Characterization of Soils and Assessment of Land Degradation in West Coast of Southern Karnataka

SIDHARAM.PATIL
PALB 1275

DEPARTMENT OF SOIL SCIENCE AND AGRICULTURAL CHEMISTRY
UNIVERSITY OF AGRICULTURAL SCIENCES
BANGALORE- 560 065

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SIDHARAM. PATIL

PALB 1275

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Affectionately Dedicated to My beloved Parents, Basawaraj Patil & Mahadevi Patil

And my chairperson

Dr. Anil Kumar, K.S

DEPARTMENT OF SOIL SCIENCE AND AGRICULTURAL CHEMISTRY
UNIVERSITY OF AGRICULTURAL SCIENCES, GKVK, BANGALORE- 560 065

CERTIFICATE

This is to certify that the thesis entitled **"Characterization of Soils and Assessment of Land Degradation in West Coast of Southern Karnataka"** *submitted by* **Mr. Sidharam. Patil, ID No. PALB 1275** *for the degree of Master* **of Science** *in* **SOIL SCIENCE AND AGRICULTURAL CHEMISTRY** *to the University of Agricultural Sciences, Bangalore, is a record of research work carried out by him during the period of his study in this university, under my guidance and supervision and the thesis has not previously formed the basis for the award of any degree, diploma, associateship, fellowship or other similar titles.*

BANGALORE
July, 2013

(Dr. Anil Kumar, K. S.)
Principle Scientist, NBSS and LUP (ICAR),
Regional centre, Hebbal, Bangalore.

Approved by:

Chairman: ______________________
(Dr. Anil Kumar, K. S.)

Members: 1. ______________________
(Dr. K. M. NAIR)

2. ______________________
(Dr. C. A. Srinivasamurthy)

3. ______________________
(Dr. V. Ramamurthy)

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"Characterization of Soils and Assessment of Land Degradation in West Coast of Southern Karnataka"

Sidharam Patil

THESIS ABSTRACT

The research programme was undertaken to characterize the land resources and to assess degradation of west coast of Southern Karnataka using toposheets, imagery and field studies.

Soil profiles were studied from all seven major physiographic divisions in two long transects. Methodology and flow chart for land resources appraisal for degradation studies have been devised. The soils have been described for their site characteristics, morphology, physical, chemical characteristics and fertility.

The study could find out that deep, strongly to moderately acid red and lateritic soils of Ultisol order with low CEC and BS occupy considerable area with rich organic carbon status in foot hill zone.

The major taxa of soils identified at great group level of Soil Taxonomy are Palehumults, Kandihumults, Kanhaplohumults, Kandiustults, Kanhaplustults and Haplustults.

The study could bring out the native fertility and available nutrient status of soils of west coast and its ability to supply essential plant nutrients to crops.

Liming and soil test based nutrient application is essential as all the soils studied are strongly or moderately acid and poor in all major, secondary and micronutrients except Fe, Mn and Cu.

Using the land qualities studied and datasets of SRM of Karnataka, the study could bring out land degradation status map of southern coastal Karnataka with Kollur with very low, Brahmavar low, Belthangadi medium, Sullya and Ullal moderate and Molahalli and Murdeshwar with high degradation status and vulnerability using a numerical scale of 0 to 1 devised in the present study by grading each land quality.

Department of SS and AC Signature of the Chairman

UAS, GKVK, Bengaluru-65 **(K. S. Anil Kumar)**

ದಕ್ಷಿಣ ಕರ್ನಾಟಕದ ಪಶ್ಚಿಮ ಕರಾವಳಿಯ ಮಣ್ಣಿನ ಗುಣಾವಲೋಕನ ಮತ್ತು ಭೂ ಅವನತಿ ಅಂದಾಜಿನಲ್ಲಿ ಕೈಗೊಂಡ

ಸಂಶೋಧನೆ

ಸಿದ್ದಾರಾಮ ಪಾಟೀಲ

ಪ್ರಬಂಧದ ಸಾರಾಂಶ

ಈ ಸಂಶೋದನಾ ಕಾರ್ಯಕ್ರಮದಲ್ಲಿ ಭಾರತೀಯ ಸರ್ವೇಕ್ಷಣ ಸಂಸ್ಥೆಯ ನಕ್ಷೆಗಳು, ಉಪಗ್ರಹ ಬಿಂಬ ಚಿತ್ರಗಳು ಮತ್ತು ಕ್ಷೇತ್ರಾಧ್ಯಾಯನವನ್ನು ಅಳವಡಿಸಿ, ದಕ್ಷಿಣ ಕರ್ನಾಟಕದ ಪಶ್ಚಿಮ ಕರಾವಳಿಯ ಭೂಮಿಯ ಸಂಪನ್ಮೂಲಗಳ ಲಕ್ಷಣಗಳು ಮತ್ತು ಅವನತಿ ಹೊಂದುತ್ತಿರುವ ಬಗ್ಗೆ ಸಂಶೋಧನೆಯನ್ನು ಕೈಗೊಳ್ಳಲಾಯಿತು.

ಏಳು ಪ್ರಮುಖ ಭೌಗೋಳಿಕ ವಿಭಾಗಗಳಲ್ಲಿ ಮಣ್ಣಿನ ಪಾರ್ಶ್ವ ದೃಶ್ಯಗಳನ್ನು ತೆಗೆದು ಅಧ್ಯಯನವನ್ನು ಮಾಡಲಾಯಿತು. ಭೂ ಸಂಪನ್ಮೂಲಗಳನ್ನು ಅಧ್ಯಯನ ಮಾಡಲು ಗತಿ ನಕ್ಷೆಯನ್ನು ರೂಪಿಸಿ ಭೂಮಿಯು ಅವನತಿಯ ಹೊಂದಿತ್ತಿರುವ ಬಗ್ಗೆ ಅಧ್ಯಯನ ಮಾಡಲಾಯಿತು. ಮಣ್ಣಿನ ಅಧ್ಯಯನದ ಸಮಯದಲ್ಲಿ ಸ್ಥಳದ ಗುಣಲಕ್ಷಣಗಳು, ಭೂಮಿಯ ಅಂಗರಚನಾಶಾಸ್ತ್ರ, ಭೌತಿಕ, ರಾಸಾಯನಿಕ ಗುಣಲಕ್ಷಣಗಳು ಮತ್ತು ಫಲವತ್ತತೆಯನ್ನು ಅಧ್ಯಯನ ಮಾಡಿ ವಿವರಿಸಲಾಗಿದೆ.

ಆಳವಾದ, ಬಲವಾದ ಆಮ್ಲೀಯ ಕೆಂಪು ಮತ್ತು ಜಂಬಿಟ್ಟಿಗೆ ಮಣ್ಣನ್ನು ಹೊಂದಿ, ಅಲ್ಟಿಸಾಲ್ ಪ್ರಧಾನ ವರ್ಗ ಸೇರಿದ್ದು ಕಡಿಮೆ ಧನವಿದ್ಯುತ್ ಕಣ ವಿನಿಮಯ ಸಾಮರ್ಥ್ಯ ಮತ್ತು ಪ್ರತ್ಯಾಮ್ಲ ಸಂತೃಪ್ತಿ ಜೊತೆ ಸೇರಿರುವ ಬೆಟ್ಟಗಳು ಮತ್ತು ತಪ್ಪಲು ಪ್ರದೇಶದಲ್ಲಿ ಸಮೃದ್ಧ ಸಾವಯವ ಇಂಗಾಲದ ಸ್ಥಾನಮಾನದ ಗಮನಾರ್ಹ ಪ್ರದೇಶವನ್ನು ಒಳಗೊಂಡಿದೆ. ಮಣ್ಣಿನ ಪ್ರಮುಖ ಶ್ರೇಣಿಗಳಲ್ಲಿ ಪೇಲ್‌ಹ್ಯೂಮಲ್ಟ್ಸ್, ಕ್ಯಾಂಡಿ ಹ್ಯೂಮಲ್ಟ್ಸ್, ಕ್ಯಾನ್ ಹಾಪ್ಲೋ ಹ್ಯೂಮಲ್ಟ್ಸ್, ಕ್ಯಾಂಡಿ ಉಸ್ಟಲ್ಟ್ಸ್. ಕ್ಯಾನ್ ಹಾಪ್ಲೋ ಉಸ್ಟ್‌ಲ್ಟ್ಸ್ ಮತ್ತು ಹಾಪ್ಲೋ ಉಸ್ಟಲ್ಟಗಳನ್ನು ಗುರುತಿಸಲಾಗಿದೆ. ಪಶ್ಚಿಮ ಕರಾವಳಿಯ ಮಣ್ಣಿನ ಸ್ಥಳೀಯ ಫಲವತ್ತತೆ ಮತ್ತು ಬೆಳೆಗಳಿಗೆ ಬೇಕಾದ ಪೋಷಕಾಂಶಗಳನ್ನು ಪೂರೈಸುವ ಸಾಮರ್ಥ್ಯದ ಬಗ್ಗೆ ಈ ಅಧ್ಯಯನದಿಂದ ತಿಳಿದು ಬಂದಿದೆ.

ಈ ಅಧ್ಯಯನದಿಂದ ಸುಣ್ಣ ಮತ್ತು ಮಣ್ಣು ಪರೀಕ್ಷೆ ಆಧಾರಿತ ಪೋಷಕಾಂಶಗಳ ಅಗತ್ಯ ಮಾಹಿತಿ, ಸಾಧಾರಣದಿಂದ ಬಲವಾದ ಆಮ್ಲೀಯ ಮತ್ತು ಕಬ್ಬಿಣ, ಮ್ಯಾಂಗನೀಸ್ ಹಾಗೂ ತಾಮ್ರದ ಹೊರತುಪಡಿಸಿ ಉಳಿದ ಎಲ್ಲಾ ಪ್ರಮುಖ, ದ್ವಿತೀಯ ಮತ್ತು ಲಘುಪೋಷಕಾಂಶಗಳ ಕೊರತೆ ಇರುವುದು ತಿಳಿದು ಬಂದಿದೆ. ಭೂಮಿ ಗುಣಗಳನ್ನು ಮತ್ತು ಕರ್ನಾಟಕದ ಮಣ್ಣು ಸಂಪನ್ಮೂಲ ನಕ್ಷೆಯ ದತ್ತಾಂಶಗಳನ್ನು ಬಳಸಿಕೊಂಡ ಅಧ್ಯಯನದಲ್ಲಿ ಭೂ ಅವನತಿ ಸ್ಥಿತಿ ನಕ್ಷೆಯ ಪ್ರಕಾರ ಕರ್ನಾಟಕದ ದಕ್ಷಿಣ ಕರಾವಳಿಯ ಕೊಲ್ಲೂರಿನ ಭೂಮಿಯ ಅತೀ ಕಡಿಮೆ, ಪ್ರಮಾಣದಲ್ಲಿ ಅವನತಿಹೊಂದಿದೆ. ಹಾಗೆಯೇ ಬ್ರಹ್ಮಾವರ ಕಡಿಮೆ, ಬೆಳ್ತಂಗಡಿ ಸಾಧಾರಣ, ಸೂಳ್ಯ ಹಾಗೂ ಉಲ್ಲಾಳ ಮಧ್ಯಮ, ಮೊಲಹಳ್ಳಿ ಹಾಗೂ ಮುರುಡೇಶ್ವರದ ಭೂಮಿಯ ಹೆಚ್ಚಿನ ಅವನತಿ ಸ್ಥಿತಿಯನ್ನು ಹೊಂದಿದೆ ಮತ್ತು ಸಂಖ್ಯಾತ್ಮಕ ಪ್ರಮಾಣದಲ್ಲಿ ವರ್ಗೀಕರಿಸಿದಾಗ 0 ಯಿಂದ 1 ರ ವರಿಗೆ ದುರ್ಭಲತೆಯನ್ನು ಹೊಂದಿರುವ ಗುಣಮಟ್ಟದ ಶ್ರೇಣಿಗಳಾಗಿ ಪ್ರಸ್ತುತ ಅಧ್ಯಯನದಲ್ಲಿ ಅಳವಡಿಸಬಹುದಾಗಿದೆ.

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I INTRODUCTION

Soil is the foundation of basic ecosystem function and provides ecosystem services critical for life and socio-economic development of nation. Soil is finite resource and it has to be conserved and protected for future generations. Each soil has had its own history, like a river, a mountain, a forest or any natural things, its present condition is due to the influence of anything and events of past (Kellogg, 1950). Soil provide food, fodder and fuel for meeting basic needs of human and animal. With the growth in human and animal population demand on soils for more production is on the increase.

However, the capacity of soil to produce is limited and is decided by its intrinsic characteristics, agro-ecological settings and its use and management (FAO, 1993). This demands systematic appraisal of our soil resource with respect to their extent, distribution, characteristics, behavior and use potential, which is very important for developing an effective land use system for augmenting agricultural production on a sustainable basis.

Soils are formed due to the interaction of various soil forming factors and processes, their effect is reflected in soils, which shows significant variation in there evolution suggesting a close relationship between soils and different soil forming factors.

West facing slopes of Western Ghats include high and low hill ranges, ridges, dissected hills and narrow valleys, isolated hills, flat hill slopes, undulating uplands and lateritic plateaus as well as mounds and coastal landform. Humid tropical climate with heavy rainfall and high temperature experienced in this region induce intense leaching of bases. Leaching of bases lead to formation of deep well drained acidic soils which responds differently towards crop production under different levels of management.

Land degradation is a global phenomenon caused by various factors or processes which include soil erosion by water/wind, deterioration in physical, chemical and biological or economic properties of the soil and long-term loss of natural vegetation. It is estimated that about 2 billion ha area in the world that once was biologically productive is now affected by various forms of land degradation (Oldeman, 1991). About 5-7 million ha of arable land of the world is lost annually through land degradation (Lal and Stewart, 1992). Globally, land degradation affects about one-sixth of the world's population, 70 percent of all dry lands (about 3.6 billion ha) and one-quarter of the total land area of the world. The continental percentage of land degradation is highest in Asia (37 %) followed by Africa (25 %), South America (14 %), Europe (11 %), North America (4 %) and Central America (3 %), the world total being 15 per cent.

In India, the estimates of land degradation by different agencies vary widely from about 53 M ha to 188 M ha, mainly due to different approaches adopted in defining degraded lands and/or differentiating criteria used

Scarcity of land and demographic pressure are the driving forces responsible for bringing marginal lands under cultivation. Land degradation is environmental problem which could be observed at many areas in many forms including depletion of soil nutrients, salinization, agrochemical pollution, soil erosion and vegetative degradation. Land degradation limits the productivity and reduces the carrying capacity of land. Land degradation is process, which lowers the current and potential capacity of soil to produce goods and services, qualitatively and quantitatively (FAO, 1979).

Identification and demarcation of degraded lands is the basic need for further developmental activity. Modern tools like remote sensing data products are used which are easy and time and labour saving, can be used for land resource assessment. Proper interpretation of False Colour Composite (FCC) imageries based on tonal variation, pattern, texture and spectral reflectance properties of soils, helps in accurate identification of degraded lands. The most important soil variables used to identify soil degradation at the soil surface are organic matter, soil moisture, texture and iron oxides. These diagnostic features in soil surface are affected by erosion and salt accumulation on surface, may influence the absorption of incidental radiation. The existence of spectrally detectable differences in these soil constitutes appears to be the basis for distinguishing between degraded and undisturbed soils or between the different intergrades.

Recent land degradation assessment made during 2010 indicated that around 120.4 M ha is degraded land in India (Maji *et al.*, 2010) of which 74 M ha is due to water erosion, 5 M ha is due to acid soils, 11 M ha is due to wind erosion. In Karnataka 8.09 M ha is affected by different types of degradation of which 7.45 M ha is due to water erosion and 0.07 M ha is due to acid soils.

In coastal soils, soil acidification, removal of bases, low CEC, coastal erosion and vegetative degradation are the main type of degradation seen. Acid soils cover an area of 49 M ha in India out of which 25 M ha have pH below 5.5 and 24 M ha between 5.5 and 6.5 (Misra, 2004) and in Karnataka it covers 50 per cent of total geographical area (Sharda, 2011). Soil acidification in coastal soils of Karnataka is mainly due to heavy rainfall, which causes leaching of bases resulting in soil acidification and nutrient loss. Soil erosion is mainly caused by the heavy wind and water which removes soil containing organic matter and other plant nutrients thus causing loss of productivity. It was estimated that About 73 km of coastal Karnataka is affected by Soil erosion (Joshi, 1995). Vegetative degradation mainly caused due to deforestation and consequent leaching of bases and nutrients along with organic matter and finer soil particles with assorting of gravels on surface. These soils can afford to have only grass or scrub vegetation.

West coast of southern Karnataka is very important and significant agro-climatic zone where, more of the commercially important crops like rubber, cashew, coconut and paddy, are being grown in addition to agro-tourism activities. The information on soils and their characterization of west coast and land degradation is not documented systematically. Therefore, the present investigation was under taken for characterization of soils and assessment of land degradation in west coast of southern Karnataka with the following objectives

1. To characterize soils of west coast of Southern Karnataka to assess land quality.
2. To assess the extent of land degradation in the study area by field studies and using satellite imageries and toposheets.

II. REVIEW OF LITERATURE

Soil characterization mainly involves morphological, physical, chemical and biological property of soil which varies from place to place. Soil acidification can be natural or human induced processes where as the erosion is mainly natural process affecting the production and productivity of the land. When the human activity interferes in the process, the degradation is accelerated. Present status of degradation especially erosion and acidification, assessment and its effect on soil and land quality helps in monitoring the soil and other resources in a sustainable manner. Some of the important works carried out, both within and outside India, along with amelioration measures suggested are presented here under following chapters.

1. Application of remote sensing techniques in the identification of degraded lands
2. Morphological characteristics of soils
3. Physical characteristics of soils
4. Chemical characteristics of soils
5. Available nutrients
6. Land degradation and its assessment

2.1 Application of remote sensing techniques in the identification of degraded lands

Land resource information is vital for any developmental activity. All types of land are used for agricultural production indiscriminately. Identification of good and poor lands is crucial for land use planning. Conventional survey is time consuming and expensive. When the remote sensing data products used for collecting such information, the efficiency and accuracy of data gets improved.

Visual interpretation of Landsat imagery along with intensive ground truth enabled in preparing the soil and physiography map of

Sirsa district which was very helpful for identifying and delineating problematic soils. Based on the constraints, suitable measures were suggested for optimal land use planning (Mallik *et al.*, 1990).

Expansion of gullies occurring in different environmental condition in Sikar district of Rajasthan was studied and mapped by using remote sensing data products and it was observed that gully form of land degradation is serious and enlarging problem of sandy soils in state, in which even a single heavy downpour may permanently erode the topsoil's (Balak Ram and Chauhan, 1992).

Ghosh *et al.* (1996) studied different indicator of degraded processes in the semiarid lands of Karnataka state by using temporal satellite information along with the surface and statistical data with the aid of a geographical information system. The results showed that the degradation was a natural process but was aggravated by human activity.

Nizeymana *et al.* (1998) explained different methods of soil degradation assessment and the usefulness of FCC imageries in assessment. The method provides accurate results particularly where the degradation processes produce features large enough to show distinctive characteristic such as tone, shape and pattern of FCC imageries.

Mahapatra *et al.* (2000) assessed the degradation status of soils of Jammu and Kashmir by remote sensing and field studies and reported that the degradation was mainly due to water erosion, wind erosion and partly due to flooding and water logging. About 31 per cent area of the state is under various form of degradation and about 57 per cent is unfit for agriculture due to rock outcrop, ice caps and glaciers.

Yasser (2005) assessed the visual changes in a rapidly developing coastal area of Egypt using remotely sensed data (satellite images and aerial photographs) and raster GIS modeling. The analysis assesses changes between a period characterized by a vernacular, relatively natural landscape (1950s) and the beginning of the exploitation of the region for resorts (1990s). Using land use/land cover classes extracted from the satellite images and aerial photographs, four visual attributes of landscape are identified: land use/land cover diversity, activity (degree of naturalness), proximity to the shoreline, and topographic variety. A composite index is also developed. Although these attributes and the composite index rely mostly on the type of land use/land cover information on the landscape under consideration, the adopted techniques succeed in detecting several changes in the attributes, spatially locating them and mapping the magnitude of their changes. This study demonstrates what can be done to analyze and assess what is usually considered an incommensurable resource, the visual attributes of landscapes. It also reveals the extent of the impact of unplanned or ill-planned activities on one of the fragile resources of arid landscapes.

Mini *et al.* (2007) carried out work on coastal agro ecosystem of Karnataka and studied the relationship of topography by remote sensing technique, ground survey and laboratory analysis. Based on morphological (tone, texture, colour and contours) analysis, the different physiographic units identified in study area are hills and hill ranges, low hills, midlands and low lands. Soil temperature and moisture regimes in the areas are 'isohyperthermic' and 'ustic' respectively. At family level the soil of hills and hill ranges are classified as loamy-skeletal, mixed, and Typic Dystustepts. The low hills and mid lands qualify for loamy-skeletal, kaolinitic, and Typic/Inceptic/Ultic Haplustalfs. The low land soils are classified as fine-loamy, mixed, Aquic Dystrusteps/Aquic Ustifluvents where as garden lands soils qualify for clayey-skeletal, mixed, Oxic Dystrustepts. The classified pedon of low hills and mid lands showed a better development and were classified into Dystrustepts. The

Alluvial soils of low lands with shallow water table were classified as Ustifluvents.

Adel and Ryutaro (2007) derived a supervised classification on the six reflective bands for the two images individually in the Northwestern coast of Egypt with the aid of ground truth data. Ground truth information collected during six field trips conducted between 1998 and 2002 and land cover map of 1987 were used to assess the accuracy of the classification results. Using ancillary data, visual interpretation and expert knowledge of the area through GIS further refined the classification results. Post-classification change detection technique was used to produce change image through cross-tabulation. Changes among different land cover classes were assessed.

Ademola and Alabi (2011) Utilized remote sensing and spatial-statistical geostatistics to model future land degradation in the mud-beach coast of south-west Nigeria. Attribution of weights to variables was done through multi-criteria evaluation. These weights were used to develop logistic regression function for simulating probability surface maps. Degraded lands accounted for about 30.2 per cent of the total land cover with permanently inundated lands and bare surfaces contributing 22.4 per cent. The results suggest that soils, geology, elevation, distance to ocean, and location of old bitumen wells as the most important predictor variables. Simulated composite probabilities for transmitting into degraded lands range between 0.4184 and 0.4871 in the next 20 years (from 2001) to between 0.4284 and 0.4973 in the next 100 years.

2.2 Morphological characteristics of soils.

Sharma *et al.* (1996) observed while characterizing soils in a toposequence over basaltic terrain of southern Rajasthan, that the soils are brown to grayish color. The presence of non hydrated iron oxides; might be the reason for the development of brown colour.

Walia and Rao (1997) studied the characteristics and elemental composition of soils of four pedons representing four landforms of Banda plain in Uttar Pradesh, they observed that the soils of piedmont plain are well drained, reddish brown, clay loam of moderately eroded, while soils of recent dissected flood plain were somewhat excessively drained, light yellowish brown sandy clay loam with lime concentrations. The soils of undulating flood plain were moderately well drained, dark grayish brown, clayey soil with deep cracks and weak slickensides, whereas the soils of level flood plains are imperfectly drained, fine grained, brown to olive brown, silty clay, showing surface cracks and redoximorphic features.

Challa *et al.* (2000) while doing the characterization and classification study of the problematic Vertisols in Maharastra reported that Khondwad and Kadambhe soils of piedmont plain are dark grayish brown while Amalner and Valpi soils of flood plain are dark yellowish brown in colour.

While characterizing the soils of different physiographic unit in sub-humid ecosystem of Kashmir valley Mahapatra *et al.* (2000) observed that attitude and relief have significant bearing on the properties like depth, color, texture, structure, consistence etc. the surface horizon was darker than the subsoil suggesting high organic matter content in the surface layer.

Rudramurthy and Dasog (2001) while studying properties and genesis of red and black soils in North Karnataka reported that red soils were characterized by redder hue, high chroma and abundance of coarse fragments. Black soils on the other hand were characterized by yellower hue, low chroma and fewer coarse fragments.

Sitanggang *et al.* (2006) observed that the depth of soil in the study area varied from 35 to more than 150 cm due to variation in topography and slope gradients and the weak structure development is due to the low clay and low organic carbon.

Saha and Mishra (2007) evaluated the long term effect of different land use systems on soil hydro-physical properties under hilly eco system. Saturated water content in forestry system was 23.30 per cent higher than that in the shifting cultivation plot. Significant increase in available water under modified land use systems as compared to shifting cultivated areas may attributed to the differences in quantity and nature of colloidal material present, pore size distribution and organic C content (2.70-3.06 %).

2.3 Physical characteristics of soils

Rajamannar and Krishnamoorthy (1978) noticed that the clay content of the forest soils of Western Ghats in South India increased with depth of the profile.

Datta *et al.*, (1990) noticed that undulating terrain affected by erosion in Tripura recorded the bulk density ranging from 1.25 to 1.50 Mg/ m^3 under lowland, upland and river valley. Lowland recorded lowest bulk density where as river valley recorded the highest bulk density.

Sahu *et al.* (1990) while characterizing the red and lateritic soils of Northern plateau zone of Orissa formed on highly weathered gneissic parent material, observed that the content of clay increased with depth in all profiles with a simultaneous decrease in sand content indicating translocation of clay under well drained condition. There was evidence of argillic horizon because of illuviation of clay.

While characterizing the typical pedons of hill slope soils of middle Andaman Island, Nirmalya Bala and Sahu (1993) observed that the clay distribution down the profile did not follow any regular pattern.

Bulk density of laterites and associated soils of east coast of Andhra Pradesh varied from 1.2 to 1.7 Mg/ m^3. When the depth increased, the bulk density was also increased (Bhaskar and Subbaiah, 1995).

Depth of the laterites and associated soils of east coast of Andhra Pradesh varied from 36 to 92 cm. shallow depth is mainly due to water erosion which was accelerated due to quarrying activity in this area (Bhaskar and Subbaiah, 1995)

Sharma *et al.* (1996) observed while characterizing soils in a toposequence over basaltic terrain of southern Rajasthan, that the soils at elevated topography were shallow to moderately shallow, clayey to loamy skeletal texture and yellowish brown, while a lower topography soils were deep to very deep, fine to fine loamy texture and grayish colour.

While characterizing the soils of an irrigated river flood plain in the eastern coastal region, Sahu and Mishra (1997) observed that sand and silt content in all pedons decreased from downwards whereas clay content gradually increased down the depth indicating Pedogenic soil development.

Sarma *et al.* (1997) studied the physical properties of two soils (Alfisols and Inceptisols) from different command areas of Assam and observed that bulk density was higher in Alfisols and Inceptisols and it increased with depth in both the soils. The surface layer of both soils contained higher percentage of aggregates less than 0.25 mm when compared to subsurface layers. The clay content was found to be the single most dominant factor influencing the physical attributes of soils

While studying the characteristics of Kandibelt soils of Jammu region under land use Gupta *et al.* (2001) observed a great variation in texture in surface and subsurface soils of different locations attributed it as translocation of clay.

Dutta *et al.* (2001) observed that the soil in south India are shallow to medium indicating that the process of denundation and erosion were more active than the weathering process, soils were well drained, there is no observable clay cutans in Bt horizon. This may be due to the continuous ploughing which must have obliterated and coarser fractions dominate which could be largely siliceous nature because of granite- gneiss parent material.

Gangopadhyay *et al.* (2001) while studying rubber growing soils of Tripura that increase in clay content with depth and the development of soil structure, indicate the development of cambic horizon (Bw).

Sitanggang *et al.* (2006) observed that the texture of soil varied from sandy loam to clay loam. The textural variation is due to variation in the parent material and topography. Soils having high percentage of sand or gravel have more bulk density than those having high clay content. High bulk density is due to their coarser texture.

2.4 Chemical characteristics of soils

2.4.1 Soil reaction (pH)

Soils of Bangalore district were found to be acidic to near neutral and showed decreasing trend with the depth as reported by Reddy *et al.* (1993).

In Vijayapura and Tyamagondlu soil series of Karnataka, pH values ranged from moderately acidic to slightly acidic and increasing with the depth of the profile (Prakash *et al.*, 1993).

In a study on red soils of Bundelkhand region of Uttar Prdesh, Walia and Rao (1996) noted that there is tendency of pH to increase with depth possibly due to the leaching of bases.

Shivaprasad *et al.* (1998) while characterizing the soils of Karnataka observed that soils derived from granite gneissic parent material were found to be slightly acidic to near neutral in soil reaction.

Dutta *et al.* (2001) while studying the characterization and classification of Paleosols in part of south India observed that KCl-pH values are much lower than water pH values though the acidity measured by 1.0 N KCl is negligible.

Das *et al.* (1991), the pH showed a decreasing trend at higher doses of manure. Humic and Fulvic carbon contents did not show any definite trend. The degree of decrease was more pronounced under soil with low organic matter status than under high organic matter status. The pH, humic and fulvic carbon contents showed differential patterns with nutrient availability at different intervals.

2.4.2 Electrical Conductivity

Working with red and black soils of Andhra Pradesh, Krishnamoorthy and Govinda Rajan (1977) observed that in red soils electrical conductivity values ranged from less than 0.15 to 0.25 dSm^{-1} and did not show any trend with the depth of soil while electrical conductivity of black soil ranged from 0.15 to 0.80 dSm^{-1} and showed increasing trend with depth.

While characterizing the lateritic soils of Dakshina Kannada district of Karnataka, Sathisha (1991) reported that the electrical conductivity of these soils was very low, ranging from 0.08 to 0.32 dSm^{-1} and did not show any relation with depth of the profile.

Sivasankaran *et al.* (1993) while characterizing the soils of Western Ghats in Karnataka observed that the electrical conductivity values ranged from 0.1 to 0.4 dSm^{-1} indicating no accumulation of salts in the soils.

2.4.3 Organic carbon (OC)

Pal *et al.* (1985) on characterizing three soil profiles of Darjeeling forest soils noticed a sharp decrease of organic matter with depth in two profiles while in the other organic carbon was more in second layer than in first layer but decreased with further increase in depth.

Sathisha and Badrinath (1994) while characterizing the soils of Western Ghats in Dakshina Kannada in Karnataka observed that the organic carbon decreases with terrain elevation; soils of high elevation at Agumbe were rich in organic matter followed by soils situated in Hillocks.

Walia and Rao (1996) working with red soils of Bundelkhand region of Uttar Pradesh, noticed that the organic carbon content of soils (0.5 % to 1.5 %) decreased with depth. The distribution is mainly associated with physiography and land use.

The organic carbon content of lateritic soils (Bangalore plateau) varied between low to medium and showed decreasing trend regularly down the profile (Shivaprasad *et al.* 1998).

Gan-lin Zhang *et al.* (2007) found that rubber cultivation resulted in significant decline of soil organic C and microbial biomass C in highly weathered ferrosols of tropical China.

