6	6-12	12-20	-	> 20
Soil fertility characteristics (f)					
CEC cmol (p ⁺) kg ⁻¹	> 16	< 16(-)	< 16 (+)	-	-
B.S. (%)	> 50	50-35	< 35	-	-
pH, H ₂ O	6.5-7.5	7.5-8.0	8.0-8.5	-	> 8.5
Organic carbon (%)	> 0.8	0.5-0.8	< 0.5	-	-
Salinity alkalinity (n)					
ECe (dSm ⁻¹)	0-5	5-8	8-10	10-14	> 14
ESP (%)	0-10	10-15	15-20	-	> 20

Appendix-VI Contd...

(j) Mustard (Sys *et al.*, 1991 & NBSS & LUP, 1994)

1	2	3	4	5	6
Climatic (c)					
Precipitation (mm)	250-350	150-250	100-150	< 100	-
Mean temp.(⁰ C)	20-28	18-20	16-18	< 16	-
Topography (t)					
Slope (%)	< 3	3-8	3-8	> 8	-
Wetness					
Drainage	Moderately well drained	Imp./some what excessive	Very low V excessive	-	-
Physical characteristics (s)					
Texture / structure	cl, l	sl	ls	s	-
Coarse fragments (%)	< 15	15-35	> 35	-	-
Soil depth (cm)	> 75	75-50	50-25	< 25	-
CaCO ₃ (%)	< 20	20-30	30-40	> 40	-
Gypsum (%)	< 3	3-5	5-10	> 10	-
Soil fertility characteristics (f)					
CEC cmol (P ⁺) kg ⁻¹	> 16	8-16	< 8	-	-
B.S. (%)	> 50	50-35	< 35	-	-
Organic carbon (%)	> 0.4	0.2-0.4	0.1-0.2	-	-
Salinity alkalinity (n)					
ECe (dsm ⁻¹)	< 8	8-12	12-16	> 16	-
ESP (%)	< 15	15-25	25-35	> 35	-

(k) Pearl millet (Sys *et al.*, 1991 & NBSS & LUP, 1994)

1	2	3	4	5	6
Climatic (c)					
Precipitation (mm)	400-600	300-400	200-300	< 200	-
Mean temp.(⁰ C)	20-28	18-20	16-18	< 16	-
Topography (t)					
Slope (%)	< 1-3	3-8	8-15	> 15	-
Wetness					
Drainage	Well	Mod.	Imp.	Poor	Poor
Physical characteristics (s)					
Texture / structure	c, cl, fl	cl-s, scl	ls, lfs, cl-s	fs-s	cs, s
Coarse fragments (%)	< 15	15-35	35-55	> 55	-
Soil depth (cm)	> 50	25-50	< 25	-	-
CaCO ₃ (%)	0-25	25-50	< 25	-	-
Gypsum (%)	0-6	6-10	10-20	> 20	-
Soil fertility characteristics (f)					
CEC cmol (p ⁺) kg ⁻¹	> 5	3-5	2-3	< 2	-
B.S. (%)	> 50	50-35	< 35	-	-
Organic carbon (%)	0.4	0.2-0.4	< 0.2	-	-
Salinity alkalinity (n)					
ECe (dsm ⁻¹)	< 4	4-8	8-12	> 12	-
ESP (%)	< 25	25-35	35-45	> 45	-

Appendix-VI Contd...

(I) Sunflower (FAO, 1976 and Sys *et al.*, 1991)

1	2	3	4	5	6
Climatic (c)					
Precipitation					
I st month	105-215	> 215	-	-	-
II nd month + III rd month	195-230	> 230	-	-	-
IV th month	250-450	450-750	> 750	-	-
V th month	100-150	> 150	-	-	-
Mean temp. of grain yield (⁰ C)	22-26	26-28	28-30	-	> 30
Topography (t)					
Slope (%)	0-2	2-4	4-6	-	> 6
Wetness					
Drainage	Good to moderate	Imperfect	Poor & aeric	Poor but drainable	Poor not drainable
Physical characteristics (s)					
Texture / structure	c<60s	c<60v	<cs, fs, s	-	cm, sicm
Coarse fragments (%)	0-15	15-35	35-55	-	> 55
Soil depth (cm)	> 100	100-75	75-50	-	< 50
CaCO ₃ (%)	0-15	15-75	25-35	-	> 35
Gypsum (%)	0-4	4-10	10-20	-	> 20
Soil fertility characteristics (f)					
CEC cmol (p ⁺) kg ⁻¹	> 16	< 16(-)	< 16(+)	-	-
BS (%)	< 35	35-20	< 20	-	-
pH, H ₂ O	6.6-7.5	7.5-8.0	8.0-8.5	-	8.5
Organic carbon (%)	> 1.2	1.2-0.8	< 0.8	-	-
Salinity alkalinity (n)					
ECe (dsm ⁻¹)	0-4	4-9	9-12	-	> 12
ESP (%)	Not specified				

* S₁ - Highly suitable, S₂ – Moderately suitable, S₃ – Marginally suitable

N₁ – Actually unsuitable but potentially suitable,

N₂ – Actually and potentially unsuitable

APPENDIX – VII

Rating class for different parameters.

(a) Soil depth classes

Soil depth (cm)	Use for defining	
	Phases	Subgroup
< 25	Very shallow	Lithic
25 – 50	Shallow	Lithic
50 – 80	Moderately shallow	--
80 – 120	Moderately deep	--
120 – 150	Deep	--
> 150	Very deep	--

Source : Sehgal (1986)

(b) Rating class for saturated hydraulic conductivity.

Saturated hydraulic conductivity (cm hr ⁻¹)	Used for defining
< 0.125	Very slow
0.125 – 0.50	Slow
0.50 – 2.00	Moderately slow
2.00 – 6.30	Moderate
6.30 – 12.50	Moderately rapid
12.50 – 25.00	Rapid
> 25.00	Very rapid

Source : Jalota *et al.* (1998)*

(c) Rating class for infiltration rate.

Infiltration rate (cm hr ⁻¹)	Used for defining
< 0.1	Very slow
0.1 – 0.5	Slow
0.5 – 2.0	Moderately slow
2.0 – 6.3	Moderate
6.3 – 12.5	Moderately rapid
12.5 – 25.4	Rapid
> 25.4	Very rapid

Source : Jalota *et al.* (1998)*

* Source : Jalota, S.K., Khera, R. and Ghuman, B.S. (1998). Methods in soil physics. Narosa Publishing House, New Delhi.

Appendix-VII Contd...

(d) Rating for classification of soil test values.

Sr. No.	Available nutrient	Rating			Method followed
		Low	Medium	High	
1	Available N (kg ha^{-1})	<250	250-500	>500	Alkaline KmnO_4 method
2	Organic carbon (%)	<0.50	0.50-0.75	>0.75	Walkley and Black method
3	Available phosphorus ($\text{kg P}_2\text{O}_5 \text{ ha}^{-1}$)	<28	28-56	>56	Olsen's method
4	Available potassium ($\text{kg K}_2\text{O ha}^{-1}$)	<140	140-280	>280	Neutral normal NH_4OAC extractant
5	Available iron (ppm)	<5.0	5-10	>10.0	DTPA (0.005 M) extractant method
6	Available manganese (ppm)	<5.0	5-10	>10.0	DTPA (0.005 M) extractant method
7	Available zinc (ppm)	<0.5	0.5-1.0	>1.0	DTPA (0.005 M) extractant method
8	Available copper (ppm)	<0.2	0.2-0.4	>0.4	DTPA (0.005 M) extractant method

Source : Kanwar, J.S. (1976). Soil fertility, theory and practice. ICAR, New Delhi.

(e) pH of soils.

pH	Used for defining
6.6 – 7.3	Neutral
7.4 – 7.8	Mildly alkaline
7.9 – 8.4	Moderately alkaline
8.5 – 9.0	Strongly alkaline
9.1 and higher	Very strongly alkaline

Source : Soil Survey Staff (1951). Soil survey Manual, Oxford & IBH Pub. Co., New Delhi. pp. 235.

(f) EC and SAR values for different classes of salinity and sodium hazard of irrigation waters.

Salinity hazard	Class	EC (dSm^{-1})	Sodium hazard	Class	SAR
Low	C_1	< 0.25	Low	S_1	< 10
Medium	C_2	0.25-0.75	Medium	S_2	10-18
High	C_3	0.75-2.25	High	S_3	18-26
Very high	C_4	2.25-5.00	Very high	S_4	> 26

Source : USSL Staff (Richards, 1954)

(g) Bicarbonate hazard.

RSC (me l^{-1})	Quality of irrigation water

< 1.25	Safe
1.25 – 2.50	Marginal
> 2.50	Not suitable

Source : USSL Staff (Richards, 1954)

APPENDIX – VIII

List of farmers for the profiles description study.

Pedon No.	Name of farmer	Village	Taluka	District
	T₁ : Hiran toposequence			
P ₁	Forest land, Gujarat Government	Sasan (Gir)	Talala	Junagadh
P ₂	Rupareliya Kala Karshan	Borvav	Talala	Junagadh
P ₃	Solanki Devashi Naran	Maljinjava	Talala	Junagadh
P ₄	Zala Bhikha Mashri	Kajali	Veraval	Junagadh
	T₂ : Shingoda toposequence			
P ₅	Sakhareliya Bava Naran	Jamwala	Una	Junagadh
P ₆	Rathod Rambhai Gangabhai	Kareda	Kodinar	Junagadh
P ₇	Vala Karshan Naran	Devali	Kodinar	Junagadh
P ₈	Chauhan Kachara Lakhman	Chauhani kahn	Kodinar	Junagadh
	T₃ : Machhundri toposequence			
P ₉	Dhanani Jadav Lakhman	Fatsar	Una	Junagadh
P ₁₀	Ramani Savaji Arjan	Judavadali	Una	Junagadh
P ₁₁	Makawana Bharat Parsotam	Delawada	Una	Junagadh
P ₁₂	Chauhan Labhubhai Karshan	Rampara	Una	Junagadh
	T₄ : Rayadi toposequence			
P ₁₃	Waste land area, Gujarat Govt.	Dedan	Khambha	Amreli
P ₁₄	Jani Yogesh Ramaji	Dedan	Khambha	Amreli
P ₁₅	Kikani Himat Lakhman	Chotara	Rajula	Amreli
P ₁₆	Solanki Jinuben Ramsinh	Kadiyali	Jafrabad	Amreli