2.4.4 Cation exchange capacity and exchangeable bases

Walia and Chamuah (1988) studied the acidic catenary soils in old flood plains of Assam and reported that cation exchange capacity values are low which were attributed to predominance of kaolinitic clay in the soil. Under heavy rainfall and intensive leaching, variation in cation exchange capacity values with depth in both the profiles was related to clay content.

Increase in cation exchange capacity with depth was noted in red and lateritic soils of Northern plateau zone of Orissa by Sahu *et al.* (1990) and it was attributed to gradual increase in clay content with the depth of the profile.

While characterizing the various pedochemical characteristics of Mizoram soils, Singh *et al.* (1991) observed high cation exchange capacity in the surface layer compared to subsurface. Low values of cation exchange capacity in subsurface was attributed to the presence of pH dependent exchange sites occupied by either hydrogen or hydroxyl aluminum ions at low pH. Exchangeable calcium, magnesium and potassium decreased with depth at all altitudes.

Das *et al.* (1992) reported that cat ion exchange capacity of lateritic soils of Orissa varied from 2.9-13.4 cmol (p^+) kg^{-1} of soil and increased with depth. Base saturation percentage of these soils ranged from 34 to 80 per cent.

While characterizing the red soils of Manipur, Sen *et al.* (1993) observed that the cation exchange capacity and base saturation values showed decreasing trends with depth.

While characterizing the lateritic soils of North Karnataka, Narayana Rao *et al.* (1993) observed that both cation exchange capacity and per cent base saturation values showed regular increasing trend down the profile.

Sen *et al.* (1997) while characterizing some of the soils of Barak valley in Assam observed that cation exchange capacity of the soils was generally low and it varied from 6 to 12 cmol (p^+) kg^{-1}. The cation exchange capacity of surface soil was higher due to organic matter content.

Sitanggang *et al.* (2006) observed that the Depth wise distribution of CEC followed the pattern of clay distribution and low CEC is due to low clay content and also type of clay mineral present in the soil.

2.4.5 Nature of acidity

Lindsay *et al.* (1959) reported that major portion of acidity in acid soils originate from hydrolysis of Al, Fe and Mn, thereby forming HO which lowers the pH of the soil.

Misra *et al.* (1989) working with Inceptisols, Alfisols and Entisol of Orissa reported that total soil acidity varied from 1.3 to 11.6 cmol (p^+) kg^{-1}. The pH dependent acidity was more than 83 per cent of potential acidity and was mainly associated with inorganic fraction of soil such as oxides of iron and aluminum. Free iron oxides of soil ranged from 0.29 to 9.18 per cent.

According to Sharma *et al.* (1990) the total acidity of Indian soils comprised of pH dependent and exchangeable acidity. The most important soil factors which control the different kinds of soil acidity are pH, organic matter content, exchangeable and extractable aluminum.

Acidity of soil is related to the parent material, rainfall and topography as the soils developed on granite gneiss were relatively more acidic than the soil developed on alluvium. In sedentary soil the acidity was directly related with the age of soil. Whereas in alluvial soil, it was governed by vertical leaching of soil at lower physiographic level (Singh *et al.*, 1993). Noted that in acid soil on granite gneiss, the exchange acidity was more in upland than the lowland.

Misra and Saithantuaanga (2000) observed in acid soils of Mizoram, that the relationship between pH and Al saturation of soil provides a quantitative assessment whether Al toxicity is likely to be a problem or not. Aluminium saturation of soil was essentially zero at pH 5.6 and 43 percent at pH 4.5. Most of the Mizoram soils had higher Al saturation, which was a constraint for crop production.

While working with characterization and classification of

Paleosols in part of South India, Dutta *et al.* (2001) observed that the $BaCl_2$-TEA acidity gives higher values due to large amounts of Al.

2.5 Available nutrients

2.5.1 Available nitrogen

The available nitrogen content of the surface soil ranged from 0.019 to 0.029, 0.020 and 0.014 to 0.016 per cent in Peelamedu, Periyanayakkanpallam and Dasarpatty series, respectively and decreased with depth (Parasuram and Jayaraj, 1982).

In Karnataka about 10.3 per cent of soils fall under low category, 35.8 per cent under medium and 53.9 per cent under high category of available nitrogen status as reported by Shivaprasad *et al.* (1998).

Misra and Saithantuaanga (2000) while studying the distribution of organic carbon and nitrogen in Terai soils of West Bengal reported that the available nitrogen in the soil profile decreased with depth, this follow similar trend as that of organic carbon. A relatively higher content of nitrate nitrogen in the surface horizon may be on the other hand due to high nitrification.

2.5.2 Available phosphorous

Working with characterization of soils of Western Ghats in Dakshina Kannada district, Karnataka, Sathisha and Badrinath (1994) observed that low status of available phosphorous was mainly attributed to its higher removal than replenishment and also high P fixing capacity.

The data on the available phosphorous status in the soils of Karnataka showed that about 83 per cent of the soils are low in phosphorous and 17 per cent area is under medium category (Shivaprasad *et al.*, 1998).

Misra and Saithantuaanga (2000) observed that the acid soils of Mizoram were low in available phosphorous.

Gan-lin Zhang *et al.* (2007) Available P was extremely low for all soils, resulting from the naturally low P content and the high sorption capacity of highly weathered Ferralsol.

2.5.3 Available potassium

Badrinath *et al.* (1986) while studying the fertility status some typical soils of coastal Karnataka reported that the available potassium varied from 30 to 220 kg ha^{-1}. The Puthur soils have low potassium content. Coarse textured and gravelly soils with deeper solum are particularly low in potassium.

While characterizing and classifying soils of an irrigated river flood plain in the eastern coastal region, Sahu and Mishra (1997) reported that the available potassium content varied from 171.0 to 211.7 kg per hectare and was in medium level.

The available potassium is medium to high in most of the soils of the Karnataka state except in laterite soils of coastal and western Ghats and in shallow red and black soils (Shivaprasad *et al.*, 1998).

In the acid soils of Mizoram, Misra and Saithantuaanga (2000) observed that 71 per cent of Entisols, 100 per cent of Inceptisols and 77 per cent of Ultisols were high in available K.

2.5.4 Micronutrients

Ghosh and Sarkar (1994) recorded the available zinc status up to 4.15 ppm in some acid sedentary soils of Chota Nagpur region indicating the importance organic carbon in the available pool of zinc as these bore significant correlation.

Bhaskar *et al.* (2004) recorded the micro nutrient distribution in soils on hill slopes of Narang-Kongripara watershed of Meghalaya.

The iron content in surface horizon ranged from 6.1 to 46 mg kg^{-1} and in sub- surface it ranged from 4.22 to 131.8 mg kg^{-1}.

2.6 Land degradation and its assessment

Land degradation reduces the productivity and carrying capacity of land. Land degradation is a process, which lowers the current and potential capability of soils to produce goods and services, qualitatively and quantitatively (FAO, 1979).

According to the latest estimate, 188 M. ha (57 % of the TGA) of land area is affected by various forms of degradation in India. Out of this, 162.4 M. ha is due to the displacement of soil materials by water and wind erosion and 10.1 M. ha is due to salinity (Sehgal and Abrol, 1994).

Tamgadge *et al.* (2000) assessed the status of soil degradation in Madhya Pradesh and found that about 59 per cent of total geographical area of state is degraded by various factors and processes. The degradation was mainly due to water erosion specially loss of top soil and terrain deformation, which amounts to 55.7 per cent of the total geographical area of the state.

In Karnataka, saline soils occur in about 1.0 lakh hectares and sodic soils in about 10,000 ha (Natrajan *et al.*, 2005). About 7.7 M. ha of land, out of 19.1 M.ha of total geographic area is under various forms of soil degradation problems. Water erosion is the major problem in 5.9 M. ha (30.9 %) and salinity, sodicity and water logging in about 1.8 M.ha (Prasad *et al.*, 1998) in the state.

Sidhu *et al.* (2007) assessed the degradation status of Himachal Pradesh and reported that about 53.8 per cent area of the state is affected by water erosion. Stoniness is the next main problem, mostly associated with water erosion and occupying area of 23.1 per cent of TGA. About 23 per cent is under rock outcrops, glaciers, and icecaps and hold unfit for agriculture in the state.

III. MATERIAL AND METHODS

In order to meet the objectives of the research programme seven locations were selected in west coast of southern Karnataka in order to study external land features, land use and soil qualities. The description of study area and sites selected, soil sampling and methods of soil analysis are presented in this chapter. This chapter has been subdivided into 7 sub chapters *Viz.*,

3.1 Climatic data and analysis

Climatic data recorded by Indian Meteorological Department (IMD) for 1980 to 2002 was used in the present study and arriving at climatic parameters (Table 1).

Weekly rainfall and potential evapotranspiration were used in the study. Length of dry season is taken as the number of months in which the precipitation falls below 50 mm.

Water balance diagrams were prepared using climate and soil data of study area as per the method suggested by Thornth waite and Mather (1955).

3.2 Acquiring of data base for preparation of base map Data base

The survey of India toposheet of 1:2,50,000 scales, which covers the west coast of southern Karnataka, was used to prepare base maps (48J, 48N, 48K, 48O, 48L) in conjunction with satellite imageries IRS LISS-III P6 FCC and Google earth imageries where ever necessary.

A tracing film was overlaid on the toposheet covering the study area. Boundary of the west coast and important land features like rivers, tanks, roads, etc., were extracted. Thus a map having the above common land feature was used as a base map for preparing different thematic maps.

3.3 Interpretation of imageries conjunction with toposheets

Imageries of west coast of southern Karnataka were collected from Karnataka Remote Sensing Application Center, Bangalore. All the imageries were interpreted on conjunction with respective toposheets, based on tonal variation, texture and pattern. Permanent structures like roads, railway lines, lakes, were marked first in the tracing sheet mounted on toposheets and it was super imposed with imageries.

3.3.1 Preparation of soil physiography map

Soil physiography map (Fig 2) has been prepared by super imposing 1:2, 50, 000 scale toposheet and in some cases 1:50, 000 scale toposheets and IRS LISS-III P6 FCC imageries.

3.3.2 Study of soil resource map of west coast of Southern Karnataka

Soil units description was studied by excavating soil resource map (Fig 3) of West Coast of Southern Karnataka in detail which is depicted in (Table 2).

3.3.3 Preparation of degradation map by interpreting Satellite imageries

Degradation map of the study area was prepared by interpreting satellite imageries in conjunction with respective toposheets, based on tonal variations, texture and pattern. Permanent structures like roads, railway lines, and water bodies were first traced digitized and super imposed on the interpreted satellite imageries and different types of degradation were demarked on the imageries.

3.3.4 Flow chart for developing land degradation status map

A flow chart has been devised and followed (Fig 4) for characterization of land resources of west coast of southern Karnataka

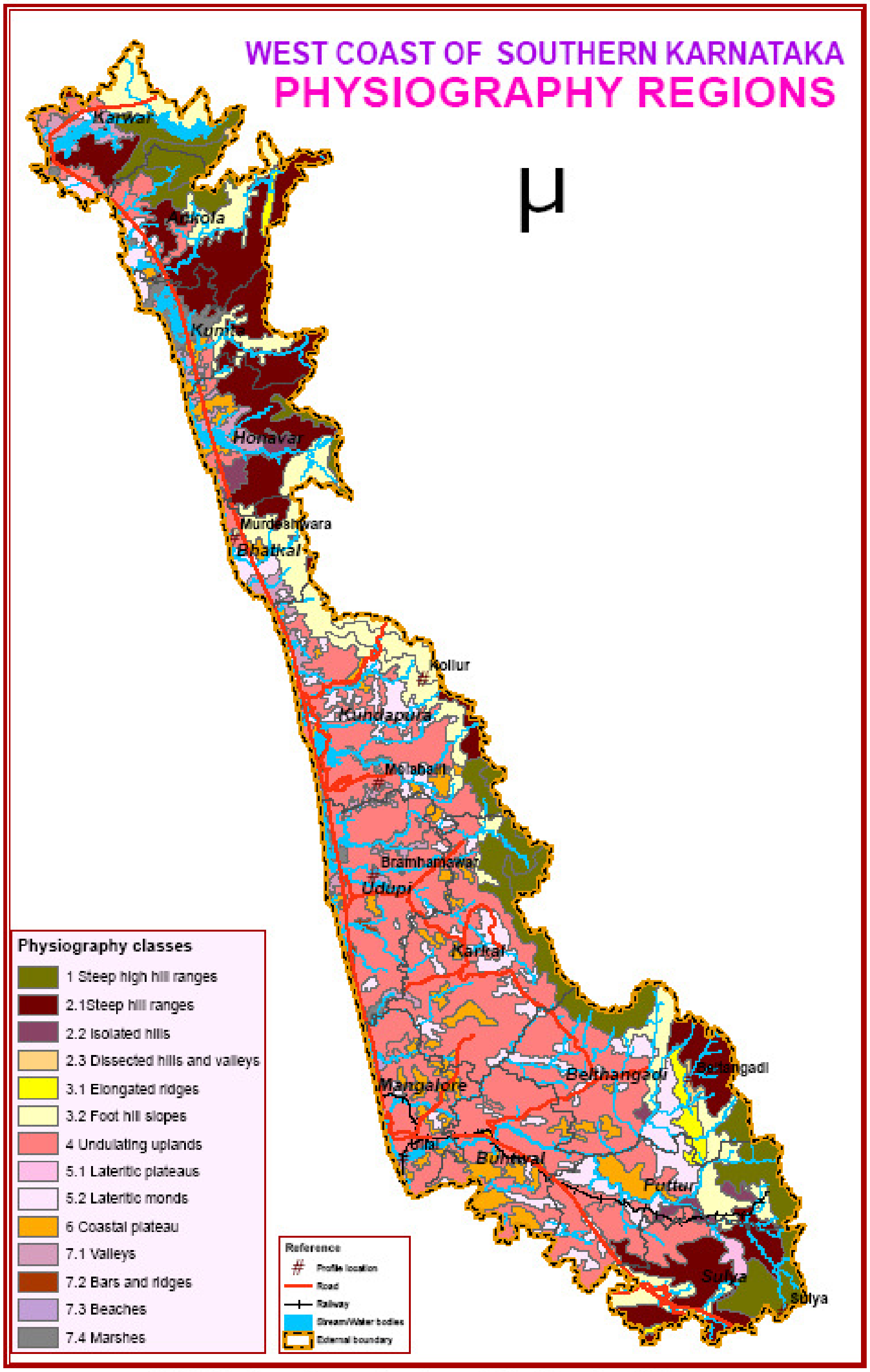


Fig 2: Physiography map of west coast of southern Karnataka

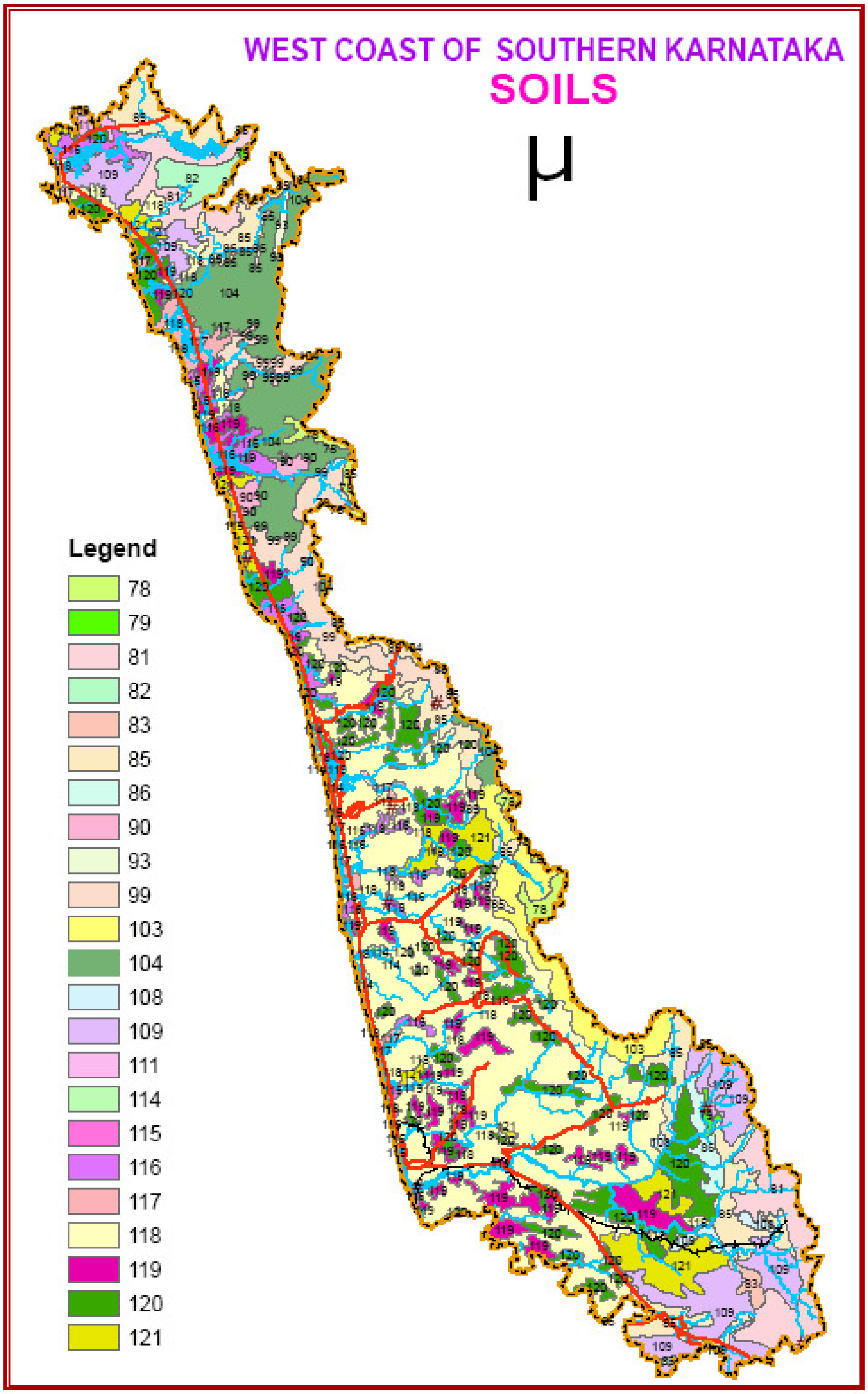


Fig 3: Soil map of west coast of southern Karnataka excavated out of SRM Karnataka

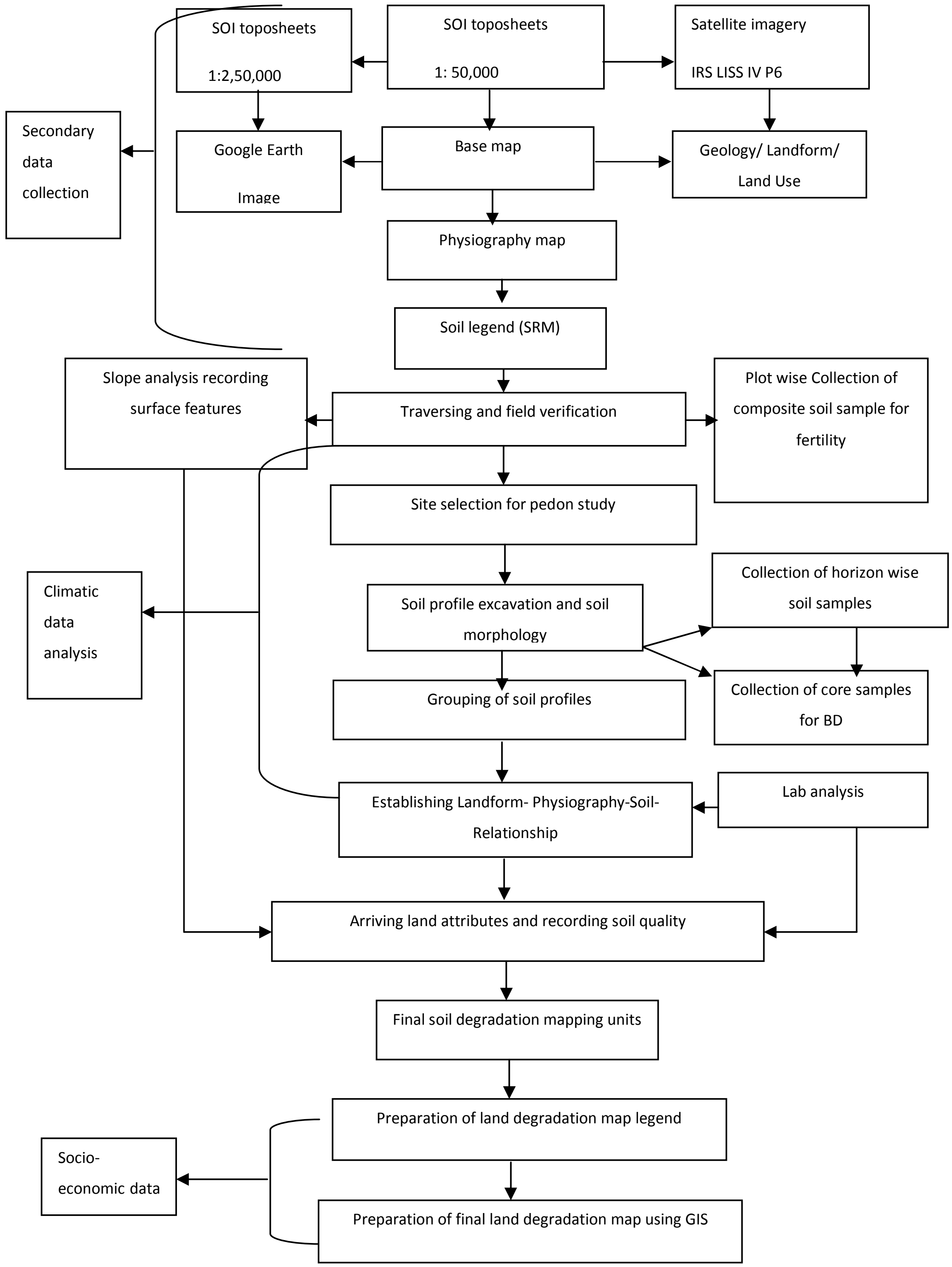
Table 2: Description of soil map of west coast of southern Karnataka extracted from soil resource map of Karnataka

Sl no.	Description
78	Very deep, well drained, gravelly clay soils, strongly gravelly in the sub soils on steeply sloping high hill ranges, with moderate erosion, associated with: very deep, well drained, clayey soils. · Clayey-skeletal, kaolinitic family of Typic Kandiustalfs. . Fine, kaolinitic family of Kandic Paleustalfs.
79	Deep, well drained, clayey soils on dissected hills and valleys with moderate erosion; associated with: very deep, well drained, clayey soils. · Fine, kaolinitic family of Typic Kanhaplustalfs. · Fine, mixed, Typic Argiustolls.
81	Deep well drained, gravelly clay soils with low AWC, strongly gravelly sub soil with, high hill ranges with steep slopes; associated with well drained, clayey soils, severely eroded. · Clayey-skeletal, kaolinitic family of Kandic Paleustalfs. · Clayey, kaolinitic, Paleustults.
82	Deep, well drained, gravelly clay soils on slopes of steeply sloping high hills ranges, with moderate erosion, associated with; moderately shallow, well drained, clay soils with low AWC, strongly gravelly in the subsoil. · Clayey-skeletal, kaolinitic family of Kandic Paleustalfs and Ustic Haplohumults.
83	Very deep, Well drained, clayey soils with medium AWC on laterite plateus, with moderate erosion; associated with: deep, well drained, clayey soils with medium AWC. · Fine, kaolinitic, Kandic Paleustalfs. · Clayey, kaolinitic, Kanhaplic Haplustults.

85	Deep, Well drained, clayey soils with medium AWC on foot hill slopes, with severe erosion; associated with: moderately deep, well drained loamy soils. · Fine, kaolinitic, Kandic Paleustalfs · Fine-loamy, mixed Kanhaplic Rhodustalfs.
86	Deep, well drained, clayey soils with medium AWC on elongated ridges, with slight erosion, associated with: deep, well drained, clayey soils, severely eroded. · Fine, mixed,Rhodic Paleustalfs. · Clayey-skeletal, mixed Typic-Rodiustalfs.
90	Moderately shallow, well drained, gravelly clay soils with very low AWC on isolated hills, with moderate erosion, associated with: moderately shallow, well drained, gravelly clay soils with very low AWC. · Clayey-skeletal, kaolinitic family of Kanhaplic Haplustalfs and Ustoxic Dystropepts.
93	Deep, well drained, clayey soils with medium AWC on elongated ridges with moderate erosion associated with: Deep, somewhat excessively drained, clayey soils. · Fine, mixed, Kanhaplic Haplustalfs. · Clayey -skeletal, mixed, Typic Ustropepts.
99	Moderately shallow, well drained, clayey soils with low AWC on foot hill slopes, with moderate erosion; associated with: Deep, well drained, clayey soils with medium AWC. · Fine, kaolinitic, Ustoxic Dystropepts. · Clayey, kaolinitic, Ustic Kandihumults.
103	Very deep, well drained, gravelly clay soils with low AWC on steeply sloping high hill ranges, associated with: moderately deep, somewhat elxcessively drained, gravelly clay soils, moderately eroded. · Clayey-skeletal, kaolinitic family of Ustic Kandihumults and Ustic Kanhaplohumults.
104	Deep, well drained, clayey soils with medium AWC on low hill ranges, with moderate erosion; associated with: moderately deep, well drained, clayey soils. · Clayey, kaolinitic, Ustic Kandihumults. · Fine, mixed, Typic Argiuistills.

108	Very deep, well drained, clayey soils with medium AWC on isolated hills, with moderate erosion, associated with: deep, somewhat excessively drained, gravelly loamy soils with stoniness, severely eroded. · Clayey, kaolinitic, Ustic Palehumults. · Loamy-skeletal, mixed, Ustic Kandihumults.
109	very deep, well drained, gravelly clay soils, with low AWC on low hill ranges, with moderately erosion, associated with; moderately deep, somewhat excessively drained, gravelly clay soils. · Clayey skeletal, kaolinitic, Ustic Haplohumults. · Clayey-skeletal, kaolinitic, Ustic Kanhaplohumults.
111	Deep, well drained, clayey soils, with medium water AWC on high ranges, with moderate erosion: associated with deep, wel drained, gravelly clay soils with Low AWC · Clayey, kaolinitic, Ustic Haplohumults · Clayey, kaolinitic, Ustic Kandihumults
114	Very deep, moderately well drained, sandy soils with very low AWC on bars and ridges; Associated with: Very deep, imperfectly drained, clayey soils. · Mixed, Typic Ustipsamments. · Fine, kaolinitic, Ustoxic Dystropepts.
115	Deep, imperfectly drained, sandy soils on beaches, associated with: Deep, imperfectly drained, sandy soils with shallow water table. · Mixed, Typic Ustipsamments · Mixed, Aquic Ustipsamments
116	Deep, imperfectly drained, sandy over loamy soils of valleys, with shallow water table; associated with: deep, imperfectly drained, clayey over sandy soils. · Sandy over loamy, mixed, Aquic Ustifluvents. · Clayey, over sandy, mixed, Aquic Ustifluivents.
117	

	Very deep, poorly drained, loamy over sandy soils of marshes with very shallow water table; associated with: deep, poorly drained, clayey soils with shallow, water table. · Loamy over sandy, mixed, Aquic Ustifluvents. · Fine, mixed, Aquic Ustifluvents.
118	Very deep, well drained, gravelly clay soils with surface crusting and compaction on undulating uplands with moderate erosion; associated with: very deep, well drained, gravelly clay soils with surface crusting and compaction. · Clayey-skeletal, kaolinitic family of Typic Kandiustults and Rhodic Kandiustalfs.
119	Moderately shallow, somewhat excessively drained, gravelly clay, soil with hard iron stone on coastal plateaus summits, with moderate erosion; associated with iron-stone crust. · Clayey skeletal, kaolinitic, Petroferric Haplustults.
120	Very deep, well drained, gravelly clay soils with low AWC on laterite mounds with slight erosion; associated with; moderately shallow, well drained, gravelly claysoils with low AWC and surface crustind. · Clayey-skeletal, kaolinitic family of Ustic Haplohumults and Kanhaplic Haplustults.
121	Moderately deep, well drained gravelly clay soils with low AWC and surface crusting on undulating uplands, with moderate erosion, associated with; moderately deep, well drained, gravelly clay soils. · Clayey-skeletal, kaolinitic family of Kanhaplic Haplustults.



Modified from Nalina (2010).

Fig 4: Flow chart for land degradation map preparation.

and to arrive at soil degradation mapping unit by systematically following steps in which base map preparation, physiography and soil map preparation taking help of SRM (Karnataka) data base and degradation type map made out of satellite imageries IRS LISSS III P6 and land use, land cover.

3.4 Study area

Physiography of transects marked at the time of interpretation were traversed in detail in the field. It consists of steep high hill ranges, steep low hill ranges, isolated hills and dissected hills and valleys, elongated ridges and foot hill slopes, undulating uplands, lateritic plateau and lateritic mounds, coastal plateau summits, valleys, bars and ridges, beaches and marshes, which were used for the study of land use such as, in steep high hill ranges, in steep low hill ranges, isolated hills and dissected hills and valleys it was under rubber cultivation, in elongated ridges and foot hill slopes it was under rubber plantation, undulating uplands it was in forest area, in lateritic plateaus and lateritic mounds it was under rubber plantation, in coastal plateau summits it was under cashew plantation, in valleys, bars and ridges, beaches and marshes it was in harvested paddy field. Soils are deep to moderately deep.

Seven representative sites were selected for profile study in west coast of southern Karnataka *Viz.*, Sullya, Beltangadi, Kollur, Molahalli, Brahmavar, Murdeshwar and Ullal (Table 3). These areas experiences Humid climatic conditions. According to delineation of NARP Zones in the state these areas comes under Zone 10 (Coastal Zone).

The sites for sampling were chosen on the basis of physiography, geology, vegetation, microclimate, degree of erosion, away from field boundaries, roads and rivers. The sites selected were representative of the area. A profile of dimension of 1.5 x 1.5 x 2 m was dug. The profile was oriented in such a manner that a face was

Table 3: Details of physiographic division identified for characterization and assessing land degradation in West coast of Southern Karnataka.

Pedon	Physiographic division	Location	Land use
Pedon 1	Steep hill ranges	Sullya	Rubber
Pedon 2	Steep low hill ranges, isolated hills and dissected hills and valleys	Beltangadi	Rubber
Pedon 3	Elongated ridges and foot hill slopes	Kollur	Rubber
Pedon 4	Undulating uplands	Molahalli	Forest
Pedon 5	Lateritic plateaue and lateritic monds	Brahmavar	Rubber
Pedon 6	Coastal plateau summits	Murdeshwar	Cashew
Pedon 7	Valleys, bars and ridges and beaches and marshes (lower laterite terrace)	Ullal	Paddy

well lighted. Side to be examined was made even and different horizons were demarcated based on variability in colour, texture and structure. The details like depth, colour, texture, rock fragments, structure, presence of mottles, consistency were studied and recorded in the standard proforma for soil profile description.

3.4.1 Sampling site no.1 (12° 31' 11.4" N latitude, 75° 31' 00.4" E longitude)

Location: Kadamakkala estate, Sullya Taluq, Dakshina kannada District

Sullya experiencing humid tropical climate receives average annual rainfall of 3738 mm (Fig 5). Length of growing period (LGP) for annual crops (period of soil moisture availability) is 238 days. Site characteristics and soil morphology are explained below and google earth imager, landscape view, land use and soil profile photo are given in plate 1 and 2.

A soil profile was excavated and studied in Sullya. The site description and soil morphology are presented in the following section.

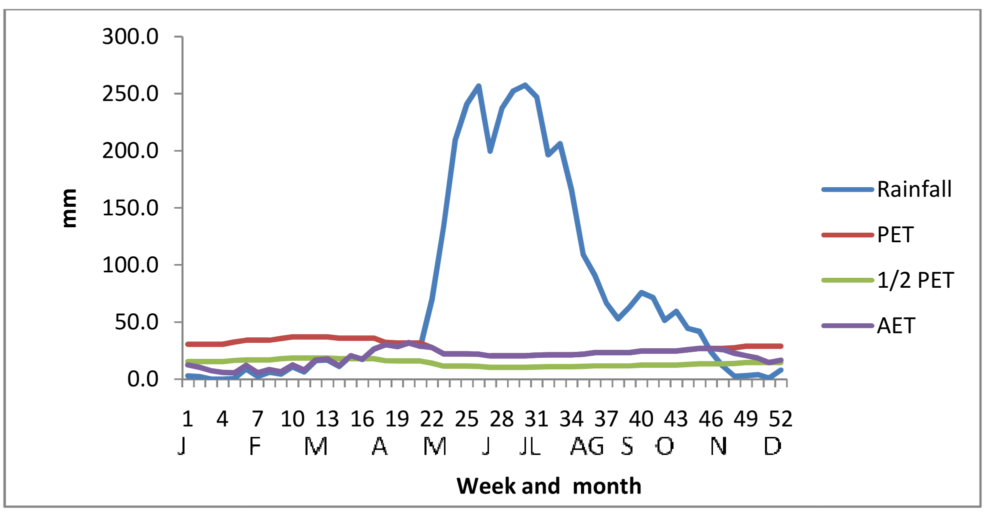


Fig .5 Rainfall, PET, AET data of Sullya

PET- Potential Evapotranspiration

AET- Actual Evapotranspiration

Pedon 1: Sullya

Climate	: Hot humid tropics
Elevation	: 252 m above MSL
Rainfall	: 3738 mm
Slope	: 5-10 %
Physiography	: Steep high hill ranges
Erosion	: Severe
Drainage	: Well drained
Soil parent material	: Granite gneiss
Land use	: Rubber
Soil classification	: Fine, kaolinitic, isohyperthermic, Ustic Kandihumults

Horizon	Depth (cm)	Soil characteristics
Ap	0-10	Dark reddish brown (5YR 3/4) gravelly sandy clay loam; weak, medium, sub-angular blocky structure; slightly hard, friable, sticky and plastic consistency; many fine roots; common fine pores; 16 per cent fine gravel; strongly acid (pH 5.4); clear smooth boundary.
Bt1	10-33	Reddish brown (5YR 4/4) sandy clay loam; moderate medium sub-angular blocky structure; friable, sticky and plastic consistency; many fine roots; few fine pores; 12 per cent fine gravel; patchy thin clay skins; strongly acid (pH 5.2); gradual smooth boundary.
Bt2	33-54	Reddish brown (5YR 4/4) clay; moderate medium sub-angular blocky structure; friable, sticky and plastic consistency; few medium roots; common fine pores; 8 per cent fine gravel; patchy thin clay skins; strongly acid (pH 5.1); gradual smooth boundary.

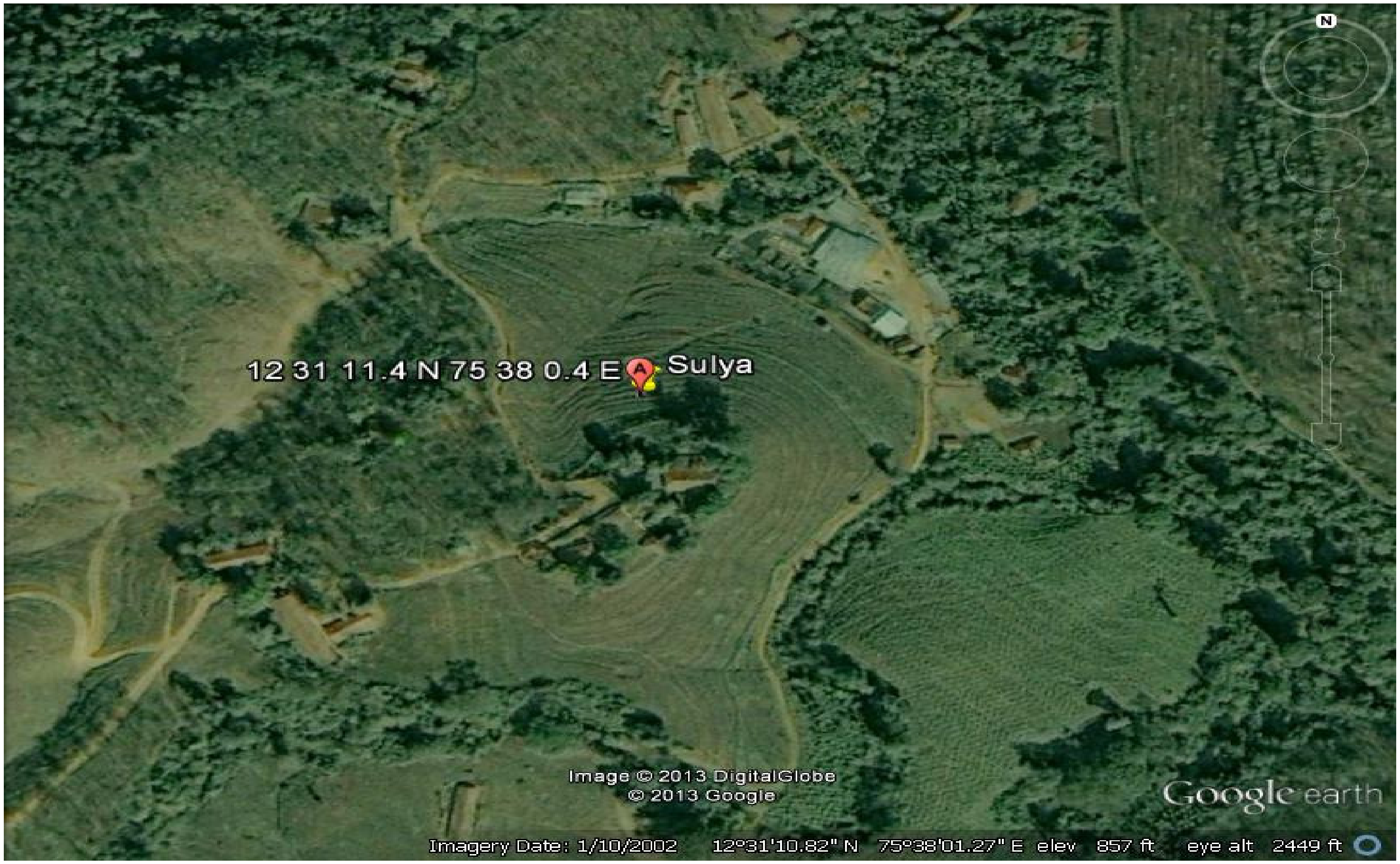


Plate 1: Landscape view of profile location in Sullya (magnified from 1:2,50,000 scale image)


Plate 2: Land scape, land use and profile view of Sullya

Bt3	54-90	Reddish brown (2.5YR 4/4) gravelly clay, moderate medium sub-angular blocky structure, very friable, sticky and plastic consistency; few medium roots; few coarse pores; 16 per cent fine gravel; patchy thick clay skins; very strongly acid (pH 4.8); gradual smooth boundary.
Bt4	90-121	Dark red (2.5YR 3/6) gravelly clay; moderate medium sub-angular blocky structure; friable, sticky and plastic consistency; few fine roots; few very fine pores; 24 per cent fine gravel; patchy thick clay skins; strongly acid (pH 5.2); clear smooth boundary.
Bt5	121-150	Dark red (2.5YR 3/6) gravelly clay; moderate medium sub-angular blocky structure; friable, sticky and plastic consistency; few very fine roots; common fine pores; 16 per cent fine gravel; patchy thick clay skins; strongly acid (pH 5.1)

3.4.2 Sampling site no. 2 (13° 0' 11.1" N latitude, 75° 26' 10.3" E longitude)

Location: Neriya village, Belthangadi Taluk, Dakshina Kannada District

Beltangadi experiencing humid tropical climate receives average annual rainfall of 4485 mm (Fig 6). Length of growing period (LGP) for annual crops (period of soil moisture availability) is 231 days. Site characteristics and soil morphology are explained below and google earth imager, landscape view, land use and soil profile photo are given in plate 3 and 4.

A soil profile was excavated and studied in Beltangadi. The site description and soil morphology are presented in the following section.

Plate3: Landscape view of profile location in Beltangadi (magnified from 1:2,50,000 scale image)

Plate 4: Land scape, land Use and profile view in Beltangadi

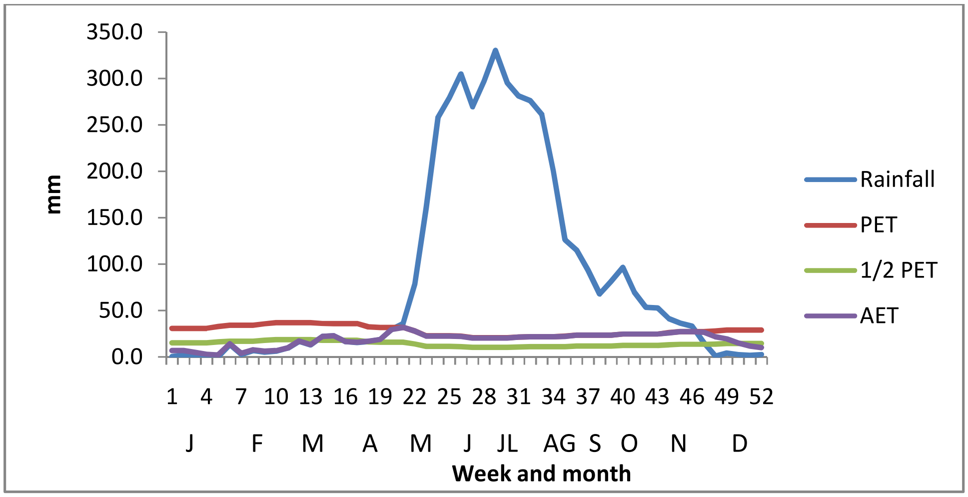


Fig .6 Rainfall, PET, AET data of Beltangadi

PET- Potential Evapotranspiration

AET- Actual Evapotranspiration

Pedon 2: Beltangadi

Climate : Humid tropics

Elevation : 148 m above MSI

Rainfall : 4485 mm

Slope : 1-3 %

Physiography : Steep low hill ranges, isolated hills and dissected hills and valleys

Erosion : Slight

Drainage : Well drained

Soil parent material : Granite gneiss

Land use : Rubber

Soil classification : Fine-loamy, kaolinitic, isohyperthermic, Ustic Kanhaplohumults

Horizon	Depth (cm)	Soil characteristics
Horizon	**Depth (cm)**	Dark reddish brown (5YR 3/3) gravelly sandy clay loam; weak fine, sub-angular blocky structure; friable, sticky and plastic consistency; many medium roots; common fine pores; about 28 per cent stones; strongly acid (pH 5.2); clear smooth boundary.
Ap	0-18	Dark reddish brown (5YR 3/4) gravelly sandy loam; weak medium sub-angular blocky structure; friable, sticky and plastic consistency; few fine roots; common fine pores; 21 per cent stones; patchy thin clay skins; very strongly acid (pH 5.0); abrupt smooth boundary.
AB	18-41	Dark Reddish brown (2.5YR 3/4) gravelly sandy clay; moderate medium sub-angular blocky structure; friable, sticky and plastic consistency; few very fine roots; common fine pores; about 23 per cent stones; patchy thin clay skins; strongly acid (pH 5.3); clear smooth boundary.
Bt1	41-62	Red (2.5YR 4/6) gravelly sandy clay; moderate medium sub-angular blocky structure; friable, sticky and plastic consistency; common very fine pores; about 25 per cent stones; patchy thick clay skins; strongly acid (pH 5.4); clear smooth boundary.
Bt2	62-82	Red (2.5YR 4/6) gravelly sandy clay; loam; moderate medium sub-angular blocky structure; friable, sticky and plastic consistency; common very fine pores; 15 per cent fine gravel; strongly acid (pH 5.4); abrupt smooth boundary.
Bt3C	82-119	Yellowish red (5YR 4/6) gravelly clay loam; moderate coarse sub-angular blocky structure; friable, slightly sticky and slightly plastic consistency; few fine distinct mottles dark red (10YR 3/6); common very fine pores; 15 per

		cent fine gravel; strongly acid (pH 5.3); clear smooth boundary.
BC1	119-139	Yellowish red (5YR 4/6) sandy clay; weak coarse sub-angular blocky; friable, slightly sticky and slightly plastic consistency; few fine distinct mottles strong brown (7.5YR 5/8); few very fine pores; 14 per cent fine gravel; strongly acid (pH 5.4).
BC2	139-153	Yellowish red (5YR 4/6) sandy clay; weak coarse sub-angular blocky; friable, slightly sticky and slightly plastic consistency; few fine distinct mottles strong brown (7.5YR 5/8); few very fine pores; 14 per cent fine gravel; strongly acid (pH 5.4).

3.4.3 Sampling site no.3 (13° 47' 59.1" N latitude, 74° 53' 27.5" E longitude)

Location: Mudur maidan village, Kollur,Kundapur Taluk, Udupi District

Kollur experiencing humid tropical climate receives average annual rainfall of 3844 mm (Fig 7). Length of growing period (LGP) for annual crops (period of soil moisture availability) is 203 days. Site characteristics and soil morphology are explained below and google earth imager, landscape view, land use and soil profile photo are given in plate 5 and 6.

A soil profile was excavated and studied in Kollur. The site description and soil morphology are presented in the following section.

Plate 5: Land scape view of profile location in Kollur (magnified from 1:2,50,000 scale image)

Plate 6: Land scape, land Use and profile view in Kollur

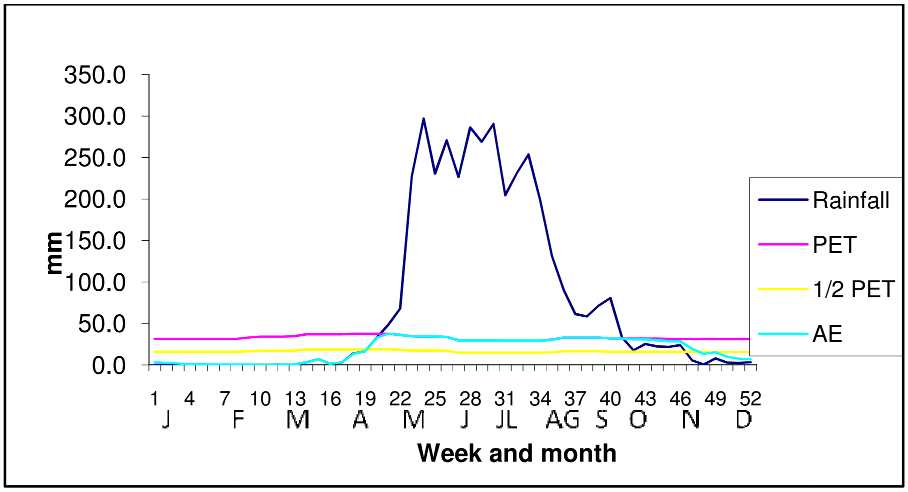


Fig.7 Rainfall, PET, AET of Kollur

PET- Potential Evapotranspiration

AET- Actual Evapotranspiration

Pedon 3; Kollur

Climate	: Humid tropics
Elevation	: 141 m above MSL
Rainfall	: 3844 mm
Slope	: 1-3 %
Physiography	: Elongated ridges and foot hill slopes
Erosion	: Slight
Drainage	: Well drained
Soil parent material	: Weathered ferruginous quartzite schist
Land use	: Rubber
Soil classification	: Fine, mixed, isohyperthermic, Kandic Palehumults

3.4.4 Sampling site no.4 (13° 35' 39.4" N latitude, 74° 48' 06.5" E longitude)

Location: Molahalli village, Coondapur Taluk, Udupi District

Molahalli experiencing humid tropical climate receives average annual rainfall of 3887 mm (Fig 8). Length of growing period (LGP) for annual crops (period of soil moisture availability) is 196 days. Site characteristics and soil morphology are explained below and google earth imager, landscape view, land use and soil profile photo are given in plate 7 and 8.

A soil profile was excavated and studied in Molahalli. The site description and soil morphology are presented in the following section

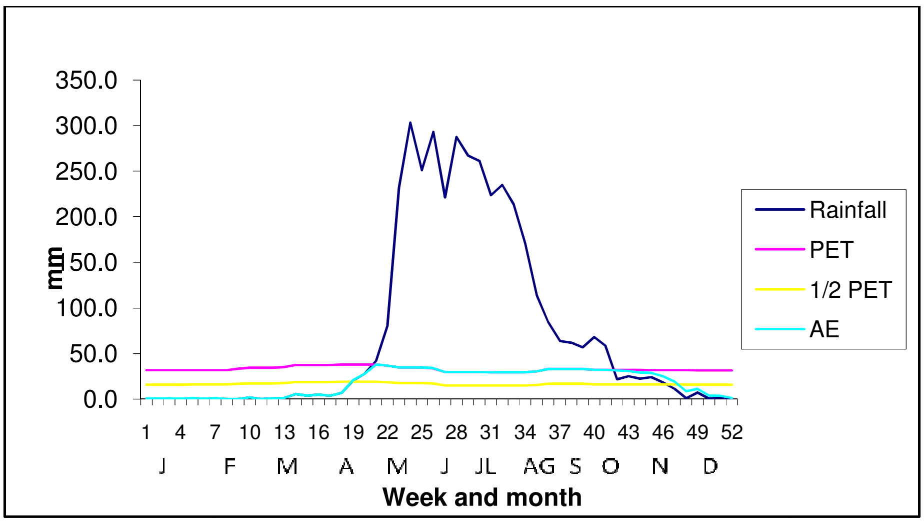


Fig.8 Rainfall, PET, AET data of Molahalli

PET- Potential Evapotranspiration

AET- Actual Evapotranspiration

Pedon 4: Molahalli

Climate	: Humid tropics
Elevation	: 25 m above MSL
Rainfall	: 3844 mm
Slope	: 3-5 %
Physiography	: Undulating uplands
Erosion	: Moderate

Plate 7: Land scape view of profile location in Molahalli (magnified from 1:2,50,000 scale image)

Plate 8: Land scape, land Use and profile view in Molahalli

Drainage : Well drained

Soil parent material : Laterite/Ferrugious quartzite schist

Land us : Forest

Soil classification : Loamy, kaolinitic, isohyperthermic, Kanhaplic Haplustults

Horizon	**Depth (cm)**	**Soil characteristics**
Ap	0-10	Red (2.5YR 4/6) gravelly sandy loam; weak fine sub-angular blocky structure; slightly hard, friable, slightly sticky and slightly plastic consistency; many very fine roots; common fine pores; 31 per cent fine gravel; moderately acid (pH 5.7); abrupt smooth boundary
Bt1	10-28	Red (2.5YR 4/6) gravelly clay loam; moderate medium sub-angular blocky structure; friable, sticky and plastic consistency; many fine roots; common fine pores; patchy thin clay skins; 32 per cent fine gravel; moderately acid (pH 5.6); clear smooth boundary.
Bt2C	28-50	Dark yellowish brown (10YR 4/6) gravelly sandy loam; moderate coarse sub-angular blocky structure; friable, slightly sticky and slightly plastic consistency; common fine roots; few fine pores; 33 per cent fine gravel; patchy thin clay skins; moderately acid (pH 5.7); clear smooth boundary.
BC1	50-78	Dark Yellow brown (10YR 4/6) gravelly loam; weak coarse sub-angular blocky structure; friable, slightly sticky and slightly plastic consistency; few fine distinct mottles strong brown (7.5YR 5/8); few very fine roots; common fine pores; 34 per cent fine gravel, moderately acid (pH 5.7); clear smooth boundary.

BC2	78-109	Dark Yellow brown (10YR 4/6) very gravelly clay loam; weak coarse sub-angular blocky structure; friable, slightly sticky and slightly plastic consistency; few fine distinct mottles strong brown (7.5YR 5/8); common fine pores; 37 per cent fine gravel; strongly acid (pH 5.5); abrupt smooth boundary.
Cr	109-140+	Hard weathered laterite rock

3.4.5 Sampling site no. 5 (13° 24' 23" N latitude, 74° 46' 04.2" E longitude)

Location: Uppur village, Bramhavar, Udupi Taluk, Udupi District

Brahmavar experiencing humid tropical climate receives average annual rainfall of 3887 mm (Fig 9). Length of growing period (LGP) for annual crops (period of soil moisture availability) is 210 days. Site characteristics and soil morphology are explained below and google earth imager, landscape view, land use and soil profile photo are given in plate 9 and 10.

A soil profile was excavated and studied in Brahmavar. The site description and soil morphology are presented in the following section

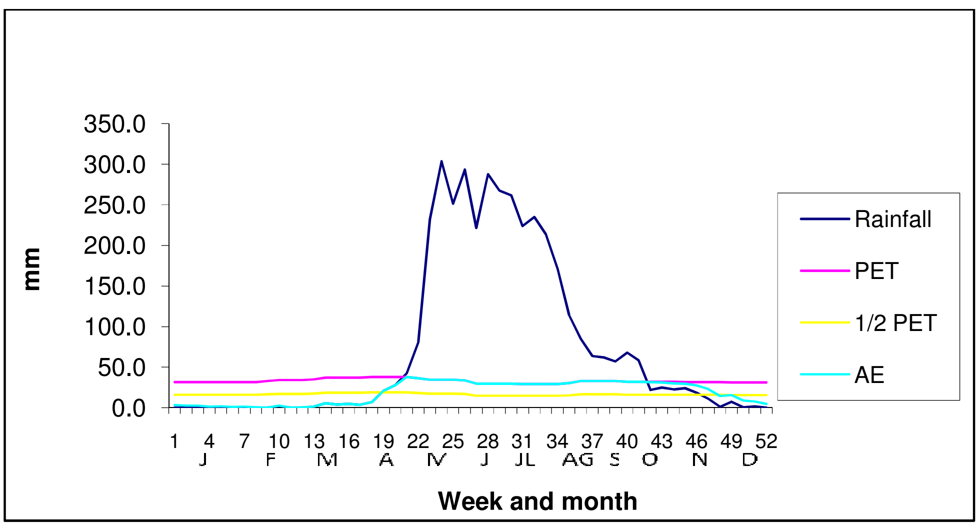


Fig .9 Rainfall, PET, AET data of Brahmavar

PET-Potential Evapotranspiration

AET- Actual Evapotranspiration

Plate 9: Land scape view of profile location in Brahmavar (magnified from 1:2,50,000 scale image)

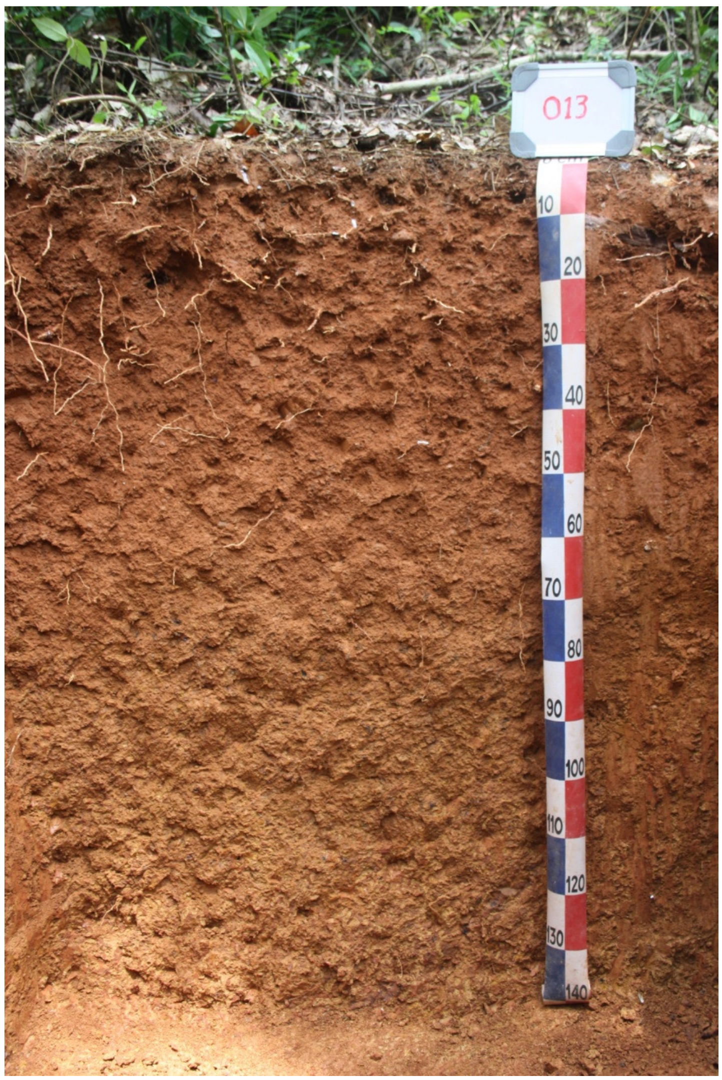


Plate 10: Land scape, land Use and profile view in Brahmavar

Pedon 5: Brahmavar

Climate	: Hot humid tropics
Elevation	: 38 m above MSL
Rainfall	: 3887 mm
Slope	: 3-5 %
Physiography	: Lateritic plateaus and lateritic mounds
Erosion	: Slight
Drainage	: well drained
Soil parent material	: Laterite
Land use	: Rubber
Soil classification	: Fine-loamy, kaolinitic, isohyperthermic, Typic- Kanhaplustults

Horizon	Depth (cm)	Soil characteristics
Ap	0-10	Reddish brown (5YR 4/3) gravelly clay; weak fine sub-angular blocky structure; friable, sticky and plastic consistency; many fine roots; common fine pores; 21 per cent stones; moderately acid (pH 5.9); abrupt smooth boundary.
BA	10-38	Red (2.5YR 4/6) gravelly clay loam; moderate medium sub-angular blocky structure; friable, sticky and plastic consistency; many fine roots; common fine pores; 20 per cent coarse gravel; patchy thin clay skins; strongly acid (pH 5.5); clear smooth boundary.
Bt1	38-59	Red (2.5YR 4/6) gravelly clay; moderate medium sub-angular blocky structure; friable, very sticky and plastic consistency; few fine roots; common very fine pores; 19 per cent coarse gravel, patchy thick clay skins; strongly acid (pH 5.3); clear smooth boundary.

Bt2C	59-79	Dark red (2.5YR 3/6) clay loam; moderate coarse sub-angular blocky structure; friable, sticky and plastic consistency; few very fine roots; common very fine pores; 14 per cent coarse gravel; patchy thin clay skins; strongly acid (pH 5.3); clear smooth boundary.
BC1	79-113	Yellowish red (5YR 4/6) gravelly clay loam; weak coarse sub-angular blocky structure; friable, slightly sticky and slightly plastic consistency; few very fine roots; few fine pores; 22 per cent coarse gravel; strongly acid (pH 5.3); clear smooth boundary.
BC2	113-148	Yellowish red (5YR 4/6) gravelly clay loam; weak coarse sub-angular blocky structure; friable, slightly sticky and slightly plastic consistency; few very fine roots; few fine pores; 24 per cent coarse gravel; strongly acid (pH 5.2).
C	148+	Hard weatherd variegated laterite layer

3.4.6 Sampling site no.6 (14° 04' 57.3" N latitude, 74° 30' 21.6" E longitude)

Location: Ayyammanahalli village, Murdeshwar, Bhatkal Taluk, North Kanara District

Murdeshwar experiencing humid tropical climate receives average annual rainfall of 3200 mm (Fig 10). Length of growing period (LGP) for annual crops (period of soil moisture availability) is 150 to 180 days. Site characteristics and soil morphology are explained below and google earth imager, landscape view, land use and soil profile photo are given in plate 11 and 12.

Plate 11: Land scape view of profile location in Murdeshwar (magnified from 1:2,50,000 scale image)

Plate 12: Land scape, land Use and profile view in Murdeshwar

A soil profile was excavated and studied in Murdeshwar. The site description and soil morphology are presented in the following section

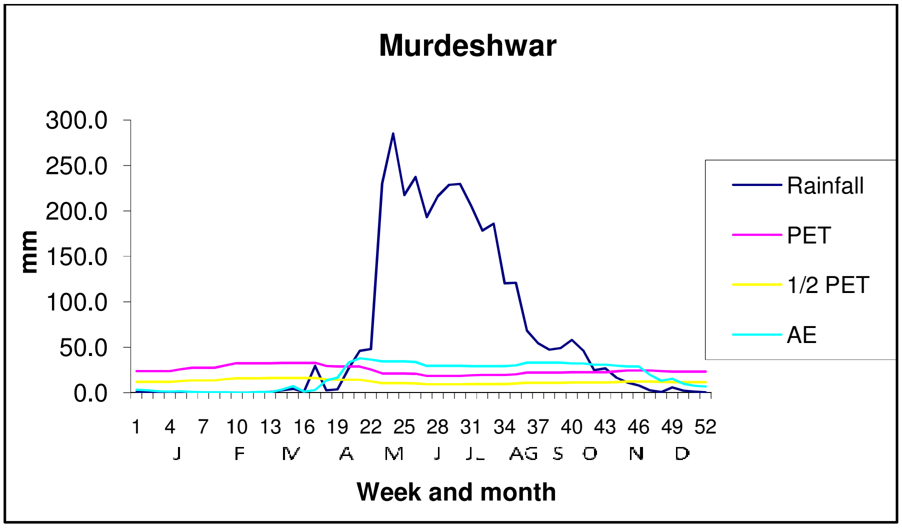


Fig .10 Rainfall, PET, AET data of Murdeshwar

PET- Potential Evapotranspiration

AET- Actual Evapotranspiration

Pedon 6: Murdeshwar

Climate	: Humid tropics
Elevation	: 8m above MSL
Rainfall	: 3200 mm
Slope	: 3-5 %
Physiography	: Sub divided coastal plateau summits
Erosion	: Moderate
Drainage	: well drained
Soil parent material	: Laterite
Land use	: Cashew
Soil classification	: Clayey-skeletal, kaolinitic, isohyperthermic, Typic- Kandiustults

Horizon	Depth (cm)	Soil characteristics
Ap	0-20	Dark reddish brown (2.5YR 3/4) gravelly sandy clay loam; weak fine sub-angular blocky structure; friable, slightly sticky and slightly plastic consistency; many fine roots; common coarse pores; 28 per cent fine gravel; moderately acid (pH 5.7); abrupt smooth boundary.
Bt1	20-47	Dark red (2.5YR 3/6) gravelly sandy clay; weak fine sub-angular blocky structure; friable, sticky and plastic consistency; many fine roots; common coarse pores; 35 per cent fine gravel; patchy thin clay skins; moderately acid (pH 5.6); clear smooth boundary.
Bt2	47-82	Red (2.5YR 4/6) very gravelly sandy clay; moderate fine sub-angular blocky structure; friable, very sticky and plastic consistency; many very fine roots; common coarse pores; 60 per cent coarse gravel; patchy thick clay skins; moderately acid (pH 5.5); clear smooth boundary.
Bt3	82-112	Red (2.5YR 4/6) very gravelly clay; weak coarse sub-angular blocky structure; friable, very sticky and plastic consistency; few fine distinct mottles strong brown (7.5YR 5/8); common very fine roots; common coarse pores; 50 per cent stones; patchy thick clay skins; moderately acid (pH 5.7); clear smooth boundary.
Bt4C	112-155+	Red (2.5YR 4/8) extremely gravelly clay; 50 per cent stones; weak coarse sub-angular blocky structure; friable, very sticky and plastic consistency; few fine distinct mottles strong brown (7.5YR 5/8); few very fine roots; common coarse pores; moderately acid (pH 5.5); clear smooth boundary.