APPENDIX – IX

List of farmers for the collection of underground water samples.

Sample Sr.No.	Name of farmer	Village	Taluka	District
1	2	3	4	5
	T₁ : Hiran toposequence			
1	Memam Mahmad Isub	Sasan (Gir)	Talala	Junagadh
2	Barad Hamir Mandan	Sasan (Gir)	Talala	Junagadh
3	Makalai Faruk Ibrahim	Sasan (Gir)	Talala	Junagadh
4	Rupareliya Kala Karsan*	Borvav	Talala	Junagadh
5	Savalia Jivraj Nathu	Borvav	Talala	Junagadh
6	Radadiya Naran Valji	Borvav	Talala	Junagadh
7	Solanki Babubhai	Maljinjava	Talala	Junagadh
8	Solanki Naja Naran	Maljinjava	Talala	Junagadh
9	Solanki Bhimji Sarman	Maljinjava	Talala	Junagadh
10	Zala Bhikha Mashari*	Kajali	Veraval	Junagadh
11	Parmar Kala Rasim	Kajali	Veraval	Junagadh
12	Sumara Abdul Kalu	Kajali	Veraval	Junagadh
13	Sakhareliya Bava Naran*	Jamwala	Una	Junagadh
14	Dhameliya Babu Premaji	Jamwala	Una	Junagadh
15	Rakholiya Jina Devaraj	Jamwala	Una	Junagadh
16	Vadher Jagmal Mala	Sayaji Rajapara	Kodinar	Junagadh
17	Vadher Dhiru Siddibhai	Sayaji Rajapara	Kodinar	Junagadh
18	Poriya Karsan Ranchhod	Kareda	Kodinar	Junagadh
19	Kher Bhikha Oghabhai	Devali	Kodinar	Junagadh
20	Barad Siddibhai Boghabhai	Devali	Kodinar	Junagadh
21	Dodiya Punja Parbat	Devali	Kodinar	Junagadh
22	Chauhan Kachara Lakhaman*	Chauhani khan	Kodinar	Junagadh
23	Chauhan Baghu Karsan	Chauhani khan	Kodinar	Junagadh
24	Chauhan Gandabhai Arjanbhai	Chauhani khan	Kodinar	Junagadh
25	Dhanani Jadav Lakhaman*	Fatsar	Una	Junagadh
26	Dhahani Shantilal Bhimji	Fatsar	Una	Junagadh
27	Dhanani Vinu Ranchhod	Fatsar	Una	Junagadh
28	Ramani Himaj Arjan	Judavadali	Una	Junagadh
29	Ramani Savaji Arnan*	Judavadali	Una	Junagadh
30	Ramani Balu Bagavanji	Judavadali	Una	Junagadh
31	Makawana Bharat Parsotam	Delawada	Una	Junagadh
32	Purohit Navnit Narmadashankar	Delawada	Una	Junagadh
33	Mevada Puna Daya	Delawada	Una	Junagadh
34	Chauhan Labhubhai Karsan*	Rampara	Una	Junagadh
35	Ram Ebha Punja	Rampara	Una	Junagadh
36	Ram Ramsinh Ebha	Rampara	Una	Junagadh
37	Kumbhar Ravaji Madha	Dedan (North side of hill)	Khambha	Amreli
38	Kachchhi Ghanshyam Madhu	- ' -	Khambha	Amreli
39	Parmar Kadava Bhoja	- ' -	Khambha	Amreli

Appendix-IX Contd...

1	2	3	4	5
40	Siroya Jeram Nagaji	Dedan (South side of hill)	Khambha	Amreli
41	Jani Yogesh Ramaji*	- ‘ ’ -	Khambha	Amreli
42	Jani Prabhashankar Jeram	- ‘ ’ -	Khambha	Amreli
43	Radadiya Jivan Nanji	Chotara	Rajula	Amreli
44	Kikani Himat Lakhaman*	Chotara	Rajula	Amreli
45	Radadiya Pragaji Ramaji	Chotara	Rajula	Amreli
46	Solanki Jinuben Ramsinh*	Kadiyali	Jafrabad	Amreli
47	Makawana Lakhaman Nanji	Kadiyali	Jafrabad	Amreli
48	Solanki Bhagavan Bhana	Kadiyali	Jafrabad	Amreli

* Profile description also done.