3.4.7 Sampling site no. 7 (12° 51' 28.8" N latitude, 74° 51' 47.5"E longitude)

Location: Ekkur village, Ullal, Manglore Taluk, Manglore District

Ullal experiencing humid tropical climate receives average annual rainfall of 3769 mm (Fig 11). Length of growing period (LGP) for annual crops (period of soil moisture availability) is 210 days. Site characteristics and soil morphology are explained below and google earth imager, landscape view, land use and soil profile photo are given in plate 13 and 14.

A soil profile was excavated and studied in Ullal. The site description and soil morphology are presented in the following section

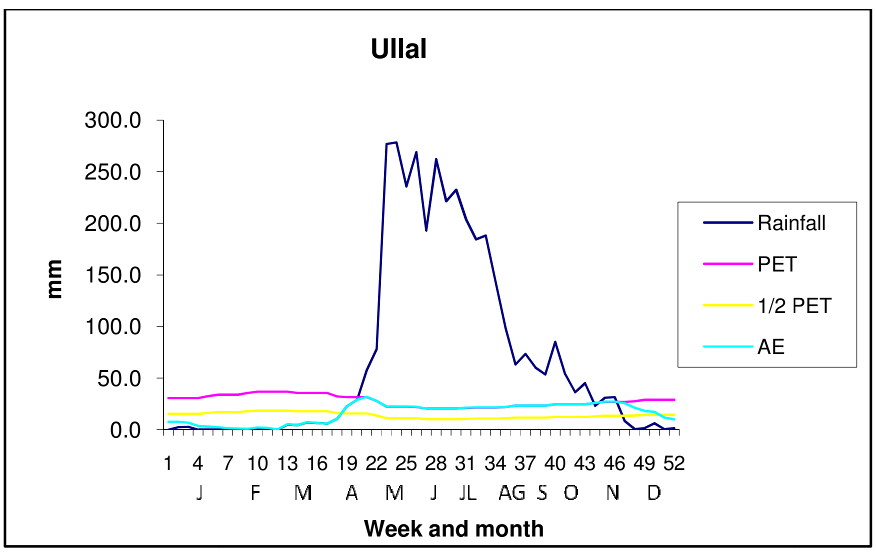


Fig .11 Rainfall, PET, AET data of Ullal

PET-Potential Evapotranspiration

AET- Actual Evapotranspiration

Pedon 7: Ullal

Climate	: Hot humid tropics
Elevation	: 7 m
Rainfall	: 3769 mm
Slope	: 3-5 %

Plate 13: Land scape view of profile location in Ullal (magnified from 1:2,50,000 scale image)

Plate 14: Land scape, land Use and profile view in Ullal

Physiography : Very gently sloping lateritic valley

Erosion : Slight

Drainage : Moderately well drained

Soil parent material : Laterite

Land use : Harvested paddy land with stubbles

Soil classification : Fine, kaolinitic, isohyperthermic, Typic-Kanhaplustults

Horizon	**Depth (cm)**	**Soil characteristics**
Ap	0-10	Yellow brown (10YR 5/6) sandy clay loam; moderate, fine sub-angular blocky structure; slightly hard, friable, sticky and plastic consistency; few very fine roots; common fine pores; 3 per cent fine gravels; strongly acid (pH 5.2); abrupt smooth boundary
BA	10-20	Dark yellow brown (10YR 4/6) sandy clay loam; strong fine sub-angular blocky structure; slightly hard, friable, sticky and plastic consistency; few very fine roots; common fine pores; 5 per cent fine gravels; strongly acid (pH 5.5); abrupt smooth boundary.
Bt1C	20-47	Yellowish red (5YR 5/6) clay; moderate coarse sub-angular blocky structure; friable, very sticky and plastic consistency; few fine distinct mottles having strong brown (7.5YR 5/6) and red (10R 4/6); common very fine pores; 14 per cent fine gravels; patchy thin clay skins; strongly acid (pH 5.4); clear smooth boundary.
Bt2C	47-78	Yellowish red (5YR 5/6) clay loam; moderate coarse sub-angular blocky structure; 10-15 per cent fine gravels; friable, very sticky and plastic consistency; few fine distinct mottles having light yellowish brown (10YR 4/6) and weak red (10 R 5/4); common very fine pores; 27 per cent fine gravels; patchy thin clay skins; strongly acid (pH 5.4); gradual smooth boundary.

Bt3C	78-103	Yellowish red (5YR 5/6) clay; weak coarse sub-angular blocky structure; friable, very sticky and plastic consistency; few fine distinct mottles having very pale yellow (10YR 7/4) and dark red (10R 3/6); few common fine pores; 14 per cent fine gravels; patchy thin clay skins; strongly acid (pH 5.4); gradual smooth boundary.
BC	103-133	Yellowish red (5YR 5/6) clay loam; weak coarse sub-angular blocky structure; friable, very sticky and plastic consistency; few fine distinct mottles having very pale yellow (10YR 7/4) and dark red (10R 3/6); common very fine pores; 15 per cent fine grave ls; strongly acid (pH 5.4); gradual smooth boundary.
CB	133-151+	Light reddish brown (5YR 6/4) clay loam; weak coarse sub-angular blocky structure; friable, very sticky and plastic consistency; few fine distinct mottles having very pale (10YR 7/4) and red (10R 4/6); common very fine pores; 15 per cent fine gravels; moderately acid (pH 5.7).

3.5 Soil sampling

Soil sample from each horizon of the profile was collected in polythene bags, labelled properly and transported to laboratory for processing and analysis. Samples for determination of bulk density were collected using a metallic core of known volume which was driven into each horizon. The cutting edge of the core was pressed into the soil and driven in using a wooden hammer and then carefully removed to gather a known volume of soil sample. Duplicate core samples were collected from each horizon of the pedon. The protruding soil on either end of the core were removed.

Surface samples were collected from cultivated fields of major land use systems at the study sites. Samples were collected from four different spots of the field so as to be representative of the entire field. A 'V' shaped cut of 15 cm depth was made after scraping away the surface litter and stones. A thin slice of soil was taken from each spot. The samples collected were mixed thoroughly and the required quantity was drawn through quartering technique.

3.5.1 Preparation of Soil Samples

Soil samples upon arrival at the laboratory were air dried under shade. These were ground in a wooden mortar with a wooden pestle and then passed through a 2 mm sieve to separate the coarse fragments. The fine earth was stored in polythene bags for analytical purpose.

3.6 METHODS OF SOIL ANALYSIS

3.6.1 Bulk Density

Bulk density was determined gravimetrically by core sampler method. Bulk density of field moist samples and oven dry bulk density were determined for the samples.

The coarse fragments (>2 mm) in core samples were separated after sieving through 2 mm sieve. Sonicator was used to separate fine particles from the gravel. The gravel was weighed after oven drying. Volume of gravel was measured by water displacement method using a measuring cylinder.

3.6.2 Particle Size Analysis

Particle size analysis was done by International pipette method as described by Piper (1942). Air dry soil (<2 mm) was treated with hydrogen peroxide for destroying organic matter. The treated soil was dispersed using ultrasound sonicator with the addition of sodium hexa metaphosphate as a dispersing agent. The dispersed solution was passed through 300 mesh sieve to separate sand particles. The suspension obtained after sieving was analysed for silt and clay.

3.6.3 Soil Reaction (pH)

Soil pH was determined in 1:2.5 soil:water suspension, 1:2.5 soil by potentiometric method (Jackson, 1973).

3.6.4 Electrical Conductivity

Electrical conductivity was determined in suspension of 1:2.5 soil: water extract using conductivity bridge (Jackson, 1973).

3.6.5 Organic Carbon

The dry soil sample was powdered using agate pestle and mortar to pass through 0.2 mm sieve. A known weight of powdered sample was treated with known volume of standard $K_2Cr_2O_7$ and concentrated H_2SO_4. The unused $K_2Cr_2O_7$ was quantified by back titration with standard ferrous ammonium sulphate using ferroin indicator (Walkley and Black, 1934).

3.6.7 Soil organic carbon stocks

For each of the soil profiles SOC stocks were calculated for 100cm by summing the stocks of different layers in proportion of their occurrence within this reference thickness. The total organic carbon stock in kg m^{-2} soil for each pedon was estimated using the general equation presented below (Grossman *et al.*, 2001).

$$SOC = \frac{L_1 \times SOCP_1 \times \rho 33_1 \left(\frac{1 - V_{>2_1}}{100}\right) + L_2 \times SOCP_1 \times \rho 33_2 \left(\frac{1 - V_{>2_2}}{100}\right) + ..)}{10}$$

Where SOC = soil organic carbon in kg m^{-2} soil

SOCP = soil organic carbon per cent

L = thickness of the layer in cm (if only surface 15 cm; L_1= 15 cm; ignore L_2, L_3...)

$P33_1$, $P33_2$ = Moist bulk density of<2 mm fraction of core samples of horizons 1, 2,...

V> 2 = volume percent of > 2 mm (gravel)

3.6.8 Cation Exchange Capacity and Exchangeable Bases

Cation exchange capacity of soil was determined by ammonium acetate leaching method (Jackson, 1973). A known quantity of soil sample was saturated with NH_{4+} using neutral normal ammonium acetate. The excess NH4OAc was washed with alcohol. The quantity of NH_{4+} retained on the exchange surface was estimated by microkjeldahl distillation technique. The ammonium acetate extract obtained was used to determine exchangeable bases. Ca and Mg were determined using atomic absorption spectrophotometer and sodium and potassium by flame photometry (Sarma *et al.*, 1987).

3.6.9 Extractable Acidity ($BaCl_2$-TEA)

Extractable acidity is the acidity released from the soil by $BaCl_2$-TEA solution buffered at pH 8.2. It includes all the acidity generated by replacement of H^+ and Al^{3+} from permanent and pH-dependent exchange sites. (Sarma *et al.,* 1987).

3.6.10 Extractable acidity (1 N KCl)

Extractable acidity (H^+ and Al^{3+}) was estimated by extracting the soil with 1*N* NaOH using phenolphthalein indicator. Extractable Al was determined by adding a drop or two of 0.05 N H_2SO_4 to bring the solution back to colourless and adding 10 ml of KF solution and titrating against standard 0.05 N H_2SO_4 till pink colour disappears. The difference between exchange acidity and exchangeable Al was recorded as exchangeable H (Sarma *et al.*, 1987).

3.6.11 Effective Cation Exchange Capacity

The effective cation exchange capacity (ECEC) was calculated as the sum of exchangeable Ca, Mg, Na, K, H and KCl extractable Al.

3.6.12 CEC Sum of Cations

The cation exchange capacity by sum of cations was estimated by summing up the total exchangeable bases and $BaCl_2$ –TEA extractable acidity.

3.6.13 Available Plant Nutrients

Available nitrogen

Available nitrogen was estimated by Kjeldhal digestion and distillation method. To 5 g soil, 25 ml 0.32 per cent $KMnO_4$ and 25 ml 2.5 per cent NaOH were added and distilled. Ammonia liberated was collected in 4 per cent boric acid with mixed indicator and titrated against standard acid (H_2SO_4).

Available phosphorus

The soil samples were both in acidic and alkaline range. Hence, both Bray's reagent (for acid soils) and Olsen's reagent (for neutral and alkaline soils) were used for extraction. The phosphorus content in the soil extract was determined by the blue colour formed by ascorbic acid-molybdate complex and the colour intensity was read at 660 nm using spectro-photometer (Jackson,1973).

Available potassium

The exchangeable potassium was extracted with neutral normal ammonium acetate from a known quantity of soil. The filtered extract was fed to flame photometer for measuring potassium content (Page *et al*, 1982).

Exchangeable calcium and magnesium

The same extract obtained for potassium was used to determine exchangeable calcium and magnesium contents also. Calcium and

Magnesium were determined from the extract using atomic absorption spectrophotometer (Page *et al.*, 1982).

Available Sulphur

The sulphate form of sulphur in soil was extracted using 0.15 per cent $CaCl_2$ solution. Sulphate in the extract was determined by developing turbidity with $BaCl_2$ and the absorbance was measured using spectrophotometer at 420 nm (Hesse, 1994).

Available micronutrients

The status of micronutrients, Fe, Mn, Cu and Zn were determined by extracting the soil using 0.1 N HCl as an extractant in 1:10 ratio and 0.01 M DTPA in 1:2 ratio, shaken for 5 min and 2 hrs respectively, filtered and fed into the atomic absorption spectrophotometer (Mortvedt *et al*, 1991). Boron in soil was extracted by refluxing with 0.02 M $CaCl_2$. The B in the extract was estimated by developing yellow colour with Azomethine H and the colour intensity was read at 420 nm (Gupta, 1967).

3.7 preparation of degradation status map

Degradation status map of southern coastal Karnataka have been prepared by superimposing physiography region map demarcated from toposheet and satellite imageries taking the help of soil resource map of Karanataka (Shivaprasad *et al.*, 1998) with the land attributes considered to help in aggravating land degradation process.

Degradation status map is prepared by considering the climatic, soil physical and chemical variables assigning grades for each parameter depending on its impact on making soil degradation in the study area, the parameters considered are total rainfall and its deviation from normal duration of dry spell, thickness of surface horizons, surface texture, B.D of surface horizon, O.C per cent of surface horizon CEC/Kg clay of control section and base saturation by sum of cations of surface horizon.

Deviation of rainfall from normal to high is an indication of more stormy rains, while deviation towards lower is an indication of extended dryness.

Dry spell below 5 months and its increase to 6 months duration has been graded to show the impact of high temperature and subsequent decomposition of organic matter before rains and its subsequent removal to lower layers and beyond solution.

Thickness of surface horizon is a variable which indicate how much finer particles have selectively removed from the soil surface due to rain drop impact and is displayed by the reduced thickness of surface horizon.

Surface texture including gravellyness is a property which decides how fast the rain water which is received in plenty on soil surface is infiltrated and percolated for soil retention.

B.D of soil surface horizon is considered to depict the vulnerability and impact of the soil towards degradation process like crusting and compaction.

O.C of surface horizon is considered to depict the soil degradation, maintenance of beneficial soil micro flora and inturn its impact on better soil moisture retention capacity and soil plant root interface.

CEC/kg clay of control section is considered to know how best the soils can supply needed plant nutrient from the soil solution as well as from the active root zone.

Base saturation by sum of cations of the surface horizon is a property which indicates the nutrient supplying capacity of the soil as well as proneness degree of soil acidification and low base status.

From the above parameters soil degradation status is assessed by assigned grades (Table 4) for each parameters added together and divided by the total maximum scores possible which is 25 here. For this the value arrived will range from 0-1 and the status degradation is assessed by following the range given in the table in which very low is less than 0.55, 0.55-0.6 low, 0.6-0.7 medium, 0.7-0.75 moderate, greater than 0.75 is high respectively.

Table 4: Assigning of grades for land degradation in west coast of southern Karnataka

Rainfall (mm)	Dry months	Thickness of surface horizon	Surface texture	B.D of surface horizon	OC % of surface horizon	CEC/clay of control section	B.S/Sum of cations surface horizon	Status of Land degradation
3500-4000= (1)	<5=1	>20=1	scl=1	<1.2 = 1	>2.5 = very high (1)	> 16 =1	> 30 = 1	<0.55 = Very Low
>4000=(2)	5-5.5=2	10-20=2	gscl=2	> 1.2 =2	1.5-2.5 = high (2)	12-16=2	22.5-30 =2	0.55-0.60 = Low
<3500=(2)	5.5-6.0=3	<10=3	gc= 2		0.75-1.5 = Medium (3)	8-12=3	15-22.5 =3	0.60-0.75 = Medium
			gsl= 3		> 0.75 = low (4)		7.5-15=4	> 0.75 = high
							<7.5= 5	

IV. RESULTS

Results of investigation carried out on Characterization of soils and assessment of land degradation in west coast of southern Karnataka are presented in this chapter under following headings.

1. Use of satellite imageries and toposheets for characterization and land degradation assessment
2. Morphological characteristics, physical and chemical properties of profile and surface samples
3. Soil classification
4. Soil organic carbon stocks
5. Soil degradation status

4.1 Use of satellite imageries and toposheets for characterization and assessment of land degradation

Land degradation is serious problem in West Coast of Southern Karnataka. Based on the information available and interpretation of imageries seven locations were selected for study.

Satellite imageries were interpreted using toposheets and found that Vegetative degradation, Sheet erosion and Barren land are active in the study area. Based on these seven physiographic transacts were marked. It consists of steep high hill ranges (Sullya), steep low hill ranges, isolated hills and dissected hills and valleys (Beltangadi), elongated ridges and foot hill slopes (Kollur), undulating uplands (Molahalli), lateritic plateau and lateritic monds (Brahmawar), coastal plateau summits(Murdeshwar), valleys, bars and ridges, beaches and marshes (Ullal).

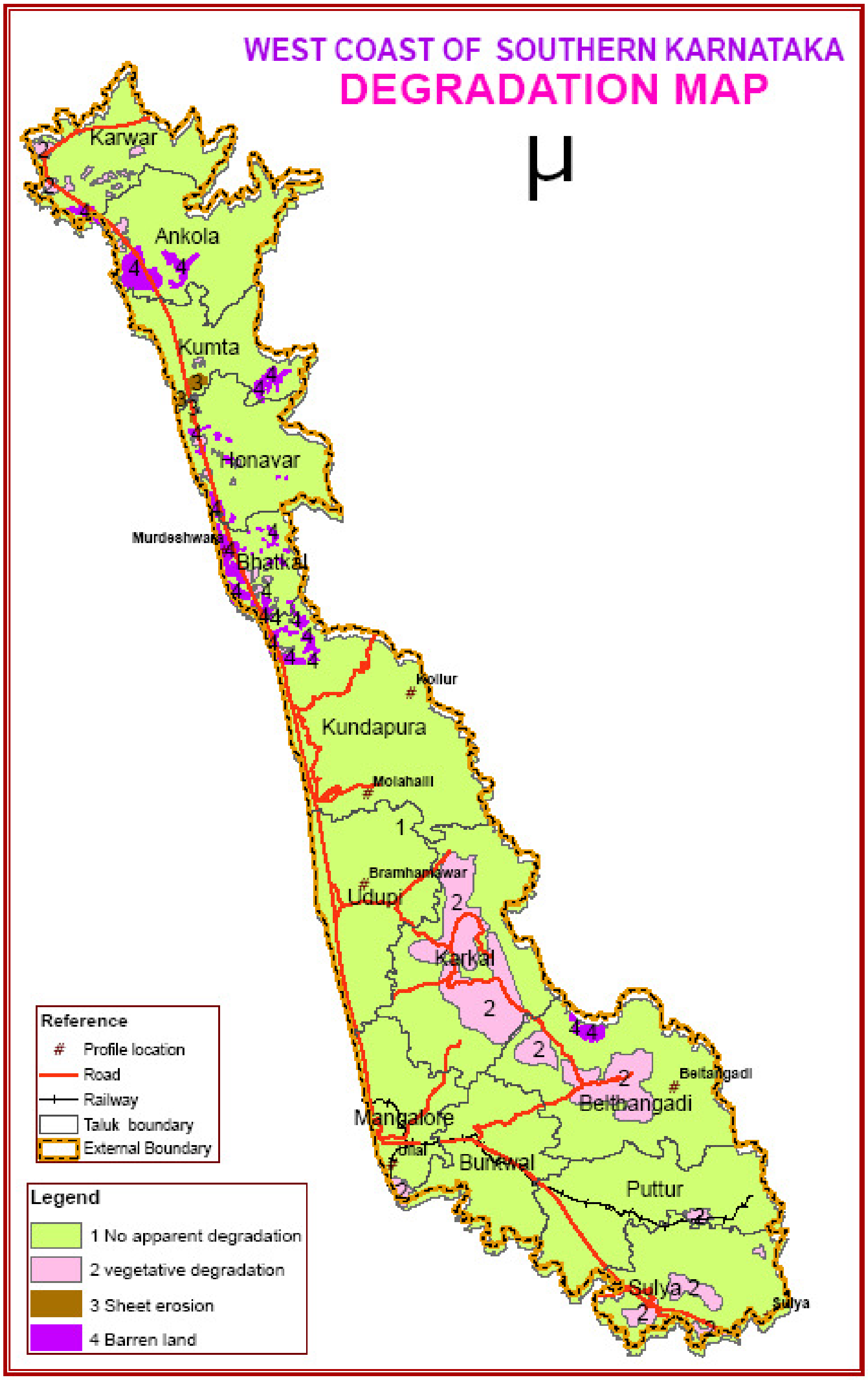


Fig 4 : Land degradation map prepared out of IRS LISSS III P6 (FCC) Satellite imageries.

4.2 Morphological characteristics, physical and chemical properties of profile and surface samples

4.2.1 SITE 1: Sullya

4.2.1.1 Soil Morphology

This site is experiencing a humid tropical climate. The average annual rainfall is 3738 mm. Soil moisture is adequate to support annual crop production for 210 to 240 days. The site for soil profile study was located on steep high hill ranges with 5-10 per cent slope with elevation of 252 m above mean sea level. Surface features indicated severe erosion with rapid run off. The soil developed from weathered granite gneiss was well drained.

The soil profile was excavated to depth of 150 cm. The lowest layer was (121-150 cm). The 10 cm thick Ap horizon was dark reddish brown (5YR 3/4), gravelly sandy clay loam in texture containing 16 per cent of fine gravels with weak medium sub-angular blocky structure. Moist consistency of soil was slightly hard friable and wet, sticky and plastic. The horizon had common fine pores and many fine roots. The horizon merged into the subsoil horizon smoothly.

The subsoil B horizons were designated as Bt1, Bt2, Bt3, Bt4 and Bt5 with depth interval of 10-33, 33-54, 54-90, 90-121 and 121-150 cm respectively. The Bt1 horizon was reddish brown in colour (5YR 4/4), sandy clay loam texture containing 12 per cent of fine gravels with moderate medium sub-angular blocky structure. Moist consistency of soil was friable and wet, sticky and plastic. The horizon had common fine pores, and many fine roots in cracks. The horizon had thin patchy clay skins. The horizon merged into the sub horizon smoothly.

The Bt2 horizon was reddish brown (2.5YR 4/4) clay in texture containing 8 per cent of fine gravels with moderate medium sub-angular blocky structure. Moist consistency of soil was friable and wet, sticky and plastic. The horizon had common fine pores, and few fine roots. The horizon had medium thin patchy clay skins. The horizon merged into the sub horizon smoothly.

The Bt3 horizon was reddish brown (2.5YR 4/4) clay in texture containing 16 per cent of fine gravels with moderate medium sub-angular blocky structure. Moist consistency of soil was very friable and wet, sticky and plastic. The horizon had common fine pores, and few fine roots. The horizon had thick patchy clay skins. The horizon merged into the sub horizon smoothly.

The Bt4 horizon was dark red (2.5YR 3/6) gravelly clay in texture containing 24 per cent of fine gravels with moderate medium sub-angular blocky structure. Moist consistency of soil was friable and wet, sticky and plastic. The horizon had common very fine pores, and many fine roots. The horizon had thick patchy clay skins. The horizon merged into the sub horizon smoothly.

The Bt5 horizon was dark red (2.5YR 3/6) gravelly clay in texture containing 16 per cent of fine gravels with moderate medium sub-angular blocky structure. Moist consistency of soil was friable and wet, sticky and plastic. The horizon had common fine pores, and few very fine roots. The horizon had thick patchy clay skins.

4.2.1.2 Physical Properties

The sand content is ranged from 32.3 to 64.8 per cent. The maximum was observed in (Ap) horizon and least in (Bt5) horizon. The silt content ranged from 10.5 to 17.9 per cent. The maximum was observed in (Bt5) horizon and minimum in (Ap) horizon. The clay content ranged from 24.7 to 49.8 per cent. The maximum was observed in (Bt5) horizon and minimum was observed in (Ap) horizon. The textural class (USDA) gravely sandy clay loam was observed in surface (Ap) horizon, gravely sandy clay loam in (Bt1) horizon, clay in

(Bt2) horizon, gravelly clay in (Bt3, Bt4 and Bt5) horizons. The bulk density ranged from 1.04 to 1.23 mg m^{-3}. The maximum was found in the (Bt4) horizon and minimum in (Bt1) horizon. (Table 5)

4.2.1.3 Chemical Properties

Soil reaction was strongly acidic throughout the pedon with pH in soil water suspension ranging from pH 4.8 to 5.4. The maximum pH was observed in Ap horizon and minimum was observed in Bt3 horizon. Electrical conductivity ranged from 0.01 to 0.03 dS m^{-1}. The maximum was observed in Bt1 horizon and minimum was observed in Ap, Bt4 and Bt5 horizons. Organic carbon ranged from 0.90 to 12.2 g kg^{-1} soil. The maximum was observed in Bt2 horizon which decreased in subsoil horizons with depth and minimum was observed in Bt3, Bt4 and Bt5 horizons.

Exchangeable calcium ranged from 0.99 to 1.82 cmol(+)kg^{-1} soil. The maximum was observed in Ap horizon which decreased with depth up to Bt3 horizon. Exchangeable magnesium ranged from 0.08 to 0.22 cmol(+)kg^{-1} soil. The maximum was observed in Bt2 horizon and minimum was observed in Ap horizon. Exchangeable potassium ranged from 0.01 to 0.03 cmol(+)kg^{-1} soil. The maximum was observed in Bt1 horizon and minimum was observed in Bt3 and Bt5 horizons. Exchangeable sodium ranged from 0.06 to 0.08 cmol(+)kg^{-1} soil. The maximum was observed in Bt3 horizon and minimum was observed in Bt2 and Bt4 horizon. Base saturation per cent ranged from 24 to 46 per cent. The maximum was observed in Bt5 horizon and minimum was observed in Bt1 horizon.

$BaCl_2$-TEA extractable acidity ranged from 7.0 to 17 cmol(+)kg^{-1} soil. The maximum was observed in Ap and minimum was observed in Bt4 horizon. Extractable H+ ranged from 0.01 to 0.06 cmol(+)kg^{-1} soil. The maximum was observed in Bt5 horizon and minimum was observed in Bt1 horizon. Extractable Al^{3+} ranged from 0.16 to 0.28 cmol(+)kg^{-1} soil. The maximum was observed in Bt2 horizon and minimum was observed in Bt4 horizon. Cation exchange capacity ranged from 3.6 to 7.4 cmol(+)kg^{-1} soil. The maximum was observed in surface Ap horizon and it decreased with the depth in subsurface horizons and minimum was observed in Bt5 horizon. Effective cation exchange capacity ranged from 1.4 to 2.2 cmol(+)kg^{-1} soil. The maximum was observed in Ap horizon which decreased with depth upto Bt3 horizon and minimum was observed in Bt3 horizon. Cation exchange capacity by sum of cations ranged from 8.5 to 18.9 cmol(+)kg^{-1} soil. The maximum was observed in Ap horizon and minimum was observed in Bt4 horizon. The CEC/clay ratio ranged from 0.07 to 0.30. The maximum was observed in Ap horizon and and it decreased with depth in subsurface horizons and minimum was observed in Bt5 horizon.

Available nitrogen content in surface soils was 360.6 kg ha^{-1} soil. It ranged from 172.4 to 423.6 kg ha^{-1} soil in the subsoil horizons. Available phosphorus in the surface soil was 2.56 kg ha^{-1} soil. It ranged from 3.54 to 11.8 kg ha^{-1} soil in the subsoil horizons. Available potassium in the surface horizon was 72.8 kg ha^{-1} soil. It ranged from 40.7 to 104.1 kg ha^{-1} soil in subsoil horizons. Available calcium in the surface horizon was 166 mg kg^{-1} soil. It ranged from 121 to 196 mg kg^{-1} in subsoil horizons. Available magnesium in the surface horizon was 68 mg kg^{-1}. It ranged from 35 to 58 mg kg^{-1} soil in the remaining subsoil horizons. Available sulphur in the surface horizon was 3.8 mg kg^{-1} soil. It ranged from 3.1 to 4.3 mg kg^{-1} soil in the subsoil horizons. Surface horizon content of available Fe, Mn, Cu, Zn and B were, 49.8, 13.9, 6.1, 1.1 and 0.29 mg kg^{-1} respectively. In subsoil it ranged from 5.1 to 80.6, 1.8 to 8.9, 4 to 10, 0.9 to 1.5 and 0.01 to 0.36 mg kg^{-1} soil respectively. (Table 5)

4.2.1.4 Properties of Composite Surface Soil Samples

Soil reaction ranged from strongly acid ranged from pH 5.1 to 5.4 and electrical conductivity from 0.01 to 0.04 dS m^{-1}. Organic

Table 5: Physical and Chemical properties of soil profile sampled at Sullya

Depth (cm)	Horizon	Size class and particle diameter (mm)								Gravel % volume	Texture (USDA)
		Sands					Total				
		V.fine	Fine	Medium	Coarse	V.coarse	Sand	Silt	Clay		
		(0.1-0.05)	(0.25-0.1)	(0.5-0.25)	(1.0-0.5)	(2.0-1.0)	(2.0-0.05)	(0.05-0.002)	(<0.002)		
		% of <2 mm									
0-10	Ap	26.8	3.8	15.2	10.5	8.5	64.8	10.5	24.7	15.9	gscl
10-33	Bt1	16.5	3.8	10.5	9.8	10.0	50.5	15.6	33.9	11.9	scl
33-54	Bt2	13.1	3.5	9.2	3.8	7.4	37.1	15.5	47.3	7.9	c
54-90	Bt3	17.8	10.5	0.07	7.4	6.4	42.2	12.9	44.9	15.9	gc
90-121	Bt4	15.6	2.9	10.2	3.4	4.8	38.5	13.2	48.3	23.8	gc
121-150	Bt5	14.2	2.6	7.5	4.7	3.2	32.3	17.9	49.8	15.9	gc

Depth	pH	OC	E.C	B.D (Mg m^{-3})	
(cm)		mg kg^{-1}	dS m^{-1}	field moist	Oven dry
0-10	5.4	9.4	0.01	1.38	1.08
10-33	5.2	12.2	0.03	1.32	1.04
33-54	5.1	5.9	0.02	1.36	1.05
54-90	4.8	0.9	0.02	1.46	1.14
90-121	5.2	0.9	0.01	1.52	1.23
121-150	5.1	0.9	0.01	1.55	1.20

Table cont...

Depth (cm)	Available nutrients											
	OC(g Kg^{-1})	N	P	K	Ca	Mg	S	Fe	Mn	Cu	Zn	B
		kg ha^{-1}			mg kg^{-1} soil							
0-10	9.4	360.6	2.56	72.8	166	68	3.8	49.8	13.9	6.1	1.1	0.29
10-33	12.2	423.3	11.80	104.1	126	40	3.1	80.6	6.5	10.0	0.9	0.31
33-54	5.9	297.9	3.78	56.0	121	35	4.0	21.2	7.3	4.2	1.4	0.01
54-90	0.9	188.1	3.54	50.4	139	43	3.4	11.9	8.9	4.0	1.1	0.36
90-121	0.9	172.4	3.78	53.7	196	58	4.1	7.8	1.8	5.2	1.4	0.08
121-150	0.9	203.8	8.92	47.0	189	56	4.3	5.1	2.9	5.2	1.5	0.23

Depth (cm)	Exchangeable bases					Extractable acidity			CEC			Base saturation		Ratio
	Ca	Mg	Na	K	Total	$BaCl_2$-TEA	1.0 *N* KCl		NH_4OAC	Sum of cations	ECEC	NH_4OAC	Sum of cations	CEC/clay
							H^+	Al^{3+}	(pH 7.0)					
	cmol(+)kg^{-1} soil											%		
0-10	1.82	0.08	0.07	0.02	1.99	17.0	0.03	0.18	7.4	18.9	2.2	27	10.4	0.30
10-33	1.46	0.12	0.06	0.03	1.67	14.4	0.01	0.23	6.8	16.1	1.9	24	10.3	0.20
33-54	1.26	0.22	0.08	0.02	1.58	10.5	0.02	0.28	5.7	12.0	1.8	28	13.0	0.12
54-90	0.99	0.14	0.06	0.01	1.20	12.0	0.03	0.19	4.7	13.2	1.4	25	9.9	0.10
90-121	1.31	0.11	0.07	0.02	1.51	7.0	0.04	0.16	4.5	8.5	1.6	33	17.7	0.09
121-150	1.46	0.14	0.07	0.01	1.68	8.5	0.06	0.20	3.6	10.1	1.9	46	16.5	0.07

carbon ranged from 6.5 to 24 g kg^{-1} soil. Available N ranged from 156 to 627 kg ha^{-1}. Available P ranged from 6.2 to 16.4 kg ha^{-1} soil and available K ranged from 80.6 to 125.8 kg ha^{-1} soil. Available Ca, Mg and S ranged from 115 to 297, 54 to 135 and 0.13 to 4.21 mg kg^{-1} soil respectively (Table 6). Available Fe, Mn, Cu, Zn and B in the soil varied from 11.3 to 90.4, 3.2 to 6.6, 2 to 10.8, 1 to 15.6 and 0.29 to 0.77 mg kg-1 soil respectively. (Table 7)

4.2.2 SITE 2: Beltangadi

4.2.2.1 Soil Morphology

This site is experiencing a humid tropical climate. The average annual rainfall is 4485 mm. Soil moisture is adequate to support annual crop production for 210 to 240 days. The site for soil profile study was located on steep low hill ranges, isolated hills and dissected hills and valleys with 1-3 per cent slope with elevation of 148 m above mean sea level. Surface features indicated moderate erosion with slow run off. The soil developed from weathered granite gneiss was well drained.

The soil profile was excavated to a depth of 153 cm. The lowest layer was (139-153 cm). The 18 cm thick Ap horizon was dark reddish brown (5YR 3/3), gravelly sandy clay loam in texture containing 28 per cent of stones with weak fine sub-angular blocky structure. Moist consistency of soil was friable and wet, sticky and plastic. The horizon had few common pores and many fine roots. The horizon merged into the subsoil horizon smoothly.

The subsoil B horizons were designated as AB, Bt1, Bt2, Bt3C, BC1 and BC2 with depth interval of 18-41, 41-62, 62-82, 82-119, 119-139 and 139-153 cm respectively. The AB horizon was dark reddish brown in colour (5YR 3/4), gravely sandy loam texture containing 21 per cent of stones with weak medium sub-angular blocky structure. Moist consistency of soil was friable and wet, sticky

Table 6: Plant available primary and secondary nutrients in surface soils of agricultural lands in Sullya

Crop	pH	EC	OC	N	P	K	Ca	Mg	S
		(dS m^{-1})	(g kg^{-1})	(kg ha^{-1} soil)			(mg kg^{-1} soil)		
Rubber (1)	5.4	0.02	18.0	329.2	14.4	80.6	116	81	4.21
Rubber (2)	5.3	0.01	11.0	450.0	6.2	99.6	171	84	0.27
Rubber (3)	5.1	0.08	24.0	627.2	6.2	107.8	115	72	2.62
Rubber (4)	5.2	0.01	11.0	425.0	9.4	85.1	277	142	0.55
Arecanut	5.4	0.03	7.5	256.0	6.8	116.5	121	64	1.45
Arecanut+Banana	5.3	0.03	7.8	311.0	8.7	85.1	177	62	0.34
Coffee+Arecanut+Banana	5.4	0.01	8.0	297.9	16.4	69.4	165	54	0.21
Forest+Cashew	5.3	0.01	6.5	289.0	10.4	99.6	179	69	0.75
Arecanut+Cocoa+Coconut	5.3	0.04	8.0	407.6	11.1	98.6	297	135	0.21
Forest	5.3	0.02	7.0	156.8	6.8	125.8	169	73	0.13
Mean	5.3	0.026	10.88	354.97	9.64	96.81	178.7	83.6	1.074
Range	5.1-5.4	0.01-0.04	6.5-24	156.8-627.2	6.2-16.4	80.6-125.8	115-297	54-135	0.13-4.21

Table 7: Plant available micro-nutrients in surface soils of agricultural lands in Sullya

Crop	Extractant used	Fe	Mn	Cu	Zn	B
		(mg kg^{-1} soil)				
Rubber (1)	0.1 *N* HCl	16.0	3.2	3.8	3.2	0.72
Rubber (2)	0.1 *N* HCl	12.8	3.3	7.4	6.5	0.77
Rubber (3)	0.1 *N* HCl	90.4	3.2	10.8	3.3	0.35
Rubber (4)	0.1 *N* HCl	34.1	6.3	2.2	1.1	0.31
Arecanut	0.1 *N* HCl	17.7	4.1	2.3	1.8	0.25
Arecanut+Banana	0.1 *N* HCl	13.8	5.5	2.4	15.6	0.37
Coffee+Arecanut+Banana	0.1 *N* HCl	24.2	5.5	3.2	2.1	0.29
Forest+Cashew	0.1 *N* HCl	14.6	4.3	2.0	1.0	0.32
Arecanut+Cocoa+Coconut	0.1 *N* HCl	19.6	6.6	2.6	1.5	0.48
Forest	0.1 *N* HCl	11.3	3.4	2.2	2.0	0.56
Mean		25.45	4.54	3.904	3.81	0.442
Average		11.3-90.4	3.2-6.6	2-10.8	1-15.6	0.29-0.77

and plastic. The horizon had common fine pores, and few very fine roots. The horizon had patchy thin clay skins. The horizon merged into the sub horizon smoothly.

The Bt1 horizon was dark reddish brown (2.5YR 3/4) clay in texture containing 23 per cent of stones with moderate medium sub-angular blocky structure. Moist consistency of soil was friable and wet, sticky and plastic. The horizon had common fine pores, and few very fine roots. The horizon had thin patchy clay skins. The horizon merged into the sub horizon smoothly.

The Bt2 horizon was red (2.5YR 4/6) gravelly sandy clay in texture containing 25 per cent of stones with moderate medium sub-angular blocky structure. Moist consistency of soil was very friable and wet, sticky and plastic. The horizon had common very fine pores. The horizon had patchy thick clay skins. The horizon merged into the sub horizon smoothly.

The Bt3C horizon was red (2.5YR 4/6) gravelly clay in texture containing 25 per cent of stones with moderate medium sub-angular blocky structure. Moist consistency of soil was friable and wet, sticky and plastic. The horizon had common very fine pores. The horizon merged into the sub horizon smoothly.

The BC1 horizon was yellowish red (5YR 4/6) gravelly clay loam in texture containing 15 per cent of fine gravels with moderate coarse sub-angular blocky structure. Moist consistency of soil was friable and wet, slightly sticky and slightly plastic. The horizon had few very fine pores. Few fine distinct mottles dark red in colour (10YR 3/6) were found in this horizon. The horizon merged into sub horizon smoothly.

The BC2 horizon was yellowish red (5YR 4/6) sandy clay in texture containing 14 per cent of fine gravels with weak coarse sub-angular blocky structure. Moist consistency of soil was friable and wet, slightly sticky and slightly plastic. The horizon had few very fine pores. Few fine distinct mottles strong brown (7.5YR 5/8) were found in this horizon.

5.2.2.2 Physical Properties

The sand content in ranged from 42.8 to 78.2 per cent. The maximum was observed in AB horizon and least in BC1 horizon. The silt content ranged from 5.8 to 24.6 per cent. The maximum was observed in BC1 horizon and minimum in Bt2 horizon. The clay content ranged from 15.3 to 38.4 per cent. The maximum was observed in Bt1 horizon and minimum was observed in AB horizon. The textural class (USDA) gravely sandy clay loam was observed in surface Ap horizon and Bt3C horizon, gravely sandy loam in AB horizon, gravelly sandy clay in Bt1 and Bt2 horizons, gravelly clay loam in BC1 horizon, sandy clay in BC2. The bulk density ranged from 1.19 to 1.42 mg m^{-3}. The maximum was found in the BC1 horizon and minimum in AB horizon.

4.2.2.3 Chemical Properties

Soil reaction was strongly acidic throughout the pedon with pH in soil water suspension ranging from pH 5.0 to 5.4. The maximum pH was observed in Bt2, Bt3C and BC2 horizons and minimum was observed in AB horizon. Electrical conductivity ranged from 0.01 to 0.03 dS m^{-1}. The maximum was observed in Ap horizon and minimum was observed in AB, Bt1, Bt2, Bt3C and BC1 horizons. Organic carbon ranged from 0.9 to 23.5 g kg^{-1} soil. The maximum was observed in Ap horizon which decreased in subsoil horizons with depth and minimum was observed in BC2 horizon.

Exchangeable calcium ranged from 0.63 to 1.78 cmol(+)kg^{-1} soil. The maximum was observed in Bt2 horizon and minimum was observed in AB horizon. Exchangeable magnesium ranged from 0.08 to 0.43 cmol(+)kg^{-1} soil. The maximum was observed in Bt1 horizon and minimum was observed in BC2 horizon. Exchangeable potassium ranged from 0.01 to 0.08 cmol(+)kg^{-1} soil. The maximum was observed in Bt2 horizon and minimum was observed in Bt3C, BC1 and BC2 horizons. Exchangeable sodium ranged from 0.05 to 0.13 cmol(+)kg^{-1} soil. The maximum was observed in AB horizon and minimum was observed in BC1 horizon. Base saturation per cent ranged from 11.5 to 50 per cent. The maximum was observed in BC2 horizon and minimum was observed in Ap horizon which increased with depth in subsoil horizons up to Bt3C horizon.

$BaCl_2$-TEA extractable acidity ranged from 5.5 to 23.5 cmol(+)kg^{-1} soil. The maximum was observed in Ap horizon and it decreased with depth up to Bt2 horizon and minimum was observed in BC1 and Bc2 horizon. Extractable H+ ranged from 0.01 to 0.06 cmol(+)kg^{-1} soil. The maximum was observed in Bt5 horizon and minimum was observed in Bt1 horizons. Extractable Al^{3+} ranged from 0.12 to 0.20 cmol(+)kg^{-1} soil. The maximum was observed in BC1 horizon and minimum was observed in Ap and Bt2 horizons. Cation exchange capacity ranged from 2.14 to 8.24 cmol(+)kg^{-1} soil. The maximum was observed in surface Ap horizon and it decreased with the depth up to Bt1 horizon and minimum was observed in BC2 horizon. Effective cation exchange capacity ranged from 1 to 2.1 cmol(+)kg^{-1} soil. The maximum was observed in Bt2 horizon and minimum was observed in Ap horizon. Cation exchange capacity by sum of cations ranged from 6.5 to 24.4 cmol(+)kg^{-1} soil. The maximum was observed in Ap horizon and minimum was observed in BC2 horizon. The CEC/clay ratio ranged from 0.05 to 0.44. The maximum was observed in AB horizon and minimum was observed in BC2 horizon.

Available nitrogen content in surface soils was 172.4 kg ha^{-1} soil. It ranged from 78.4 to 141.1 kg ha^{-1} soil in the subsoil horizons. Available phosphorus in the surface soil was 3.2 kg ha^{-1} soil. It ranged from 2.8 to 9 kg ha^{-1} soil in the subsoil horizons. Available potassium in the surface horizon was 72.8 kg ha^{-1} soil. It ranged from 32.4 to 52.6 kg ha^{-1} soil in subsoil horizons. Available calcium in the surface horizon was 165 mg kg^{-1} soil. It ranged from 163 to 294 mg kg^{-1} in subsoil horizons. Available magnesium in the surface horizon was 29 mg kg^{-1}. It ranged from 29 to 72 mg kg^{-1} soil in the remaining subsoil horizons. Available sulphur in the surface horizon was 3.8 mg kg^{-1} soil. It ranged from 3.3 to 4.0 mg kg^{-1} soil in the subsoil horizons. Surface horizon content of available Fe, Mn, Cu, Zn and B were, 18, 11.3, 6.2, 0.5 and 0.34 mg kg^{-1} respectively. In subsoil it ranged from 5.0 to 30, 2.1 to 6.1, 2.0 to 3.1, 0.6 to 1.9 and 0.17 to 0.72 mg kg^{-1} soil respectively. (Table 8)

4.2.2.4 Properties of Composite Surface Soil Samples

Soil reaction ranged from strongly acid ranged from pH 5.0 to 5.5 and electrical conductivity from 0.01 to 0.06 dS m^{-1}. Organic carbon ranged from 5 to 24.8 g kg^{-1} soil. Available N ranged from 214 to 398 kg ha^{-1}. Available P ranged from 4.9 to 12.6 kg ha^{-1} soil and available K ranged from 45.9 to 111.8 kg ha^{-1} soil. Available Ca, Mg and S ranged from 170 to 288, 32 to 150 and 0.14 to 2.21 mg kg^{-1} soil respectively (Table 9). Available Fe, Mn, Cu, Zn and B in the soil varied from 7.2 to 36.4, 2.9 to 12.3, 0.8 to 3.2, 0.8 to 7.5 and 0.18 to 0.52 mg kg^{-1} soil respectively. (Table 10)

4.2.3 SITE 3: Kollur

4.2.3.1 Soil Morphology

This site is experiencing a humid tropical climate. The average annual rainfall is 3844 mm. Soil moisture is adequate to support annual crop production for 180 to 210 days. The site for soil profile study was located on elongated ridges and foot hill slopes with 1-3 per cent slope with elevation of 141 m above mean sea level. Surface features indicated slight erosion with slow run off. The soil developed from weathered ferruginous quartzite schist

Table 8: Physical and Chemical properties of soil profile sampled at Beltangadi

Depth (cm)	Horizon	Size class and particle diameter (mm)								Gravel % volume	Texture (USDA)
		Sands					Total				
		V.fine	Fine	Medium	Coarse	V.coarse	Sand	silt	Clay		
		(0.1-0.05)	(0.25-0.1)	(0.5-0.25)	(1.0-0.5)	(2.0-1.0)	(2.0-0.05)	(0.05-0.002)	(<0.002)		
		% of <2 mm									
0-18	Ap	18.3	4.2	21.4	15.2	8.8	67.9	10.0	22.1	27.4	gscl
18-41	AB	14.8	7.4	16.6	19.9	19.5	78.2	6.5	15.3	21.4	gsl
41-62	Bt1	14.3	7.3	10.3	9.3	7.4	48.6	13.0	38.4	23.0	gsc
62-82	Bt2	14.4	5.4	9.6	16.9	12.8	59.1	5.8	35.1	25.4	gsc
82-119	Bt3C	11.1	3.8	14.0	9.7	10.4	49.0	24.1	26.9	15.2	gscl
119-139	BC1	15.8	11.4	1.1	10.3	4.2	42.8	24.6	32.6	15.1	gcl
139-153	BC2	10.2	2.7	8.9	12.5	11.4	45.7	16.4	37.9	13.5	sc

Depth (cm)	pH (1:2.5) H_2O	OC g kg^{-1}	E.C dS m^{-1}	B.D (Mg m^{-3})	
				field moist	Oven dry
0-18	5.2	23.0	0.03	1.43	1.22
18-41	5.0	9.0	0.01	1.44	1.19
41-62	5.3	4.6	0.01	1.49	1.22
62-82	5.4	1.3	0.01	1.54	1.28
82-119	5.4	1.6	0.01	1.51	1.24
119-139	5.3	1.6	0.01	1.73	1.42
139-153	5.4	0.9	0.02	1.62	1.33

Depth (cm)	Available nutrients											
	OC (g Kg^{-1})	N	P	K	Ca	Mg	S	Fe	Mn	Cu	Zn	B
		kg ha^{-1}			mg kg^{-1} soil							
0-18	23.5	172.4	3.2	72.8	165	29	3.8	18	11.3	6.2	0.5	0.34
18-41	9.9	141.1	4.0	49.2	165	29	3.3	30	2.8	3.1	1.9	0.45
41-62	4.6	109.7	9.0	48.1	198	36	3.5	21	5.5	2.0	0.6	0.31
62-82	1.3	109.7	7.4	52.6	294	72	4.0	11	6.1	2.5	0.8	0.17
82-119	1.6	94.0	5.3	43.6	268	67	3.7	4	2.1	2.3	1.3	0.72
119-139	1.6	78.4	3.0	33.6	198	33	3.7	6	3.1	2.9	1.0	0.28
139-153	9.0	78.4	2.8	32.4	163	38	3.7	5	2.1	2.3	1.6	0.24

Depth (cm)	Exchangeable bases					Extractable acidity			CEC			Base saturation		Ratio
	Ca	Mg	Na	K	Total	$BaCl_2$-TEA	1.0 *N* KCl		NH_4OAC	Sum of cations	ECEC	NH_4OAc	Sum of cations	CEC/ clay
							H^+	Al^{3+}	(pH 7.0)					
cmol(+)kg^{-1} soil												%		
0-18	0.74	0.12	0.06	0.03	0.95	23.5	0.01	0.12	8.24	24.4	1.0	11	3.8	0.37
18-41	0.63	0.33	0.13	0.02	1.11	14.0	0.01	0.15	6.81	15.1	1.2	16	7.3	0.44
41-62	0.80	0.43	0.06	0.02	1.31	11.0	0.05	0.14	4.92	12.3	1.4	27	10.6	0.13
62-82	1.78	0.11	0.08	0.08	2.05	7.5	0.02	0.12	5.31	9.5	2.1	39	21.4	0.15
82-119	1.65	0.15	0.07	0.01	1.88	8.0	0.08	0.18	4.29	9.8	2.0	44	19.0	0.16
119-139	1.05	0.12	0.05	0.01	1.23	5.5	0.10	0.20	3.06	6.7	1.4	40	18.2	0.09
139-153	0.93	0.08	0.06	0.01	1.08	5.5	0.04	0.22	2.14	6.5	1.3	50	16.4	0.05

Table 9: Plant available primary and secondary nutrients in surface soils of agricultural lands in Beltangadi

Crop	pH	EC	OC	N	P	K	Ca	Mg	S
		(dS m^{-1})	(g kg^{-1})	(kg ha^{-1} soil)			(mg kg^{-1} soil)		
Rubber (1)	5.5	0.02	13.0	398.2	6.4	111.8	274	44	0.97
Rubber (2)	5.0	0.02	18.0	359.0	8.4	102.4	169	63	2.21
Rubber (3)	5.2	0.02	24.8	266.5	6.9	85.1	201	51	2.20
Cashew (1)	5.3	0.06	5.1	256.1	5.5	62.5	288	150	1.24
Cashew (2)	5.4	0.03	5.2	254.7	6.8	71.2	170	59	1.40
Arecanut	5.3	0.01	6.0	248.2	5.5	61.6	267	94	1.59
Areca+Venilla+Coco+Pepper	5.5	0.02	5.2	235.2	12.6	104.1	158	84	1.31
Mango	5.3	0.03	5.0	214.0	9.3	71.6	287	56	2.14
Forest cassurina & Bamboo mixed	5.5	0.02	5.5	289.0	4.9	111.1	200	72	0.14
Silver oak	5.4	0.03	5.6	235.2	9.2	45.9	178	32	0.14
Mean	5.34	0.026	9.34	275.61	7.55	82.73	219.2	70.52	1.334
Range	5.0-5.5	0.01-0.06	5-24.8	214-398.2	4.9-12.6	45.9-111.8	170-288	32-150	0.14-2.21

Table 10: Plant available micro-nutrients in surface soils of agricultural lands in Beltangadi

Crop	Extractant used	Fe	Mn	Cu	Zn	B
		(mg kg^{-1} soil)				
Rubber (1)	0.1*N* Hcl	33.4	3.5	1.8	1.4	1.80
Rubber (2)	0.1*N* Hcl	17.4	3.2	0.8	0.8	0.43
Rubber (3)	0.1*N* Hcl	18.3	12.3	2.5	1.5	0.48
Cashew (1)	0.1*N* Hcl	19.3	9.1	3.2	2.8	0.19
Cashew (2)	0.1*N* Hcl	31.0	4.2	1.8	1.5	0.24
Arecanut	0.1*N* Hcl	22.4	7.8	2.8	3.4	0.24
Areca+Venilla+Coco+Pepper	0.1*N* Hcl	36.1	4.1	9.0	7.5	0.52
Mango	0.1*N* Hcl	18.1	4.3	2.3	1.9	0.51
Forest cassurina & Bamboo mixed	0.1*N* Hcl	7.2	2.9	1.1	1.5	0.16
Silver oak	0.1*N* Hcl	24.0	6.6	0.8	2.4	0.18
Mean		22.72	5.8	2.61	2.47	0.475
Range		7.2-36.1	2.9-12.3	0.8-3.2	0.8-7.5	0.18-0.52

The soil profile was excavated to a depth of 130 cm. The lowest layer (88-130 cm) comprised hard weathered quartzite schist. The 10 cm thick Ap horizon was dark reddish brown (5YR 3/3), gravelly sandy clay loam in texture containing 28 per cent of coarse gravels with weak fine sub-angular blocky structure. Moist consistency of soil was friable and wet, sticky and plastic. The horizon had common very fine pores and few fine roots. The horizon merged into the subsoil horizon smoothly.

The subsoil B horizons were designated as Bt1, Bt2, Bt3 and Bt4, with depth interval of 10-27, 27-53, 53-88 and 88-130 cm respectively. The Bt1 horizon was dark reddish brown in colour (5YR 3/4), gravelly sandy clay in texture containing 29 per cent of coarse gravels with moderate medium sub-angular blocky structure. Moist consistency of soil was friable and wet, sticky and plastic. The horizon had common fine pores, and many fine roots. The horizon had thick clay skins. The horizon merged into the sub horizon smoothly.

The Bt2 horizon was dark reddish brown (2.5YR 3/4) gravelly clay in texture containing 31 per cent of fine gravels with moderate medium sub-angular blocky structure. Moist consistency of soil was friable and wet, sticky and plastic. The horizon had common fine pores, and few fine roots. The horizon had thick patchy clay skins. The horizon merged into the sub horizon smoothly.

The Bt3 horizon was dark red (2.5YR 3/6) gravelly silt clay loam in texture containing 30 per cent of fine gravels with moderate medium sub-angular blocky structure. Moist consistency of soil was friable and wet, sticky and plastic. The horizon had common very fine pores, and few fine roots. The horizon had patchy thick clay skins. The horizon merged into the sub horizon smoothly.

The Bt4 horizon was red (2.5YR 4/6) very gravelly clay in texture containing 39 per cent of fine gravels with weak coarse sub-angular blocky structure. Moist consistency of soil was friable and wet, sticky and plastic. The horizon had common fine pores, and many fine roots. The horizon had medium patchy thin clay skins.

4.2.3.2 Physical Properties

The sand content in ranged from 19.6 to 72.9 per cent. The maximum was observed in Ap horizon and least in Bt4 horizon. The silt content ranged from 6.4 to 43.7 per cent. The maximum was observed in Bt4 horizon and minimum in Ap horizon. The clay content ranged from 20.8 to 64.1 per cent. The maximum was observed in Bt4 horizon and minimum was observed in Ap horizon. The textural class (USDA) gravely sandy clay loam was observed in surface Ap horizon, gravelly sandy clay in Bt1 horizon, gravelly clay in Bt3 horizon, gravelly silty clay loam in Bt3 horizon and very gravely clay in Bt4 horizon. The bulk density ranged from 1.12 to 1.33 mg m^{-3}. The maximum was found in the Bt4 horizon and minimum in Bt1 horizon.

4.2.3.3 Chemical Properties

Soil reaction was strongly acidic throughout the pedon with pH in soil water suspension ranging from pH 5.3 to 5.6. The maximum pH was observed in Bt4 horizon and minimum was observed in Ap and Bt2 horizons. Electrical conductivity decreased with depth and it ranged from 0.02 to 0.08 dS m^{-1}. The maximum was observed in Ap horizon and minimum was observed in Bt2, Bt3 and Bt4 horizons. Organic carbon ranged from 0.30 to 54.9 g kg^{-1} soil. The maximum was observed in Ap horizon which decreased with the depth and minimum was observed in Bt4 horizon.

Exchangeable calcium ranged from 6.20 to 0.98 cmol(+)kg^{-1} soil. The maximum was observed in Ap horizon which decreased abruptly to 3.07 cmol(+) kg^{-1} in subsoil horizon and minimum was observed in Bt4 horizon. Exchangeable Magnesium ranged from 0.18 to 0.42 cmol(+)kg^{-1} soil. The maximum was observed in Bt2 horizon and minimum was observed in Bt4 horizon. Exchangeable potassium ranged from 0.02 to 0.06 cmol(+)kg^{-1} soil. The maximum was observed in Ap horizon and it decreased with depth in subsoil horizons and minimum was observed in Bt4 horizon. Exchangeable sodium ranged from 0.06 to 0.08 cmol(+)kg^{-1} soil. The maximum was observed in Bt3 horizon and minimum was observed in Bt2 and Bt4 horizons. Base saturation per cent ranged from 24 to 64 per cent. The maximum was observed in Ap horizon it decreased with the depth in subsoil horizons and minimum was observed in Bt4 horizon.

$BaCl_2$-TEA extractable acidity ranged from 10.2 to 21.5 cmol(+)kg^{-1} soil. The maximum was observed in Ap horizon and it decreased with depth in subsoil horizons and minimum was observed in Bt4 horizon. Extractable H^+ ranged from 0.01 to 0.04 cmol(+)kg^{-1} soil. The maximum was observed in Bt4 horizon and minimum was observed in Ap horizon. Extractable Al^{3+} ranged from 0.14 to 0.24 cmol(+)kg^{-1} soil. The maximum was observed in Ap horizon and minimum was observed in Bt3 horizon. Cation exchange capacity ranged from 5.21 to 15.21 cmol(+)kg^{-1} soil. The maximum was observed in surface Ap horizon and it decreased with the depth in subsoil horizons and minimum was observed in Bt4 horizon. Effective cation exchange capacity ranged from 1.4 to 7.0 cmol(+)kg^{-1} soil. The maximum was observed in Ap horizon it decreased with depth in subsoil horizons and minimum was observed in Bt4 horizon. Cation exchange capacity by sum of cations ranged from 11.4 to 28.2 cmol(+)kg^{-1} soil. The maximum was observed in Ap horizon it decreased with depth in subsoil horizons and minimum was observed in Bt4 horizon. The CEC/clay ratio ranged from 0.08 to 0.73. The maximum was observed in Ap horizon and minimum was observed in Bt4 horizon.

Available nitrogen content in surface soils was 705.6 kg ha^{-1} soil. It ranged from 533.1 to 752 kg ha^{-1} soil in the subsoil horizons. Available phosphorus in the surface soil was 7.30 kg ha^{-1} soil. It ranged from 3.78 to 10.6 kg ha^{-1} soil in the subsoil horizons. Available potassium in the surface horizon was 224.1 kg ha^{-1} soil. It ranged from 81.7 to 221.4 kg ha^{-1} soil in subsoil horizons. Available calcium in the surface horizon was 283 mg kg^{-1} soil it decreased with the depth to 100 mg kg^{-1}.It ranged from 100 to 224 mg kg^{-1} in subsoil horizons. Available magnesium in the surface horizon was 166 mg kg^{-1} soil and decreased abruptly to 94 mg kg^{-1} soil in the immediate subsoil horizon. It ranged from 68 to 96 mg kg^{-1} soil in the remaining subsoil horizons. Available sulphur in the surface horizon was 3.45 mg kg^{-1} soil. It ranged from 2.41 to 4.55 mg kg^{-1} soil in the subsoil horizons. Surface horizon content of available Fe, Mn, Cu, Zn and B were, 139.4, 24.9, 5.8, 1.6 and 0.35 mg kg^{-1} respectively. In subsoil it ranged from 11.3 to 120.4, 1.7 to 10.7, 2.5 to 5.7, 0.6 to 0.9 and 0.27 to 0.73 mg kg^{-1} soil respectively. (Table 11)

4.2.3.4 Properties of Composite Surface Soil Samples

Soil reaction ranged from strongly acid (pH 5.2) to moderately acid (pH 5.7) and electrical conductivity from 0.01 to 0.03 dS m^{-1}. Organic carbon ranged from 6.5 to 12 g kg^{-1} soil. Available N ranged from 256 to 581 kg ha^{-1}. Available P ranged from 3 to 19.5 kg ha^{-1} soil and available K from 33.6 to 117 kg ha^{-1} soil. Available Ca, Mg and S ranged from 120 to 271, 13 to 147 and 0.06 to 2.07 mg kg^{-1} soil respectively (Table 12). Available Fe, Mn, Cu, Zn and B in the soil varied from 10.2 to 69.7, 2.8 to 7.9, 0.6 to 5.3, 0.5 to 7.10 and 0.24 to 2.4 mg kg^{-1} soil respectively. (Table 13)

4.2.4 SITE 4: Molahalli

4.2.4.1 Soil Morphology

This site is experiencing a humid tropical climate. The average annual rainfall is 3844 mm. Soil moisture is adequate to support annual crop production for 190 to 210 days. The site for soil profile study was located on very gently slope on shoulder of undulating uplands with 3-5 per cent slope with elevation of 25 m above mean

Table 11: Physical and Chemical properties of soil profile sampled at Kollur

Depth (cm)	Horizon	Size class and particle diameter (mm)								Gravel % volume	Texture (USDA)
		Sands					Total				
		V.fine (0.1-0.05)	Fine (0.25-0.1)	Medium (0.5-0.25)	Coarse (1.0-0.5)	V.coarse (2.0-1.0)	Sand (2.0-0.05)	Silt (0.05-0.002)	Clay (<0.002)		
		% of <2 mm									
0-10	Ap	26.4	5.3	11.5	12.8	16.9	72.9	6.4	20.8	27.8	gsl
10-27	Bt1	10.3	2.2	5.5	10.1	20.7	48.8	11.6	39.6	28.8	gcl
27-53	Bt2	9.7	0.7	5.7	5.7	10.0	31.8	23.3	44.9	31.0	gsl
53-88	Bt3	5.8	0.6	2.6	4.1	6.5	19.6	43.7	36.7	32.4	gl
88-130	Bt4	6.0	1.3	4.5	3.9	10.8	26.5	9.4	64.1	38.6	vgcl

Depth	pH	OC	E.C	B.D (mg m^{-3})	
(cm)		g kg^{-1}	dS m^{-1}	field moist	Oven dry
0-10	5.3	54.9	0.08	1.46	1.13
10-27	5.5	28.0	0.03	1.41	1.12
27-53	5.3	12.2	0.02	1.57	1.22
53-88	5.4	9.9	0.02	1.55	1.21
88-130	5.6	0.30	0.02	1.73	1.33

Table cont….

Depth (cm)	OC ($g\ kg^{-1}$)	N	P	K	Ca	Mg	S	Fe	Mn	Cu	Zn	B
		Available nutrients										
		$kg\ ha^{-1}$			$mg\ kg^{-1}$ soil							
0-10	54.0	705.6	7.30	224.1	283	166	3.45	139.4	24.9	5.8	1.6	0.35
10-27	28.0	752.6	5.49	221.4	224	94	3.45	120.4	10.7	5.5	0.9	0.32
27-53	12.0	642.8	3.78	175.3	167	73	4.00	79.4	8.0	5.7	0.6	0.27
53-88	9.9	548.8	4.03	103.0	129	68	4.55	24.0	6.5	3.8	0.7	0.73
88-130	0.3	533.1	10.6	81.7	100	96	2.41	11.3	1.7	2.5	2.2	0.54

Depth	Exchangeable bases					Extractable acidity			CEC			Base saturation		Ratio
(cm)	Ca	Mg	Na	K	Total	$BaCl_2$-TEA	1.0 *N* KCl H^+	1.0 *N* KCl Al^{3+}	NH_4OAC (pH 7.0)	Sum of cations	ECEC	NH_4OAC	Sum of cations	CEC/ clay
	cmol(+)kg^{-1} soil											%		
0-10	6.2	0.41	0.07	0.06	6.74	21.5	0.01	0.24	15.21	28.2	7.0	44	23.9	0.73
10-27	3.07	0.18	0.06	0.05	3.36	19.2	0.03	0.21	12.99	22.5	3.5	26	14.8	0.32
27-53	4.06	0.42	0.08	0.05	4.61	17.5	0.02	0.18	9.35	22.1	4.8	50	20.8	0.20
53-88	1.86	0.19	0.07	0.04	2.16	12.5	0.04	0.14	7.74	14.6	2.3	28	14.7	0.21
88-130	0.98	0.18	0.06	0.02	1.24	10.2	0.03	0.20	5.21	11.4	1.4	24	10.8	0.08

Table 12: Plant available primary and secondary nutrients in surface soils of agricultural lands in Kollur

Crop	pH	EC	OC	N	P	K	Ca	Mg	S
		(dS m^{-1})	(g kg^{-1})	(kg ha^{-1} soil)			(mg kg^{-1} soil)		
Paddy harvested	5.2	0.03	7.5	261.2	16.9	59.3	271	62	0.48
Paddy	5.3	0.03	8.5	256.1	3.0	33.6	185	13	0.97
Rubber	5.4	0.03	12	344.9	11.6	103.0	217	77	2.07
Arecanut (1)	5.4	0.02	8.0	581.2	12.3	109.5	245	147	0.41
Arecanut (2)	5.3	0.03	9.0	250.1	19.5	66.0	200	107	0.21
Arecanut (3)	5.4	0.02	7.4	289.5	5.0	77.2	261	104	0.34
Cashew (1)	5.7	0.01	8.4	282.2	6.7	79.5	206	55	0.14
Cashew (2)	5.7	0.01	8.1	286.0	6.4	53.7	120	22	0.06
Coconut	5.6	0.01	8.2	289.2	6.2	117.0	169	110	0.55
Forest	5.4	0.02	5.4	332.4	9.8	43.6	177	111	0.55
Silver oak	5.3	0.01	6.5	312.0	7.7	64.9	166	40	0.21
Mean	5.42	0.02	8.09	343.89	9.55	73.39	201.54	77.17	0.54
Range	5.2-5.7	0.01-0.03	6.5-12	256.1-581.2	3-19.5	33.6-117	120-271	13-147	0.06-2.07

Table 13: Plant available micro-nutrients in surface soils of agricultural lands in Kollur

Crop	Extractant used	Fe	Mn	Cu	Zn	B
		(mg kg^{-1} soil)				
Paddy harvested	0.1 *N* HCl	67.6	4.4	9.0	1.7	0.53
Paddy	0.1 *N* HCl	69.7	5.6	0.9	3.3	0.32
Rubber	0.1 *N* HCl	35.2	5.1	5.3	7.1	0.25
Arecanut (1)	0.1 *N* HCl	18.0	5.2	1.9	1.7	0.24
Arecanut (2)	0.1 *N* HCl	20.9	7.9	2.4	0.8	2.44
Arecanut (3)	0.1 *N* HCl	30.5	4.5	3.2	2.4	0.24
Cashew (1)	0.1 *N* HCl	10.5	2.8	2.0	1.5	0.32
Cashew (2)	0.1 *N* HCl	23.7	3.9	3.6	2.5	0.42
Coconut	0.1 *N* HCl	24.7	4.2	0.6	0.7	0.51
Forest	0.1 *N* HCl	13.7	2.8	3.9	0.5	0.32
Silver oak	0.1 *N* HCl	15.5	5.1	4.6	0.6	0.24
Mean		30.0	4.68	3.40	2.07	0.53
Range		10.2-69.7	2.8-7.9	0.6-5.3	0.5-7.1	0.24-2.4

sea level. Surface features indicated moderate erosion with medium run off. The soil is developed from weathered Laterite rocks.

The soil profile was excavated to a depth of 109 cm. The lowest layer was (78-109 cm). The 10 cm thick Ap horizon was red (2.5YR 4/6), gravelly sandy loam in texture containing 31 per cent of fine gravels with weak fine sub-angular blocky structure. Moist consistency of soil was slightly hard friable and wet, slightly sticky and slightly plastic. The horizon had common fine pores and many very fine roots. The horizon merged into the subsoil horizon smoothly.

The subsoil B horizons were designated as Bt1, Bt2C, BC1 and BC2 with depth interval of 10-28, 28-50, 50-78 and 78-109 cm respectively. The Bt1 horizon was red in colour (2.5YR 4/6), gravelly clay loam texture containing 32 per cent of fine gravels with moderate medium sub-angular blocky structure. Moist consistency of soil was friable and wet, sticky and plastic. The horizon had common fine pores, and few fine roots. The horizon had thin patchy clay skins. The horizon merged into the sub horizon smoothly.

The Bt2C horizon was dark yellowish brown (10YR 4/6) gravelly sandy loam in texture containing 33 per cent of fine gravels with moderate coarse sub-angular blocky structure. Moist consistency of soil was friable and wet, slightly sticky and slightly plastic. The horizon had common fine pores, and few fine roots. The horizon had thin patchy clay skins. The horizon merged into the sub horizon smoothly.

The BC1 horizon was dark yellowish brown (10YR 4/6) gravelly loam in texture containing 34 per cent of fine gravels with weak coarse sub-angular blocky structure. Moist consistency of soil was friable and wet, slightly sticky and slightly plastic. The horizon had common fine pores, and common very fine roots. Few fine distinct mottles strong brown (7.5YR 5/8) were found in this horizon. The horizon merged into the sub horizon smoothly.

The BC2 horizon was dark yellowish brown (10YR 4/6) very gravelly clay loam in texture containing 37 per cent of stones with weak coarse sub-angular blocky structure. Moist consistency of soil was friable and wet, slightly sticky and slightly plastic. The horizon had common fine pores. Few fine distinct mottles strong brown (7.5YR 5/8) were found in this horizon. The depth 109-140 cm had hard weathered laterite rock .

4.2.4.2 Physical Properties

The sand content in ranged from 37.3 to 75.9 per cent. The maximum was observed in Ap horizon and least in Bt1 horizon. The silt content ranged from 11.1 to 32.7 per cent. The maximum was observed in BC1 horizon and minimum in Bt2C horizon. The clay content ranged from 12.1 to 36.4 per cent. The maximum was observed in Bt1 horizon and minimum was observed in Ap horizon. The textural class (USDA) gravely sandy clay loam was observed in surface Ap horizon and Bt3C horizon, gravelly sandy loam in Ap and Bt2C horizons, gravelly clay loam in Bt1 horizons, gravelly loam in BC1 horizon, very gravelly clay loam in BC2. The bulk density ranged from 1.21 to 1.3 mg m^{-3}. The maximum was found in the BC2 horizon and minimum in Ap and Bt1 horizons.

4.2.4.3 Chemical Properties

Soil reaction was strongly acidic to moderately acid throughout the pedon with pH in soil water suspension ranging from pH 5.5 to 5.7. The maximum pH was observed in Ap and BC1 horizons and minimum was observed in Bt2C and BC2 horizons. Electrical conductivity ranged from 0.01 to 0.03 dS m^{-1}. The maximum was observed in Ap horizon and minimum was observed in Bt1, BC1 and BC2 horizons. Organic carbon ranged from 0.6 to 6.6 g kg^{-1} soil. The maximum was observed in Ap horizon which decreased in subsoil horizons with depth and minimum was observed in BC2 horizon.

Exchangeable calcium ranged from 0.82 to 1.41 cmol(+)kg^{-1} soil. The maximum was observed in Ap horizon and it decreased with depth in subsoil horizons and minimum was observed in Bc2 horizon. Exchangeable Magnesium ranged from 0.09 to 0.22 cmol(+)kg^{-1} soil. The maximum was observed in BC1 horizon and minimum was observed in Ap horizon. Exchangeable potassium ranged from 0.01 to 0.02 cmol(+)kg^{-1} soil. The maximum was observed in Bt1 horizon and minimum was observed in Ap, Bt2C, BC1 and BC2 horizons. Exchangeable sodium ranged from 0.06 to 0.46 cmol(+)kg^{-1} soil. The maximum was observed in Bt1 horizon and minimum was observed in Bt2C horizon. Base saturation per cent ranged from 26 to 58 per cent. The maximum was observed in Ap horizons and minimum was observed in BC2 horizon.

$BaCl_2$-TEA extractable acidity ranged from 4.5 to 7.5 cmol(+)kg^{-1} soil. The maximum was observed in Ap, Bt1 and BC2 horizons and minimum was observed in BC1 horizon. Extractable H+ ranged from 0.01 to 0.06 cmol(+)kg-^{1} soil. The maximum was observed in Bt1 horizon and minimum was observed in Bt1 horizon. Extractable Al^{3+} ranged from 0.14 to 0.26 cmol(+)kg^{-1} soil. The maximum was observed in Bt2C horizon and minimum was observed in BC1 horizons. Cation exchange capacity ranged from 3.18 to 3.81 cmol(+)kg^{-1} soil. The maximum was observed in BC2 horizon and minimum was observed in BC1 horizon. Effective cation exchange capacity ranged from 1.2 to 2.2 cmol(+)kg^{-1} soil. The maximum was observed in Bt1 horizon and minimum was observed in BC2 horizon. Cation exchange capacity by sum of cations ranged from 6.0 to 9.4 cmol(+)kg^{-1} soil. The maximum was observed in Ap and Bt1 horizon and minimum was observed in BC1 horizon. The CEC/clay ratio ranged from 0.09 to 0.27. The maximum was observed in Ap horizon and minimum was observed in Bt1 horizon.

Available nitrogen content in surface soils was 172.4 kg ha^{-1} soil. It ranged from 156.8 to 188.1 kg ha^{-1} soil in the subsoil horizons.

Available phosphorus in the surface soil was 6.98 kg ha^{-1} soil. It ranged from 2.81 to 4.76 kg ha^{-1} soil in the subsoil horizons. Available potassium in the surface horizon was 39.2 kg ha^{-1} soil. It ranged from 23.5 to 32.4 kg ha^{-1} soil in subsoil horizons. Available calcium in the surface horizon was 288 mg kg^{-1} soil. It ranged from 98 to 165 mg kg^{-1} in subsoil horizons. Available magnesium in the surface horizon was 51 mg kg^{-1}. It ranged from 19 to 81 mg kg^{-1} soil in the remaining subsoil horizons. Available sulphur in the surface horizon was 3.7 mg kg^{-1} soil. It ranged from 3.2 to 4.5 mg kg^{-1} soil in the subsoil horizons. Surface horizon content of available Fe, Mn, Cu, Zn and B were, 21.3, 8, 2.7, 0.6 and 0.34 mg kg^{-1} respectively. In subsoil it ranged from 6.8 to 18.4, 5.5 to 8.3, 3.4 to 4.1, 0.4 to 1.2 and 0.20 to 0.41 mg kg^{-1} soil respectively. (Table 14)

4.2.4.4 Properties of Composite Surface Soil Samples

Soil reaction ranged from strongly acid to moderately acid ranged from pH 4.9 to 5.8 and electrical conductivity from 0.02 to 0.06 dS m^{-1}. Organic carbon ranged from 6.6to 23 g kg^{-1} soil. Available N ranged from 141 to 313 kg ha^{-1}. Available P ranged from 2.5 to 12 kg ha^{-1} soil and available K ranged from 40.3 to 240.8 kg ha^{-1} soil. Available Ca, Mg and S ranged from 136 to 234, 43 to 99 and 3.66 to 11.8 mg kg^{-1} soil respectively (Table 15). Available Fe, Mn, Cu, Zn and B in the soil varied from 9.1 to 43.4, 2.3 to 12.3, 2.3 to 5.2, 0.4 to 2.5 and 0.05 to 0.97 mg kg^{-1} soil respectively. (Table 16)

4.2.5 SITE 5: Brahmavar

4.2.5.1 Soil Morphology

This site is experiencing a humid tropical climate. The average annual rainfall is 3887 mm. Soil moisture is adequate to support annual crop production for 180 to 210 days. The site for soil profile study was located on lateritic plateau and lateritic mounds, gently sloping with 3-5 per cent slope with elevation of 38 m above mean sea

Table 14: Physical and Chemical properties of soil profile sampled at Molahalli

Depth (cm)	Horizon	Size class and particle diameter (mm)								Gravel % volume	Texture (USDA)
		Sands					Total				
		V.fine (0.1-0.05)	Fine (0.25-0.1)	Medium (0.5-0.25)	Coarse (1.0-0.5)	V.coarse (2.0-1.0)	Sand (2.0-0.05)	Silt (0.05-0.002)	Clay (<0.002)		
		% of <2 mm									
0-10	Ap	13.6	2.4	14.0	29.3	16.6	75.9	12.0	12.1	31.0	gsl
10-28	Bt1	4.7	4.3	8.9	9.8	9.6	37.3	26.3	36.4	32.2	gcl
28-50	Bt2C	13.2	12.7	4.7	28.1	14.6	73.3	11.1	15.6	32.6	gsl
50-78	BC1	11.4	2.4	5.2	12.7	11.7	43.4	32.7	23.9	34.2	gl
78-109	BC2	12.2	1.6	9.0	9.2	9.3	41.3	27.7	30.9	37.0	vgcl

Depth	pH	OC	E.C	B.D (Mg m^{-3})	
(cm)		g kg^{-1}	dS m^{-1}	field moist	Oven dry
0-10	5.7	6.6	0.03	1.66	1.21
10-28	5.6	1.3	0.01	1.53	1.21
28-50	5.5	1.3	0.02	1.57	1.26
50-78	5.7	1.0	0.01	1.68	1.26
78-109	5.5	0.6	0.01	1.78	1.34

Table cont…

Depth (cm)	Available nutrients											
	OC(g Kg^{-1})	N	P	K	Ca	Mg	S	Fe	Mn	Cu	Zn	B
		kg ha^{-1}			mg kg^{-1} soil							
0-10	6.6	172.4	6.98	39.2	288	51	3.7	21.3	8.0	2.7	0.6	0.34
28-50	1.3	156.8	3.54	32.4	165	81	3.2	18.4	8.3	3.4	0.4	0.35
28-50	1.3	172.4	2.81	25.7	114	19	4.5	14.3	7.4	3.1	1.0	0.41
50-78	1.0	156.8	4.76	24.6	102	61	3.7	9.8	6.5	4.1	1.2	0.2
78-109	0.6	188.1	3.54	23.5	98	48	4.1	6.8	5.5	3.8	0.8	0.27

Depth	Exchangeable bases					Extractable acidity			CEC			Base saturation		Ratio
							1.0 *N* KCl		NH₄OAC					
(cm)	Ca	Mg	Na	K	Total	$BaCl_2$-TEA	H^+	Al^{3+}	(pH 7.0)	Sum of cations	ECEC	NH_4OAC	Sum of cations	CEC/ clay
cmol(+)kg^{-1} soil												%		
0-10	1.41	0.09	0.43	0.01	1.94	7.5	0.02	0.18	3.32	9.4	2.1	58	20.5	0.27
28-50	1.34	0.10	0.46	0.02	1.92	7.5	0.06	0.24	3.34	9.4	2.2	57	20.3	0.09
28-50	1.28	0.12	0.06	0.01	1.47	6.9	0.01	0.26	3.33	8.4	1.7	44	17.5	0.21
50-78	1.26	0.22	0.07	0.01	1.56	4.5	0.04	0.14	3.18	6.0	1.7	49	25.7	0.13
78-109	0.82	0.12	0.06	0.01	1.01	7.5	0.03	0.19	3.81	8.5	1.2	26	11.7	0.12

Table 15: Plant available primary and secondary nutrients in surface soils of agricultural lands in Molahalli

Crop	pH	EC	OC	N	P	K	Ca	Mg	S
		(dS m^{-1})	(g kg^{-1})	(kg ha^{-1} soil)			(mg kg^{-1} soil)		
Rubber (3yrs)	5.5	0.06	18.0	134.7	8.7	90.7	136	84	3.66
Cashew (5 yrs)	5.5	0.02	8.5	172.4	4.2	100.8	161	99	4.21
Cashew (old plantation)	5.8	0.04	23.0	266.5	5.9	40.3	265	71	5.18
Arecanut (1)	5.5	0.02	5.2	313.6	5.4	66.0	224	56	3.79
Arecanut (2)	5.5	0.02	10.0	172.4	12.0	45.6	234	61	4.83
Coconut	5.2	0.02	7.2	109.7	3.0	63.8	209	43	4.21
Coconut fallow (grassed)	5.2	0.03	6.6	313.6	2.5	53.7	178	63	4.21
Sapota	4.9	0.03	11.0	172.4	5.9	50.8	141	86	11.8
Coconut+Arecanut+Banana	5.7	0.03	14.0	178.5	8.6	240.8	184	96	6.14
Forest thick stand	5.2	0.04	16.0	141.1	10.5	64.9	145	76	5.45
Mean	5.4	0.031	11.95	197.49	6.67	81.74	187.7	73.5	5.348
Range	4.9-5.8	0.02-0.06	6.6-23	141.1-313.6	2.5-12	40.3-240.8	136-234	43-99	3.66-11.8

Table 16: Plant available micro-nutrients in surface soils of agricultural lands in Molahalli

Crop	Extractant used	Fe	Mn	Cu	Zn	B
		(mg kg^{-1} soil)				
Rubber (3yrs)	0.1 *N* HCl	38.6	11.9	3.1	0.4	0.48
Cashew (5 yrs)	0.1 *N* HCl	27.0	15.9	4.7	1.9	0.39
Cashew (old plantation)	0.1 *N* HCl	43.4	12.3	2.4	1.5	0.36
Arecanut (1)	0.1 *N* HCl	57.0	2.3	4.6	2.5	0.14
Arecanut (2)	0.1 *N* HCl	25.3	11.8	3.8	1.5	0.33
Coconut	0.1 *N* HCl	18.3	2.9	5.2	1.5	0.21
Coconut fallow (grassed)	0.1 *N* HCl	18.7	9.9	4.7	1.8	0.05
Sapota	0.1 *N* HCl	27.3	18.8	2.3	1.4	0.65
Coconut+Arecanut+Banana	0.1 *N* HCl	9.1	1.9	2.3	2.1	0.97
Forest thick stand	0.1 *N* HCl	22.1	8.8	3.9	1.8	0.12
Mean		28.68	9.653	3.7	1.64	0.37
Range		9.1-43.4	2.3-12.3	2.3-5.2	0.4-2.5	0.05-0.97

level. Surface features indicated moderate erosion with slow run off. The soil developed from weathered Laterite rock.

The soil profile was excavated to a depth of 148 cm. The lowest layer was (113-148 cm). The 10 cm thick Ap horizon was reddish brown (5YR 4/3), gravelly clay in texture containing 21 per cent of stones with weak fine sub-angular blocky structure. Moist consistency of soil was friable and wet, sticky and plastic. The horizon had common fine pores and many fine roots. The horizon merged into the subsoil horizon smoothly.

The subsoil B horizons were designated as BA, Bt1, Bt2C, BC1 and BC2 with depth interval of 10-38, 38-59, 59-79, 79-113 and 113-148 cm respectively. The BA horizon was red in colour (2.5YR 4/6), gravelly clay loam texture containing 20 per cent of coarse gravels with moderate medium sub-angular blocky structure. Moist consistency of soil was friable and wet, sticky and plastic. The horizon had common fine pores, and many fine roots. The horizon had patchy thin clay skins. The horizon merged into the sub horizon smoothly.

The Bt1 horizon was red (2.5YR 4/6) gravelly clay in texture containing 19 per cent of coarse gravels with moderate medium sub-angular blocky structure. Moist consistency of soil was friable and wet, very sticky and plastic. The horizon had very fine pores, and few fine roots. The horizon had thick patchy clay skins. The horizon merged into the sub horizon smoothly.

The Bt2C horizon was dark red (2.5YR 3/6) clay loam in texture containing 14 per cent of fine gravels with moderate coarse sub-angular blocky structure. Moist consistency of soil was friable and wet, sticky and plastic. The horizon had common very fine pores, and few very fine roots. The horizon had thin patchy clay skins. The horizon merged into the sub horizon smoothly.

The BC1 horizon was yellowish red (5YR 4/6) gravelly clay loam in texture containing 22 per cent of coarse gravels with weak coarse sub-angular blocky structure. Moist consistency of soil was friable and wet, slightly sticky and slightly plastic. The horizon had few fine pores, and few very fine roots. The horizon merged into the sub horizon smoothly.

The BC2 horizon was yellowish red (5YR 4/6) gravelly clay loam in texture containing 24 per cent of coarse gravels with weak coarse sub-angular blocky structure. Moist consistency of soil was friable and wet, slightly sticky and slightly plastic. The horizon had few fine pores, and few very fine roots.

4.2.5.2 Physical Properties

The sand content in ranged from 21.7 to 42.1 per cent. The maximum was observed in BC1 horizon and least in Bt1 horizon. The silt content ranged from 16.3 to 42.5 per cent. The maximum was observed in Bt2C horizon and minimum in Ap horizon. The clay content ranged from 31.6 to 52.3 per cent. The maximum was observed in Bt1 horizon and minimum was observed in Bt2C horizon. The textural class (USDA) gravely clay was observed in Ap and Bt1 horizon, gravelly clay loam in BA, BC1 and BC2 horizons and clay loam in Bt2C horizon. The bulk density ranged from 1.17 to 1.29 mg m^{-3}. The maximum was found in the BC2 horizon and minimum in Ap horizon.

4.2.5.3 Chemical Properties

Soil reaction was strongly acidic to moderately acid throughout the pedon with pH in soil water suspension ranging from pH 5.2 to 5.8. The maximum pH was observed in Ap horizon and minimum was observed in Bt1, Bt2C and Bc2 horizons. Electrical conductivity throughout the profile was 0.01 dS m^{-1}. Organic carbon ranged from 1.3 to 24.8 g kg^{-1} soil. The maximum was observed in Ap horizon which decreased in subsoil horizons with depth and minimum was observed in BC2 horizon.

Exchangeable calcium ranged from 0.58 to 3.73 cmol(+)kg^{-1} soil. The maximum was observed in Ap horizon and minimum was observed in Bc1 horizon. Exchangeable Magnesium ranged from 0.10 to 0.79 cmol(+)kg^{-1} soil. The maximum was observed in BC2 horizon and minimum was observed in BC1 horizon. Exchangeable potassium ranged from 0.01 to 0.06 cmol(+)kg^{-1} soil. The maximum was observed in Ap horizon and minimum was observed in BA, Bt1 and BC1 horizons. Exchangeable sodium ranged from 0.06 to 0.10 cmol(+)kg^{-1} soil. The maximum was observed in BC2 horizon and minimum was observed in Ap, BA and Bt1 horizons. Base saturation per cent ranged from 15 to 61 per cent. The maximum was observed in BC2 horizons and minimum was observed in BC1 horizon.

BaCl2-TEA extractable acidity ranged from 9.0 to 14 cmol(+)kg^{-1} soil. The maximum was observed in Ap and Bt2C horizons and minimum was observed in BC1 horizon. Extractable H+ ranged from 0.01 to 0.04 cmol(+)kg-1 soil. The maximum was observed in Bt1 horizon and minimum was observed in Ap, BA and BC1 horizons. Extractable Al^{3+} ranged from 0.12 to 0.23 cmol(+)kg^{-1} soil. The maximum was observed in BC2 horizon and minimum was observed in Bt2C horizon. Cation exchange capacity ranged from 3.69 to 8.79 cmol(+)kg^{-1} soil. The maximum was observed in surface Ap horizon and minimum was observed in BC2 horizon. Effective cation exchange capacity ranged from 0.9 to 4.4 cmol(+)kg^{-1} soil. The maximum was observed in surface Ap horizon and minimum was observed in BC1 horizon. Cation exchange capacity by sum of cations ranged from 9.7 to 18.2 cmol(+)kg^{-1} soil. The maximum was observed in Ap horizon and minimum was observed in BC1 horizon. The CEC/clay ratio ranged from 0.01 to 0.20. The maximum was observed in Ap horizon and minimum was observed in Bt1 horizon.

Available nitrogen content in surface soils was 658.5 kg ha^{-1} soil. It ranged from 407.0 to 627.2 kg ha^{-1} soil in the subsoil horizons. Available phosphorus in the surface soil was 5.49 kg ha^{-1} soil. It ranged from 3.54 to 7.45 kg ha^{-1} soil in the subsoil horizons. Available potassium in the surface horizon was 264.4 kg ha^{-1} soil. It ranged from 32.4 to 42.5 kg ha^{-1} soil in subsoil horizons. Available calcium in the surface horizon was 291mg kg^{-1} soil. It ranged from 114 to 208 mg kg^{-1} in subsoil horizons. Available magnesium in the surface horizon was 168 mg kg^{-1}. It ranged from 43 to 84 mg kg^{-1} soil in the remaining subsoil horizons. Available sulphur in the surface horizon was 5.1 mg kg^{-1} soil. It ranged from 3.5 to 4.1 mg kg^{-1} soil in the subsoil horizons. Surface horizon content of available Fe, Mn, Cu, Zn and B were, 98.8, 49.1, 1.15, 3.2 and 0.27 mg kg^{-1} respectively. In subsoil it ranged from 2.5 to 11.2, 7 to 13.9, 2.9 to 4.4, 0.4 to 0.6 and 0.26 to 0.41 mg kg^{-1} soil respectively. (Table 17)

4.2.5.4 Properties of Composite Surface Soil Samples

Soil reaction ranged from strongly acid to moderately acid ranged from pH 4.9 to 7.8 and electrical conductivity from traces to 0.06 dS m^{-1}. Organic carbon ranged from 6 to 22 g kg^{-1} soil. Available N ranged from 125 to 266.5 kg ha^{-1}. Available P ranged from 4.2 to 25.6 kg ha^{-1} soil and available K ranged from 28 to 237.7 kg ha^{-1} soil. Available Ca, Mg and S ranged from 108 to 2787, 52 to 160 and 2.6 to 8.35 mg kg^{-1} soil respectively and high value for calcium and magnesium were seen in sample collected from Saint mary's iland (Table 18). Available Fe, Mn, Cu, Zn and B in the soil varied from 5 to 5.8, 4.8 to 19.5, 0.9 to 4.9, 0.5 to 2.6 and 0.01 to 0.68 mg kg^{-1} soil respectively. (Table 19)

Table 17: Physical and Chemical properties of soil profile sampled at Brahmavar

Depth (cm)	Horizon	Size class and particle diameter (mm)								Gravel % volume	Texture (USDA)
		Sands					Total				
		V.fine	Fine	Medium	Coarse	V.coarse	Sand	Silt	Clay		
		(0.1-0.05)	(0.25-0.1)	(0.5-0.25)	(1.0-0.5)	(2.0-1.0)	(2.0-0.05)	(0.05-0.002)	(<0.002)		
		% of <2 mm									
0-10	AP	18.9	1.9	6.6	6.8	5.7	39.9	16.3	43.8	21.4	gc
10-38	BA	12.8	2.1	3.4	4.8	4.3	27.4	40.7	31.9	19.5	gcl
38-59	Bt1	12.2	1.2	4.2	1.7	2.4	21.7	26.0	52.3	19.1	gc
59-79	Bt2C	14.8	1.0	3.8	2.7	3.4	25.9	42.5	31.6	13.9	cl
79-113	BC1	23.9	3.0	5.7	5.0	4.4	42.1	24.2	33.6	22.2	gcl
113-148	BC2	17.8	1.4	9.5	4.8	5.0	38.5	27.8	33.7	24.2	gcl

Depth	pH	OC	E.C	B.D (Mg m^{-3})	
(cm)		mg kg^{-1}	dS m^{-1}	field moist	Oven dry
0-10	5.8	24.8	0.01	1.55	1.17
10-38	5.4	4.6	0.01	1.53	1.23
38-59	5.2	4.9	0.01	1.54	1.22
59-79	5.2	4.6	0.01	1.57	1.19
79-113	5.3	3.9	0.01	1.64	1.25
113-148	5.2	1.3	0.01	1.66	1.29

Table cont….

Depth (cm)	Available nutrients											
	OC(g Kg^{-1})	N	P	K	Ca	Mg	S	Fe	Mn	Cu	Zn	B
		kg ha^{-1}			mg kg^{-1} soil							
0-10	24.8	658.5	5.49	264.4	291	168	5.11	96.8	49.1	1.1	3.2	0.27
10-38	4.6	627.2	7.45	42.5	114	79	3.66	11.2	9.4	3.6	0.4	0.26
38-59	4.9	595.8	5.74	32.4	131	49	4.14	2.5	13.9	4.4	0.6	0.31
59-79	4.6	423.3	3.54	36.9	198	43	3.5	5.3	12.2	4.4	0.6	0.39
79-113	3.9	439.0	4.27	33.6	148	53	3.8	2.8	7.0	4.1	0.5	0.41
113-148	1.3	407.0	3.54	32.4	208	84	3.78	3.1	7.7	2.9	0.6	0.30

Depth (cm)	Exchangeable bases					Extractable acidity			CEC			Base saturation		Ratio
	Ca	Mg	Na	K	Total	$BaCl_2$-TEA	1.0 *N* KCl		NH_4OAC	Sum of cations	ECEC	NH_4OAC	Sum of cations	CEC/ clay
							H^+	Al^{3+}	(pH 7.0)					
	cmol(+)kg^{-1} soil											%		
0-10	3.73	0.42	0.06	0.06	4.27	14	0.01	0.16	8.79	18.2	4.4	48	23.2	0.20
10-38	2.54	0.14	0.06	0.01	2.75	11	0.01	0.20	4.72	13.7	2.9	58	20.0	0.14
38-59	0.73	0.18	0.06	0.01	0.98	13	0.04	0.18	4.42	13.9	1.1	22	4.9	0.08
59-79	1.20	0.14	0.09	0.02	1.45	14	0.02	0.12	4.42	15.4	1.5	33	9.3	0.14
79-113	0.58	0.10	0.08	0.01	0.77	9	0.01	0.19	5.14	9.7	0.9	15	7.8	0.15
113-148	1.34	0.79	0.10	0.02	2.25	11	0.03	0.23	3.69	13.2	2.4	61	16.9	0.11

Table 18: Plant available primary and secondary nutrients in surface soils of agricultural lands in Bramhavar

Crop	pH	EC	OC	N	P	K	Ca	Mg	S
		(dS m^{-1})	(g kg^{-1})	(kg ha^{-1} soil)			(mg kg^{-1} soil)		
Rubber plantation (1)	5.5	0.04	22.0	266.5	13.8	237.7	160	84	4.07
Rubber plantation (2)	5.4	0.05	11.0	249.5	4.2	43.0	298	76	2.6
Rubber plantation (3)	5.2	0.02	16.2	213.6	4.5	89.6	289	68	3.86
Young coconut plantation	4.9	0.04	6.0	172.4	5.0	56.0	178	63	3.79
Coconut	5.6	0.003	6.0	221.0	6.7	28.0	153	72	5.8
Cashew	5.3	0.03	9.0	228.0	4.8	36.0	108	52	3.7
Arecanut	5.2	0.03	9.0	260.0	5.2	54.0	188	74	4.2
Foret thick canopy	5.4	0.06	11.5	188.1	17.9	100.8	169	84	3.86
Forest	5.7	0.02	11.5	125.4	11.8	66.0	226	98	5.66
St mary's iland	7.8	Tr	8.0	172.4	25.6	199.65	2787	160	8.35
Mean	5.6	0.032	11.02	209.69	9.95	91.075	455.6	83.1	4.589
Range	4.9-7.8	Tr-0.06	6-22	125-266.5	4.2-25.6	28-237.7	108-2787	52-160	2.6-8.35

Table 19: Plant available micro-nutrients in surface soils of agricultural lands in Bramhavar

Crop	Extractant used	Fe	Mn	Cu	Zn	B
		(mg kg^{-1} soil)				
Rubber plantation	0.1*N* HCl	11	16.5	4.9	0.8	0.36
Rubber plantation	0.1*N* Hcl	46	4.8	1.2	1.2	0.01
Rubber plantation	0.1*N* HCl	30	6.5	4.1	2.6	0.53
Young coconut plantation	0.1*N* HCl	09	17.5	3.7	1.8	0.68
Coconut	0.1*N* Hcl	18	13.0	3.4	1.0	0.10
Cashew	0.1*N* Hcl	28	6.9	0.9	0.9	0.06
Arecanut	0.1*N* HCl	35	16.0	1.5	1.3	0.01
Foret thick canopy	0.1*N* HCl	58	13.9	2.7	0.5	0.64
Forest	0.1*N* HCl	27	18.8	3.4	0.8	0.30
St mary's iland	DTPA	05	19.5	1.8	2.2	0.61
Mean		25.77	13.04	2.9	1.31	0.36
Range		5-58	4.8-19.5	0.9-4.9	0.5-2.6	0.01-0.68

4.2.6 SITE 6: Murdeshwar

4.2.6.1 Soil Morphology

This site is experiencing a humid tropical climate. The average annual rainfall is 3200 mm. Soil moisture is adequate to support annual crop production for 180 to 210 days. The site for soil profile study was located on very coastal plateau summits with 3-5 per cent slope with elevation of 8 m above mean sea level. Surface features indicated moderate erosion with medium run off. The soil developed from weathered Laterite rock.

The soil profile was excavated to a depth of 155 cm. The lowest layer was 113-155 cm. The 20 cm thick Ap horizon was dark reddish yellow (2.5YR 3/4), gravelly sandy clay loam in texture containing 28 per cent of fine gravel with weak fine sub-angular blocky structure. Moist consistency of soil was friable and wet, slightly sticky and slightly plastic. The horizon had few coarse pores and many fine roots. The horizon merged into the subsoil horizon smoothly.

The subsoil B horizons were designated as Bt1, Bt2, Bt3 and Bt4C with depth interval of 20-47, 47-82, 82-112 and 112-155 cm respectively. The Bt1 horizon was dark red in colour (2.5YR 3/6), gravelly sandy clay texture containing 35 per cent of fine gravels with weak fine sub-angular blocky structure. Moist consistency of soil was friable and wet, sticky and plastic. The horizon had few coarse pores, and many fine roots. The horizon merged into the sub horizon smoothly.

The Bt2 horizon was red (2.5YR 4/6) very gravelly sandy clay in texture containing 60 per cent of coarse gravels with moderate fine sub-angular blocky structure. Moist consistency of soil was friable and wet, very sticky and plastic. The horizon had coarse pores, and many very fine roots. The horizon had thick patchy clay skins. The horizon merged into the sub horizon smoothly.

The Bt3 horizon was red (2.5YR 4/6) very gravelly clay in texture containing 50 per cent of stones with weak coarse sub-angular blocky structure. Moist consistency of soil was friable and wet, very sticky and plastic. The horizon had many coarse pores, and few very fine roots. Few fine distinct mottles strong brown (7.5YR 5/8) were found in this horizon. The horizon had thick patchy clay skins. The horizon merged into the sub horizon smoothly.

The Bt4C horizon was red (2.5YR 4/8) extremely gravelly clay in texture containing 50 per cent of stones with weak coarse sub-angular blocky structure. Moist consistency of soil was friable and wet, very sticky and plastic. The horizon had few very fine pores, and few very fine roots. Few fine distinct mottles strong brown (7.5YR 5/8) were found in this horizon.

4.2.6.2 Physical Properties

The sand content in ranged from 36.6 to 65.3 per cent. The maximum was observed in Ap horizon and least in Bt4C horizon. The silt content ranged from 7.9 to 15.8 per cent. The maximum was observed in Bt4C horizon and minimum in Bt2 horizon. The clay content ranged from 23 to 47.6 per cent. The maximum was observed in Bt4C horizon and minimum was observed in Ap horizon. The textural class (USDA) gravelly clay loam was observed in Ap horizon, gravelly sandy clay in Bt1 horizon, very gravelly sandy clay in Bt2 horizon, very gravelly clay Bt3 horizon and extremely gravelly clay Bt4C horizon. The bulk density ranged from 1.23 to 1.32 mg m^{-3}. The maximum was found in the Bt4C horizon and minimum in Bt1 horizon.

4.2.6.3 Chemical Properties

Soil reaction was strongly acidic to moderately acid throughout the pedon with pH in soil water suspension ranging from pH 5.5 to 5.7. The maximum pH was observed in Ap and Bt3 horizons and minimum was observed in Bt2 and Bt4C horizons. Electrical conductivity of surface horizon was 0.03 dS m^{-1} and remaining all the sub-surface horizons was 0.01dS m^{-1}. Organic carbon ranged from 0.6 to 14.5 g kg^{-1} soil. The maximum was observed in Ap horizon and minimum was observed in Bt4C horizon.

Exchangeable calcium ranged from 1.38 to 2.35 cmol(+)kg^{-1} soil. The maximum was observed in Bt3 horizon and minimum was observed in Bt4C horizon. Exchangeable Magnesium ranged from 0.07 to 0.30 cmol(+)kg^{-1} soil. The maximum was observed in Bt3 horizon and minimum was observed in Bt1 horizon. Exchangeable potassium ranged from 0.01 to 0.02 cmol(+)kg^{-1} soil. The maximum was observed in Ap and Bt3 horizons and minimum was observed in Bt1, Bt2 and Bt4C horizons. Exchangeable sodium ranged from 0.06 to 0.07 cmol(+)kg^{-1} soil. The maximum was observed in Ap and Bt1 horizons and minimum was observed in Bt2, Bt3 and Bt4C horizons. Base saturation per cent ranged from 37 to 51 per cent. The maximum was observed in Bt3 horizons and minimum was observed in Ap horizon.

$BaCl_2$-TEA extractable acidity ranged from 9.2 to 16.5 cmol(+)kg^{-1} soil. The maximum was observed in Ap horizon and minimum was observed in Bt3 horizon. Extractable H^+ ranged from 0.01 to 0.08 cmol(+)kg^{-1} soil. The maximum was observed in Bt3 horizon and minimum was observed in Bt2 horizon. Extractable Al^{3+} ranged from 0.13 to 0.24 cmol(+)kg^{-1} soil. The maximum was observed in Bt1 horizon and minimum was observed in Ap horizon. Cation exchange capacity ranged from 4.23 to 5.45 cmol(+)kg^{-1} soil. The maximum was observed in Bt4C horizon and minimum was observed in Ap horizon. Effective cation exchange capacity ranged from 1.7 to 3.0 cmol(+)kg^{-1} soil. The maximum was observed in Bt3 horizon and minimum was observed in Ap horizon. Cation exchange capacity by sum of cations ranged from 11.9 to 18.0 cmol(+)kg^{-1} soil. The maximum was observed in Ap horizon and minimum was observed in Bt3 horizon. The CEC/clay ratio ranged from 0.10 to 0.18. The maximum was observed in Ap horizon and minimum was observed in Bt1 horizon.

Available nitrogen content in surface soils was 313.6 kg ha^{-1} soil. It ranged from 203.8 to 235.2 kg ha^{-1} soil in the subsoil horizons. Available phosphorus in the surface soil was 4.05 kg ha^{-1} soil. It ranged from 2.81 to 5.25 kg ha^{-1} soil in the subsoil horizons. Available potassium in the surface horizon was 64.9 kg ha^{-1} soil. It ranged from 42.5 to 72.6 kg ha^{-1} soil in subsoil horizons. Available calcium in the surface horizon was 143 mg kg^{-1} soil. It ranged from 139 to 178 mg kg^{-1} in subsoil horizons. Available magnesium in the surface horizon was 91 mg kg^{-1}. It ranged from 68 to 99 mg kg^{-1} soil in the remaining subsoil horizons. Available sulphur in the surface horizon was 5.1 mg kg^{-1} soil. It ranged from 3.5 to 6.4 mg kg^{-1} soil in the subsoil horizons. Surface horizon content of available Fe, Mn, Cu, Zn and B were, 21, 17.8, 3.6, 0.4 and 0.38 mg kg^{-1} respectively. In subsoil it ranged from 7.9 to 15.8, 8.5 to 13.8, 3.2 to 4.5, 0.5 to 1.5 and 0.10 to 0.46 mg kg^{-1} soil respectively. (Table 20)

4.2.6.4 Properties of Composite Surface Soil Samples

Soil reaction ranged from strongly acid to moderately acid ranged from pH 5.1 to 5.8 and electrical conductivity from 0.01 to 0.05 dS m^{-1}. Organic carbon ranged from 6 to 9 g kg^{-1} soil. Available N ranged from 156 to 485 kg ha^{-1}. Available P ranged from 3.8 to 16.2 kg ha^{-1} soil and available K ranged from 36.9 to 112.5 kg ha^{-1} soil. Available Ca, Mg and S ranged from 180 to 356, 34 to 173 and 0.06 to 2.2 mg kg^{-1} soil respectively (Table 21). Available Fe, Mn, Cu, Zn and B in the soil varied from 13.2 to 50.4, 2.9 to 11.8, 2 to 8.4, 1.4 to 6.2 and 0.13 to 0.68 mg kg^{-1} soil respectively. (Table 22)

Table 20: Physical and Chemical properties of soil profile sampled at Murdeshwar

Depth (cm)	Horizon	Size class and particle diameter (mm)								Gravel % volume	Texture (USDA)
		Sands					Total				
		V.fine (0.1-0.05)	Fine (0.25-0.1)	Medium (0.5-0.25)	Coarse (1.0-0.5)	V.coarse (2.0-1.0)	Sand (2.0-0.05)	silt (0.05-0.002)	Clay (<0.002)		
		% of <2 mm									
0-20	Ap	21.6	2.5	13.2	10.7	17.3	65.3	11.7	23.0	28	gcl
20-47	Bt1	14.4	2.3	6.2	9.5	15.7	48.1	11.3	40.6	35	gsc
47-82	Bt2	15.0	3.2	10.7	8.5	11.7	49.2	7.9	42.9	60	vgsc
82-112	Bt3	11.3	1.6	7.0	8.6	15.1	43.6	12.3	44.1	60	vgc
112-155	Bt4C	12.3	3.2	9.7	4.2	7.2	36.6	15.8	47.6	70	egc

Depth	pH	OC	E.C	B.D (Mg m^{-3})	
(cm)		g kg^{-1}	dS m^{-1}	field moist	Oven dry
0-20	5.7	14.5	0.03	1.41	1.24
20-47	5.6	4.6	0.01	1.53	1.23
47-82	5.5	6.2	0.01	1.57	1.26
82-112	5.7	1.3	0.01	1.68	1.28
112-155	5.5	0.6	0.01	1.78	1.32

Table cont...

Depth (cm)	OC(g kg^{-1})	Available nutrients										
		N	P	K	Ca	Mg	S	Fe	Mn	Cu	Zn	B
		kg ha^{-1}			mg kg^{-1} soil							
0-20	14.5	313.6	4.05	64.9	143	91	5.1	21.0	17.8	3.6	0.4	0.38
20-47	4.6	219.5	3.05	42.5	158	68	4.2	15.8	12.9	3.8	0.5	0.40
47-82	6.2	219.5	5.25	52.6	178	74	6.4	11.8	8.5	3.2	0.9	0.38
82-112	11.9	235.2	2.81	72.6	192	94	5.1	13.8	9.5	4.5	1.5	0.1
112-155	0.6	203.8	3.05	52.6	139	99	3.5	7.9	13.8	4.2	1.5	0.46

Depth	Exchangeable bases					Extractable acidity			CEC			Base saturation		Ratio
(cm)	Ca	Mg	Na	K	Total	$BaCl_2$-TEA	1.0 *N* KCl		NH_4OAC (pH 7.0)	Sum of cations	ECEC	NH_4OAC	Sum of cations	CEC/ clay
							H^+	Al^{3+}						
	cmol(+)kg^{-1} soil											%		
0-20	1.38	0.09	0.07	0.02	1.56	16.5	0.03	0.130	4.23	18.0	1.7	37	8.6	0.18
20-47	1.64	0.07	0.07	0.01	1.79	12.0	0.02	0.24	4.42	13.7	2.0	40	12.9	0.10
47-82	1.88	0.13	0.06	0.01	2.08	12.0	0.01	0.18	4.81	14.0	2.2	43	14.7	0.11
82-112	2.35	0.3	0.06	0.02	2.73	9.2	0.08	0.16	5.32	11.9	3.0	55	22.8	0.12
112-155	1.9	0.24	0.06	0.01	2.21	10.2	0.02	0.22	5.45	12.4	2.4	40	17.8	0.11

Table 21: Plant available primary and secondary nutrients in surface soils of agricultural lands in Murdeshwar

Crop	pH	EC	OC	N	P	K	Ca	Mg	S
		(dS m^{-1})	(g kg^{-1})	(kg ha^{-1} soil)			(mg kg^{-1} soil)		
Paddy harvested (1)	5.8	0.05	8	234.2	7.7	40.3	203	97	0.06
Paddy harvested (2)	5.3	0.05	6	248.3	14.1	36.9	224	89	0.50
Paddy field	5.6	0.01	8	254.0	10.3	106.4	211	90	0.40
Cashew	5.6	0.01	9	485.0	16.2	45.9	259	51	0.20
Arecanut (1)	5.1	0.05	6	256.4	6.9	124.0	356	173	0.30
Arecanut (2)	5.4	0.06	5	238.4	11.2	42.1	216	81	0.50
Coconut +Cocoa+Pepper	5.6	0.01	7	280.0	3.8	63.8	279	67	1.00
Silver oak	5.4	0.02	4	156.0	7.2	57.1	180	45	0.20
Forest land	5.2	0.04	5	320.0	6.2	112.5	290	114	0.06
Barren land	5.5	0.01	7	188.1	5.2	108.6	186	34	2.20
Mean	5.45	0.031	6.056	266.04	8.88	73.76	240.4	84.1	0.542
Range	5.1-5.8	0.01-0.05	6-9	156-485	3.8-16.2	36.9-112.5	180-356	34-173	0.06-2.2

Table 22: Plant available micro-nutrients in surface soils of agricultural lands in Murdeshwar

Crop	Extractant used	Fe	Mn	Cu	Zn	B
		(mg kg^{-1} soil)				
Paddy harvested (1)	0.1*N* HCl	50.4	2.9	6.0	5.5	0.68
Paddy harvested (2)	0.1*N* HCl	41.8	7.1	4.7	3.5	0.54
Paddy field	0.1*N* HCl	39.3	11.8	7.4	6.2	0.13
Cashew	0.1*N* HCl	15.8	2.9	4.6	2.6	0.23
Arecanut (1)	0.1*N* HCl	40.2	3.2	4.9	3.2	0.49
Arecanut (2)	0.1*N* HCl	47.9	3.9	8.4	2.3	0.57
Coconut +Cocoa+Pepper	0.1*N* HCl	14.2	2.8	3.4	2.5	0.21
Silver oak	0.1*N* HCl	29.7	7.9	2.0	1.8	0.16
Forest land	0.1*N* HCl	12.4	7.5	2.8	2.5	0.21
Barren land	0.1*N* HCl	13.2	5.3	2.3	1.4	0.44
Mean		30.49	5.53	4.65	3.15	0.366
Range		13.2-50.4	2.9-11.8	2-8.4	1.4-6.2	0.13-0.68

4.2.7 SITE 7: Ullal

4.2.7.1 Soil Morphology

This site is experiencing a humid tropical climate. The average annual rainfall is 3769 mm. Soil moisture is adequate to support annual crop production for 180 to 210 days. The site for soil profile study was located on gently sloping lateritic valley with 3-5 per cent slope with elevation of 7 m above mean sea level. Surface features indicated slight erosion with slow run off. The soil developed from weathered Laterite rock.

The soil profile was excavated to a depth of 151 cm. The lowest layer was 133-151 cm. The 10 cm thick Ap horizon was yellowish brown (10YR 5/6), sandy clay loam in texture containing 3 per cent of fine gravel with fine sub-angular blocky structure. Moist consistency of soil was slightly hard, friable and wet, sticky and plastic. The horizon had common fine pores and common very fine roots. The horizon merged into the subsoil horizon smoothly.

The subsoil B horizons were designated as AB, Bt1C, Bt2C, Bt3C, BC and CB with depth interval of 10-20, 20-47, 47-78, 78-103, 103-133 and 133-151 cm respectively. The AB horizon was dark yellowish red in colour (10YR 4/6), gravelly sandy clay loam texture containing 5 per cent of fine gravels with strong fine sub-angular blocky structure. Moist consistency of soil was slightly hard, friable and wet, sticky and plastic. The horizon had common fine pores, and common very fine roots. The horizon merged into the sub horizon smoothly.

The Bt1C horizon was yellowish red (5YR 5/6) clay in texture containing 14 per cent of fine gravels with moderate coarse sub-angular blocky structure. Moist consistency of soil was friable and wet, very sticky and plastic. The horizon had common very fine pores. Few fine distinct mottles strong brown (7.5YR 5/6) and red (10R 4/6) were found in this horizon. The horizon had thin patchy clay skins. The horizon merged into the sub horizon smoothly.

The Bt2C horizon was yellowish red (5YR 5/6) gravelly clay loam in texture containing 27 per cent of fine gravels with moderate coarse sub-angular blocky structure. Moist consistency of soil was friable and wet, very sticky and plastic. The horizon had few very fine pores. Few fine distinct mottles light yellowish brown (10YR 4/6) and weak red (10 R 5/4) were found in this horizon. The horizon had thin patchy clay skins. The horizon merged into the sub horizon smoothly.

The Bt3C horizon was yellowish red (5YR 5/6) clay in texture containing 14 per cent of fine gravels with weak coarse sub-angular blocky structure. Moist consistency of soil was friable and wet, very sticky and plastic. The horizon had few very fine pores. Few fine distinct mottles very pale yellow (10YR 7/4) and dark red (10R 3/6) were found in this horizon. The horizon merged into the sub horizon smoothly.

The BC horizon was yellowish red (5YR 5/6) clay loam in texture containing 15 per cent of fine gravels with weak coarse sub-angular blocky structure. Moist consistency of soil was friable and wet, very sticky and plastic. The horizon had few very fine pores. Few fine distinct mottles very pale yellow (10YR 7/4) and dark red (10R 3/6) were found in this horizon. The horizon merged into sub horizon smoothly.

The CB horizon was light yellowish brown (5YR 6/4) clay loam in texture containing 15 per cent of fine gravels with weak coarse sub-angular blocky structure. Moist consistency of soil was friable and wet, very sticky and plastic. The horizon had few very fine pores. Few fine distinct mottles very pale (10YR 7/4) and red (10R 4/6) were found in this horizon.

4.2.7.2 Physical Properties

The sand content ranged from 34.9 to 49.2 per cent. The maximum was observed in AB horizon and least in Bt2C horizon. The silt content ranged from 16.4 to 28.2 per cent. The maximum was observed in Bt2C horizon and minimum in Bt3C horizon. The clay content ranged from 27.1 to 42.8 per cent. The maximum was observed in Bt3C horizon and minimum was observed in AB horizon. The textural class (USDA) sandy clay loam was observed in Ap and AB horizons, clay in Bt1C and Bt3C horizon and gravely clay loam in Bt2C, BC and CB horizons. The bulk density ranged from 1.12 to 1.52 mg m^{-3}. The maximum was found in the AB horizon and minimum in Ap horizon.

4.2.7.3 Chemical Properties

Soil reaction was strongly acidic to moderately acid throughout the pedon with pH in soil water suspension ranging from pH 5.2 to 5.7. The maximum pH was observed in CB horizon and minimum was observed in Ap horizon. Electrical conductivity ranged from 0.02 to 0.06 dS m^{-1}. The maximum was observed in Ap horizon and minimum in Bt2C, Bt3C and BC horizons. Organic carbon ranged from 2.6 to 15.9 g kg^{-1} soil. The maximum was observed in Ap horizon and minimum was observed in Bt2C and CB horizons.

Exchangeable calcium ranged from 1.71 to 2.41 cmol(+)kg^{-1} soil. The maximum was observed in Bt1C horizon and minimum was observed in BC horizon. Exchangeable Magnesium ranged from 0.23 to 0.44 cmol(+)kg^{-1} soil. The maximum was observed in AB horizon and minimum was observed in Bt2C and CB horizons. Exchangeable potassium ranged from 0.01 to 0.04 cmol(+)kg^{-1} soil. The maximum was observed in Ap horizon and minimum was observed in Bt1C horizon. Exchangeable sodium ranged from 0.08 to 0.23 cmol(+)kg^{-1} soil. The maximum was observed in Bt3C horizon and minimum was observed in AB, Bt2C and BC horizons. Base saturation per cent ranged from 40 to 71 per cent. The maximum was observed in Bt2C horizon and minimum was observed in Ap horizon.

$BaCl_2$-TEA extractable acidity ranged from 12.5 to 19.5 cmol(+)kg^{-1} soil. The maximum was observed in Ap horizon and minimum was observed in CB horizon. Extractable H+ ranged from 0.01 to 0.04 cmol(+)kg^{-1} soil. The maximum was observed in Bt3C horizon and minimum was observed in Ap and BA horizon. Extractable Al^{3+} ranged from 0.18 to 0.26 cmol(+)kg^{-1} soil. The maximum was observed in AP horizon and minimum was observed in Bt2C horizon. Cation exchange capacity ranged from 3.88 to 6.82 cmol(+)kg^{-1} soil. The maximum was observed in surface Ap horizon and minimum was observed in BC horizon. Effective cation exchange capacity ranged from 2.3 to 3 cmol(+)kg^{-1} soil. The maximum was observed in surface Bt1C horizon and minimum was observed in BC horizon. Cation exchange capacity by sum of cations ranged from 10.5 to 15.1 cmol(+)kg^{-1} soil. The maximum was observed in CB horizon and minimum was observed in BC horizon. The CEC/clay ratio ranged from 0.09 to 0.21. The maximum was observed in Ap horizon and minimum was observed in Bt2C and Bt3C horizons.

Available nitrogen content in surface soils was 202.6 kg ha^{-1} soil. It ranged from 109.1 to 249.3 kg ha^{-1} soil in the subsoil horizons. Available phosphorus in the surface soil was 15.7 kg ha^{-1} soil. It ranged from 3.0 to 19.2 kg ha^{-1} soil in the subsoil horizons. Available potassium in the surface horizon was 10.9 kg ha^{-1} soil. It ranged from 36.9 to 59.3 kg ha^{-1} soil in subsoil horizons. Available calcium in the surface horizon was 241mg kg^{-1} soil. It ranged from 202 to 282 mg kg^{-1} in subsoil horizons. Available magnesium in the surface horizon was 61 mg kg^{-1}. It ranged from 54 to 101 mg kg^{-1} soil in the remaining subsoil horizons. Available sulphur in the surface horizon was 2.8 mg kg^{-1} soil. It ranged from 0.4 to 1.6 mg kg^{-1} soil in the subsoil horizons. Surface horizon content of available Fe, Mn, Cu, Zn and B were, 88.9, 5.5, 5.7, 4.5 and 0.45 mg kg^{-1} respectively. In subsoil it ranged from

4.1 to 110.5, 4.1 to 8.2, 1.5 to 3.5, 1.8 to 2.8 and 0.18 to 0.54 mg kg^{-1} soil respectively. (Table 23)

4.2.7.4 Properties of Composite Surface Soil Samples

Soil reaction ranged from strongly acid to moderately acid ranged from pH 5.2 to 5.7 and electrical conductivity from 0.01 to 0.04 dS m^{-1}. Organic carbon ranged from 5.0to 7.5 g kg^{-1} soil. Available N ranged from 241.5 to 298.5 kg ha^{-1}. Available P ranged from 3.8 to 34.8 kg ha^{-1} soil and available K ranged from 69.4 to 115.4 kg ha^{-1} soil. Available Ca, Mg and S ranged from 182 to 278, 39 to 133 and 0.6 to 3.25 mg kg^{-1} soil respectively (Table 24). Available Fe, Mn, Cu, Zn and B in the soil varied from 13.3 to 76.6, 1.8 to 8.80, 1.1 to 18.4, 1 to 11.5 and 0.06 to 0.65 mg kg^{-1} soil respectively. (Table 25)

4.3 Soil Classification

All the soils of study area have been classified under Ultisol order in Humults and Ustults sub orders. (Table 26)

There are 6 great groups, 6 sub groups and 7 soil families, out of 7 profiles 5 have got Kandic horizons and all the profiles have CEC per kg clay of < 24 cmol(+)kg^{-1}. And all the soils have base saturation by sum of cations of < 35 per cent in control section, except 1 all the profiles shown kaolinitic mineralogy and 1 shown mixed mineralogy, all the soil profile temperature regime is isohyperthermic and soil moisture regime of ustic.

4.4 Soil organic carbon stocks

Soil organic carbon stock in soils studied ranged from 1.7 to 14.2kg m^{-2} (Table 27). Highest soil organic carbon was seen in Kollur (14.2 kg m^{-2}) upto 100 cm depth followed by Beltangadi (8.6 kg m^{-2}) and Brahmavar (8 kg m^{-2})

Table 23: Physical and Chemical properties of soil profile sampled at Ullal

Depth (cm)	Horizon	Size class and particle diameter (mm)								Gravel % volume	Texture (USDA)
		Sands					Total				
		V.fine (0.1-0.05)	Fine (0.25-0.1)	Medium (0.5-0.25)	Coarse (1.0-0.5)	V.coarse (2.0-1.0)	Sand (2.0-0.05)	Silt (0.05-0.002)	Clay (<0.002)		
		% of <2 mm									
0-10	AP	11.7	3.3	8.8	14.1	7.6	45.5	23	31.5	3	scl
10-20	AB	9.3	2.8	9.7	16.5	10.9	49.2	23.7	27.1	5	scl
20-47	Bt1C	8.6	0.6	6.7	11.6	11.7	39.2	19.9	40.9	14	c
47-78	Bt2C	9.4	0.9	5.4	10.7	8.5	34.9	28.2	36.9	27	gcl
78-103	Bt3C	9.3	1.8	9.8	9.6	10.3	40.8	16.4	42.8	14	c
103-133	BC	10.0	4.8	2.3	14.7	9.5	41.3	20.8	37.9	15	gcl
133-151	CB	10.5	2.4	5.1	14	10.3	42.3	26.8	30.9	15	gcl

Depth	pH	OC	E.C	B.D (Mg m^{-3})	
(cm)		g kg^{-1}	dS m^{-1}	field moist	Oven dry
0-10	5.2	15.9	0.06	1.38	1.12
10-20	5.5	11.7	0.04	1.46	1.52
20-47	5.4	3.0	0.03	1.56	1.32
47-78	5.4	2.6	0.02	1.62	1.28
78-103	5.4	3.0	0.02	1.72	1.43
103-13	5.4	3.4	0.02	1.78	1.45
133-151	5.7	2.6	0.03	1.59	1.42

Table cont....

Depth (cm)	Available nutrients											
	OC(g Kg^{-1})	N	P	K	Ca	Mg	S	Fe	Mn	Cu	Zn	B
		kg ha^{-1}			mg kg^{-1} soil							
0-10	15	202.6	15.7	10.9	241	61	2.83	88.9	5.5	5.7	4.5	0.45
10-20	11	249.3	19.2	36.9	262	87	1.65	110.5	7.8	3.5	2.8	0.18
20-47	03	218.2	6.5	50.4	282	78	1.17	8.3	5.2	3.0	2.5	0.37
47-78	02	109.1	4.0	53.7	202	89	1.17	17.8	8.2	2.6	2.4	0.54
78-103	03	171.4	3.0	59.3	278	67	0.75	6.1	4.1	1.5	10	0.38
103-13	03	109.1	5.0	45.9	212	54	0.41	4.1	6.2	2.0	1.8	0.50
133-151	02	109.1	3.3	51.2	268	101	0.41	12.4	5.8	3.6	2.6	0.21

Depth (cm)	Exchangeable bases					Extractable acidity			CEC			Base saturation		Ratio
	Ca	Mg	Na	K	Total	$BaCl_2$-TEA	1.0 *N* KCl H+	1.0 *N* KCl Al^{3+}	NH_4OAC (pH 7.0)	Sum of cations	ECEC	NH_4OAC	Sum of cations	CEC/ clay
cmol(+)kg^{-1} soil												%		
0-10	2.21	0.41	0.09	0.04	2.75	19.5	0.01	0.18	6.82	22.3	2.9	40	12.3	0.21
10-20	2.26	0.44	0.08	0.02	2.80	18.0	0.01	0.16	4.72	20.8	3.0	59	13.5	0.17
20-47	2.41	0.31	0.09	0.01	2.82	16.2	0.03	0.22	5.10	19.0	3.0	55	14.8	0.12
47-78	2.11	0.23	0.08	0.02	2.44	14.5	0.02	0.26	3.42	16.9	2.7	71	14.4	0.09
78-103	2.20	0.25	0.23	0.03	2.71	15.5	0.04	0.19	4.12	18.2	2.9	66	14.7	0.09
103-13	1.71	0.25	0.08	0.02	2.06	17.5	0.03	0.21	3.88	19.6	2.3	53	10.5	0.10
133-151	1.88	0.23	0.09	0.02	2.22	12.5	0.02	0.24	4.30	14.7	2.5	52	15.1	0.14

Table 24: Plant available primary and secondary nutrients in surface soils of agricultural lands in Ullal

Crop	pH	EC	OC	N	P	K	Ca	Mg	S
		(dS m^{-1})	(g kg^{-1})	(kg ha^{-1} soil)			(mg kg^{-1} soil)		
Paddy	5.4	0.02	5.0	249.1	9.8	108.2	207	78	0.34
Banana	5.5	0.02	5.5	256.1	18.7	97.4	196	83	0.62
Arecanut	5.2	0.03	6.0	249.0	13.4	108.3	278	133	0.06
Mangroo adj to Coconut	5.6	0.02	5.0	224.5	3.8	111.5	182	86	0.13
Arecanut+Coconut	5.4	0.01	5.5	289.0	7.3	115.6	201	83	1.24
Coconut+Banana (1)	5.3	0.03	7.0	274.2	9.8	108.3	159	97	1.10
Coconut + Banana (2)	5.5	0.02	5.6	278.2	29.4	105.7	200	47	3.25
Coconut+Banana (3)	5.7	0.02	5.6	289.0	15.5	109.2	219	98	0.70
Banana+Pepper+Arecanut+Coconut	5.3	0.04	6.5	241.5	34.8	92.9	246	61	0.83
Forest	5.4	0.03	7.5	298.8	7.5	69.4	229	39	0.82
Mean	5.43	0.024	5.92	264.94	15	102.65	211.7	80.5	0.909
Range	5.2-5.7	0.01-0.04	5-7.5	241.5-298.8	3.8-34.8	69.4-115.6	182-278	39-133	0.06-3.25

Table 25: Plant available micro-nutrients in surface soils of agricultural lands in Ullal

Crop	Extractant used	Fe	Mn	Cu	Zn	B
		(mg kg^{-1} soil)				
Paddy	0.1 *N* HCl	39.8	3.9	1.4	2.3	0.32
Banana	0.1 *N* HCl	47.5	5.1	1.7	2.4	0.06
Arecanut	0.1 *N* HCl	69.6	4.9	7.4	5.9	0.62
Mangroo adj to Coconut	0.1 *N* HCl	42.7	6.2	5.0	4.5	0.49
Arecanut+Coconut	0.1 *N* HCl	76.5	1.8	16.3	11.5	0.65
Coconut+Banana (1)	0.1 *N* HCl	76.6	3.3	3.7	3.2	0.35
Coconut+ Banana (2)	0.1 *N* HCl	24.5	6.2	11.1	5.7	0.37
Coconut+Banana (3)	0.1 *N* HCl	46.4	8.8	3.9	3.9	0.44
Banana+Pepper+Arecanut+Coconut	0.1 *N* HCl	16.9	5.2	18.4	4.2	0.18
Forest	0.1 *N* HCl	16.3	6.5	1.1	1.0	0.42
Mean		45.68	5.19	7.0	4.46	0.39
Range		13.3-76.6	1.8-8.80	1.1-18.4	1-11.5	0.06-0.65

Table 26: Soil classification

Order	Suborder	Great group	Subgroup	Family	Site and pedon
Ultisols	Humults	Palehumults	Kandic Palehumults	Fine, mixed, isohyperthermic	Kollur
Ultisols	Humults	Kandihumults	Ustic Kandihumults	Fine, kaolinitic, isohyperthermic	Sullya
Ultisols	Humults	Kanhaplohumults	Ustic Kanhaplo humults	Fine,-loamy, kaolinitic, isohyperthermic	Beltangadi
Ultisols	Ustults	Kandiustults	Typic Kandiustults	Clayey-skeletal, kaolinitic, isohyperthermic	Murdeshwar
Ultisols	Ustults	Kanhapliustults	Typic Kanhaplustuts	Fine, kaolinitic, isohyperthermic	Ullal
Ultisols	Ustults	Kanhapliustults	Typic Kanhaplustuts	Fine-loamy, kaolinitc, isohyperthermic	Brahmavar
Ultisols	Ustults	Haplustults	Kanhaplic Haplustults	Loamy, kaolinitic, isohyperthermic	Molahalli

Table 27: Soil organic carbon stocks

Depth (cm)	Horizon	OC (%)	SOC stocks (kg m^{-2})			
			Horizon	0-30 cm	30-100 cm	0-100 cm
Pedon 1						
	Ap	0.94	1.00	1.00		
	Bt1	1.22	3.25	2.83	0.42	
	Bt2	0.59	1.47		1.47	
	Bt3	0.09	0.33		0.33	
	Bt4	0.09	0.30		0.09	
	Bt5	0.09	0.33			
				3.83	2.31	6.14
Pedon 2						
	Ap	2.3	4.28	4.28		
	AB	0.99	2.57	1.34	1.29	
	Bt1	0.46	1.1		1.00	
	Bt2	0.13	0.29		0.29	
	Bt3C	0.16	0.75		0.32	
	BC1	0.16	0.46			
	BC2	0.09	0.17			
				5.62	2.94	8.56
Pedon 3						
	Ap	5.4	5.69	5.69		
	Bt1	2.8	4.77	4.77		
	Bt2	1.22	3.43	0.39	2.99	
	Bt3	0.99	3.63		0.35	
	Bt4	0.03	0.12		0.03	
				10.85	3.38	14.20
Pedon 4						
	Ap	0.66	0.77	0.77		
	Bt1	0.13	0.24	0.20		
	Bt2C	0.13	0.30	0.02	0.28	
	BC1	0.10	0.30		0.30	
	BC2	0.06	0.20		0.14	
				0.99	0.72	1.71

Contd,,,,,

Depth (cm)	Horizon	OC (%)	SOC stocks (kg m^{-2})			
			Horizon	0-30 cm	30-100 cm	0-100 cm
Pedon 5						
	Ap	2.48	3.02	3.02		
	BA	0.46	1.52	1.08	0.43	
	Bt1	0.49	1.28		1.28	
	Bt2C	0.46	1.2		1.20	
	BC1	0.39	1.63		1.00	
	BC2	0.13	0.53			
				4.10	3.91	8.01
Pedon 6						
	Ap	1.45	2.88	2.84		
	Bt1	0.46	1.20	0.45	0.74	
	Bt2	0.62	1.36		1.36	
	Bt3	0.13	0.24		0.14	
	Bt4C	0.06	0.28			
				3.30	2.24	5.54
Pedon 7						
	Ap	1.59	2.13	2.03		
	AB	1.17	3.40	3.23	0.16	
	Bt1C	0.3	1.03		1.03	
	Bt2C	0.26	0.94		0.54	
	Bt3C	0.3	0.73			
	BC	0.34	0.15			
	CB	0.26	0.06			
				5.26	1.73	6.99

If we consider soil organic carbon stock of top 30 cm Kollur itself primed first with (10.9 kg m^{-2}) followed by Beltangadi (5.6 kg m^{-2}) and Brahmavar (4.10 gm^{-2})

Soil organic carbon stock of 30-100 cm was highest in Brahmavar (3.91 kg^{-2}) followed by Kollur (3.4 kg^{-2}) and Beltangadi (2.9 kg $^{-2}$).

Least soil organic carbon stock were noticed in Molahalli at 100 cm depth (1.71 kg m^{-2}), top 30 cm (0.99 kg m^{-2}) and at 30-100 cm also (0.72 kg m^{-2})

4.5 Soil degradation status

Soil degradation status was studied after arriving at the properties which are associating in lowering land qualities and making land degraded. The properties considered are rainfall, dry months, thickness of surface horizon, Surface texture, bulk density of surface horizon, organic carbon per cent of surface horizon, CEC per kg clay of control section (25-100 cm) and base saturation by sum of cations of surface horizon.

The status of land degradation has been arrived through simple model by adding the scores given for individual properties and dividing by the total possible score.

The table showing the properties and score and their classes are given in displaying the status of land degradation under each soil profile location representing the areas surrounding it.

Among the properties considered for degradation assessment OC per cent and thickness of surface horizon remained as most important indicators.

V. DISCUSSION

The investigation was carried out for Characterization of soils and to assess land degradation in west coast of Southern Karnataka and it has brought out certain facts, which are discussed here. The discussion on findings is made in eight main headings *viz.*,

1. Climatic attributes of study area
2. Identification of areas under vegetative degradation, sheet erosion and Barren land by using remote sensing data products
3. Land form-Physiography-soil relationships
4. Soil qualities in different study sites
5. Soil organic carbon stocks
6. Soil fertility and available nutrients
7. Land degradation assessment, vulnerability and remediation
8. Soil Degradation mapping

5.1 Climatic attributes of study area

5.1.1 Rainfall distribution

The study area comes under coastal zone of Karnataka with heavy rainfall with mean annual rainfall of 3000 to 4000 mm (Badrinath *et al.*, 1986). Among the study areas, Beltangadi received more mean annual rainfall of 4485 mm over other areas with 3700-3800 mm except the Murdeshwar which received only 3200 mm annually. Rain clouds move fast from the sea coast towards western ghats, remain more time towards the low zones because of the immediate high elevation of western ghats allow to make more orographic rains before going up and cross the western ghats, whereas near coastal region gets comparatively less rainfall than low hill zone, high hill zone, elongated ridges and foot hills areas like Beltangadi, sullya and Kollur as the rain clouds moves faster with wind.

5.1.2 Length of dry season

The length of dry season in coastal area of Karnataka ranged from 4-6 months. Among the study areas Beltangadi and Sullya as a part of high and low hill zone experiences 4 months of dry period from December to March and the rest have 6 months of dry period from December to May.

5.1.3 Length of growing period

All the study areas except Beltangadi and Sullya have a length of growing period of 180-210 days, while these two areas have 231-238 days of length of growing period in a year. Length of growing period in humid tropics ranges from 210-240 days where in maximum amount of rainfall occurs during months of April to November (Velayutham *et al.*, 1999).

Length of growing period indicates the period of moisture availability for crops and it starts from the day rainfall crosses half of PET and ends when the available moisture in soil reaches half of the maximum available water holding capacity of soil and this inturn is related to the quantity and duration of rainfall, PET and soil characteristics like organic carbon, soil texture and gravelliness apart from soil depth. As the study area is dominated by plantation crops and forest, life saving irrigation facilities if provided can extend the crop growing season.

5.2 Identification of areas under vegetative degradation, sheet erosion and barren land by using remote sensing data product

Decline in production and productivity and low available nutrients is an indicator of land degradation, besides low ability to supply of optimum inputs to crops. Assessing the impact of land degradation like vegetative degradation, sheet erosion and barren land needs proper delineation of affected areas. Data products of remote sensing, such as aerial photographs and satellite imageries, were used for accurate demarcation of degraded lands. Remote sensing is defined as the science of deriving information about an object from measurements of electromagnetic radiation reflected or emitted from object (Lillesand and Kiefer., 1994)

The interpretation of remote sensing data is based on knowledge of properties and behaviour of electromagnetic radiation. For this purpose IRS-LISS-III FCC imageries representing west coast of Southern Karnataka were collected from Karnataka State Remote sensing Application Center (KSRAC). To demarcate the area under vegetative degradation, sheet erosion and barren land, interpretation of imageries was done along with details from toposheets (Fig 23). The identification of degradation processes using remote sensing techniques is based on subjective judgment rather than specific measured ranges of reflectance values. Vegetative degradation due to wind, rainfall and human intervention, sheet erosion due to adverse effect of the heavy rainfall and barren lands due to the effect of climate, lack of nutrients in the area were the type of degradation commonly determined by using remote sensing in the study area. Distinct characters of tone, shape and pattern on the false colour composite imageries, terrain characteristic like slope, length and density of gullies were considered for interpretation (Nizeyimana *et al.*, 1998).

Vegetation degradation is usually regarded as a reduction in the available biomass, and decline in the vegetative ground cover, as a result of deforestation and overgrazing. Such degradation is a major contributing factor to soil degradation, particularly with regard to soil erosion and loss of soil organic matter.

Sheet erosion is the uniform removal of soil in thin layers by the forces of raindrops and overland flow. It can be a very effective erosive process because it can cover large areas of sloping land and go unnoticed for quite some time. Sheet erosion can be recognized by either soil deposition at the bottom of a slope, or by the presence of light - colored subsoil appearing on the surface. If left unattended, sheet erosion will gradually remove the nutrients and organic matter along with finer soil particles, which are important to agriculture and eventually lead to unproductive.

Lands low in available nutrients and erosion are the main cause for the barren land formation, apart from iron stone capping and expanded lateritic plateau mounds or plain area (Nair *et al.*, 2011)

5.3 Landform physiography soil relation map

After the study of soil profiles on different soil physiographic divisions (Fig 9), a relationship has been established between landform, physiography and land use on soil development which inturn is displayed by soil properties of each horizon in the soil profile

The relationship has been studied into two transects, one starting from steep high hills to coastal plateau and other from coastal plateau to coastal landform through undulating upland and lateritic mounds and displayed in (Figure 13 & 14).

5.3.1 Steep high hill ranges

Steep high hill ranges is reprepstented by Sullya pedon associated with rock out- crop, deep, well drained, gravelly sandy clay loam to clay in texture, classified as Fine, kaolinitic, isohyperthermic, Ustic Kandihumults.

Steep high hill ranges owing to heavy rainfall and hot humid tropical climate on granite gneissic landform allowed deep to very deep soils with low activity clays and consequent illuviation of clay with low base saturation and low CEC, major land use is rubber, forest and cashew.

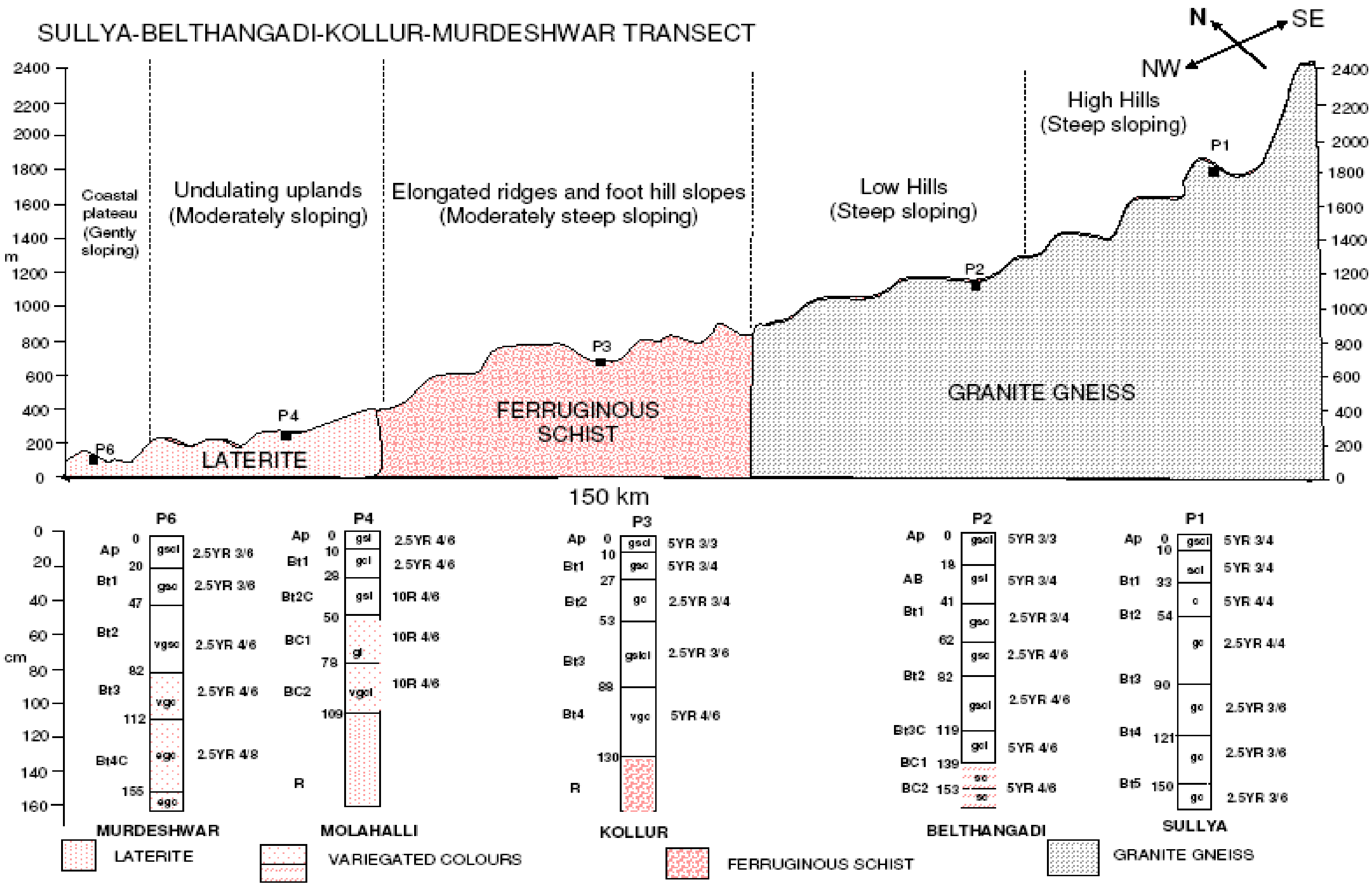


Fig 13: Landform physiography soil relationship Sullya-Beltangadi-Kollur-Murdeshwar transect

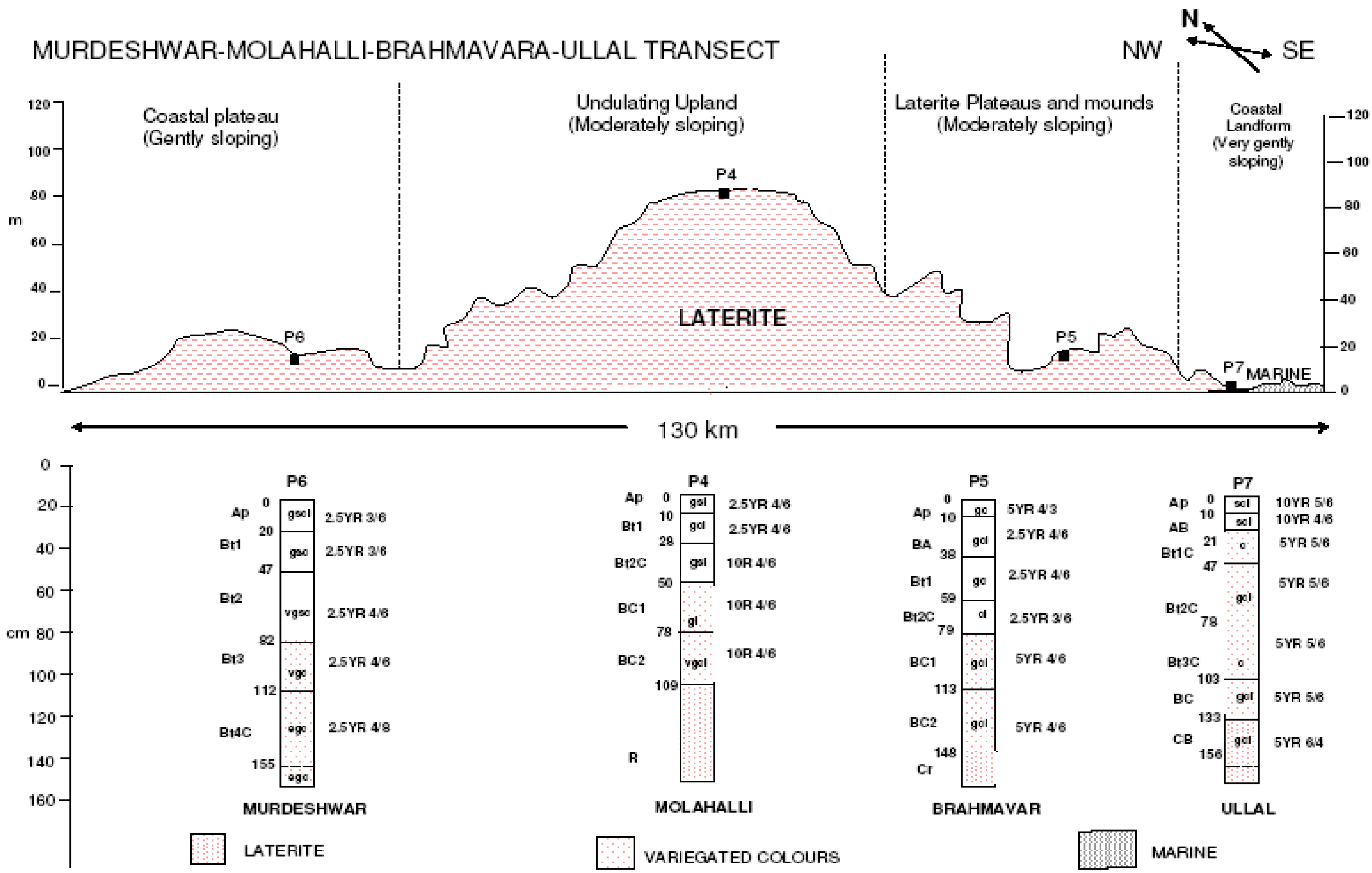


Fig 14: Landform physiography soil relationship Murdeshwar-Molahalli-Bramhavar-Ullal transect

5.3.2 Steep low hill ranges, isolated hills and dissected hills and valleys

Steep low hill ranges, isolated hills and dissected hills and valleys is represented by Beltangadi pedon which have very deep, well drained, gravelly sandy clay to sandy clay in textures and classified as Fine-loamy, kaolinitic, isohyperthermic, Ustic Kanhaplohumults.

Owing to heavy rainfall and hot humid tropical climate over steep low hill ranges, soil development has taken place with display of kandic horizon with low bases and CEC. This land form tend to have multinutrient deficiencies and respond well with terraced hitech agriculture and plantation development with soil and water conservation and high fertilizer inputs

5.3.3 Moderately steep sloping elongated ridges and foot hill slope

Moderately steep sloping elongated ridges and foot hill slope is represented by Kollur pedon where deep, well drained, gravelly sandy clay loam to gravelly clay textures and classified as Fine, mixed, isohyperthermic, Kandic palehumults.

This area is associated with ferrugious schist landform and dominated by soils having high organic carbon and high degree of soil profile development with low CEC and base saturation. This region is having good stock of soil organic carbon and respond well to well managed plantation crops and forest vegetation

5.3.4 Undulating upland

Undulating uplandis physiography is represented by Molahalli pedon where deep, well drained, gravelly sandy Loam to gravelly clay loam in textures classified as kaolinitic, isohyperthermic, kanhaplic haplustults.

Scrub forested and grass vegetation on moderately sloping lateritic landform allow soil development with low depth and with iron stone capping and high gravel content. Here the soil texture belongs to loamy and soils have low available water holding capacity, low CEC and low base saturation.

5.3.5 Lateritic plateaus and lateritic mounds

Lateritic plateaus and lateritic mounds is represented by Brahmavar pedon where deep, well drained, gravelly clay loam to clay in textures and classified as Fine, loamy, kaolinitic, isohyperthermic, Typic- Kanhaplustults.

Lateritic plateau and lateritic mounds which are moderately sloping will allow deep soil development with heavy textures red in colour with high iron and alluminium status and occupied by cashew/ coconut plantations under good management otherwise under scrub forest vegetation.

5.3.6 Gently sloping coastal plateau

Gently sloping coastal plateau is represented by Muredshwar pedon, very deep, well drained, very gravelly sandy clay to very gravelly clay in textures and classified as Clayey-skeletal, kaolinitic, isohyperthermic, Typic-Kandiustults.

Coastal plateau with little low rainfall compaired to neighboring areas will tend to make high temperature and rain dry periods allows deep gravelly clayey soils with low O.C, low CEC, base saturation and high acidity.

5.3.7 Valleys, bars and ridges, beaches and marshes

Valleys, bars and ridges, beaches and marshes physiography is represented by Ullal pedon where very deep, medium well drained, sandy clay loam to clay in textures and classified as Fine, kaolinitic, isohyperthermic, Typic-Kanhaplustult.

Soils of bars, ridges, beaches and marshes not studied specifically, but lateritic soils occupying along the lower terrace of the lateritic upland and mounds which is part of this physiographic division was studied. These soils have impeded drainage, variegated colours towards lower horizons owing to laterization and poor soil – air – water relationship. These soils are utilized for growing paddy with coconut on field bunds.

5.4 Soil qualities in different study sites

The morphological, physical and chemical properties of soils were studied in west coast of southern Karnataka are discussed based on the results from the representative soil profiles.

5.4.1 Morphological properties of pedon

5.4.1.1 Soil depth

Soil depth was varying from 109 cm to more than 150 cm. This was due to the variation in topography and slope gradient. Solum depth reflects the balance between soil formation and soil loss by erosion in any area. Pedon- 4 is deep (109 cm) due to the land have not been protected well in the past and the top soil was eroded. (Sitanggang *et al.*, 2006). Two out of seven Pedon 3 and 5 where deep with moderately steep sloping, elongated ridges and foot hills slope and moderately sloping lateritic plateau and monds. Indicating the process of denudation and erosion were more active than the vertical advancement of the weathering front (Dutta *et al.*, 2001). Pedon 1, 2 and 6 are on steep hill ranges, steep low hill ranges, isolated hills and dissected hills and valleys and coastal plateau summits. Hence the soil was very deep due to the less erosion and located in gentle slopes.

Thickness of surface horizon is another indication of loss of top soil due to erosion as indicated by the morphological characteristics of soil profile, profile-2 area is having maximum thickness of 41 cm followed by profile-7 and 6 having around 20 cm whereas other profiles have thickness of only 10 cm.

5.4.1.2 Soil colour

Soil colour of pedon-1, 2, 3, 5 and 6 varied from dark reddish brown to reddish brown in surface and yellowish red to dark Red in lower horizons. Due to the differential degrees of erosion, decrease in organic matter and iron oxide content (Patil and Dasog., 1999) and Intense leaching of bases leaving sesquioxide and further oxidation might also be the reason for the development of dark reddish brown to dark red colour. Pedon-4 and 7 showed variegated colours.

Development of dark colour or variegated colour towards lower depth is an indication of water erosion and redoximorphic conditions. Anaerobic environment with flooding leads to gleying and give grey or black colouration. Here in case of Ullal profile there is variegated BC-horizon with red and yellow colours owing to redoximorphic iron, manganese and aluminium ions.

5.4.1.3 Soil structure

Surface structure varied from weak to moderate fine sub-angular blocky in surface. Where as in sub-surface, the structure varies from weak coarse to moderate, medium sub-angular blocky. The dominant structure recorded was moderate medium sub-angular blocky. The weak structure development is due to low clay and low organic carbon content. Similar results were observed by Sitanggang *et al.*, (2006).

Soil aggregation and crusting are the other key attributes which can decide soil structure for which organic carbon status and bulk density are the indicators. Organic carbon was high in Kollur area followed by Beltangadi, Brahmavar and Molahalli had the least.

Kollur, Beltangadi and Brahmavar have better aggregation and there by better soil structure. Similarly the bulk density values shown less than 1.2 mg kg^{-1} in Kollur, Sullya and Brahmavar is due to influence of organic carbon and better soil structure, compaired to soils of other locations.

5.4.1.4 Consistency

Consistency of soil varied from slightly hard, friable, slightly sticky to very sticky and slightly plastic to plastic, clay content of soil might have played major role in consistency. The clay content plays major role in consistency of soils, as the clay content increases, the consistency will also increase. This attribute and relief have significant bearing on the consistency (Mahapatra *et al.,* 2000).

5.4.1.5 Clay cutans

Thin and thick clay cutans are observed in all pedons at varying depth, however there was no observable clay cutans in the surface. This may be due to the continuous ploughing which must have obliterated the clay cutans (Dutta *et al*., 2001). Occurrence of clay cutans and their thickness are the indicators of the clay illuviation processes, which is taking place in soil with vertical movement of finer soil particles and its arrangement along pedfaces, crotovenas and gravel surfaces.

5.4.2 Physical properties

5.4.2.1 Particle size distribution

Total sand per cent is much higher than the silt and comparatively higher than clay fractions in 2, 4, 5 and 7 pedons. The coarser fractions dominate which could be largely of silicaceous nature because of granite gneiss parent material (Dutta *et al.*, 2001). Pedon-3 and 4 observed with hard weathered ferruginous schist and hard weathered laterite rock respectively in the subsoil horizons. This might be due to the removal of clay, silt and fine sand particles by sheet erosion, leaving rock fragments and heavy soil particles.

In 1, 3 and 6 Pedons, sand fraction decreases with the depth indicates that weathering of these fractions to finer particles as evidenced by increase in clay content with concomitant decrease in sand fraction (Patil and Dasog., 1999). The uniform silt content of all the pedons in relation to the other particle fractions is the striking feature of lateritic soils and in agreement with the defined characteristics of latosols (Kellogg., 1950).

The texture in surface horizon was lighter sandy loam to sandy clay loam and sub surface varied from clay loam to clay in all the pedons except pedon-5. Clay content was increasing with depth as observed by Rajamannar and Krishnamoorthy (1978). Dispersion of clay in surface horizon and movement to lower horizons resulted in lower clay content in surface horizon. There is an evidence of illuviation of clay and formation of argillic horizon in the sub surface layer and similar result was observed by Sitanggang *et al.* (2006).

In Pedon 1, the soil texture was mostly clayey except in the surface horizon. The clay increase was high in the solum indicating advanced soil profile development, in Pedon 2 surface texture was sandy clay loam and sub-surface varies from sandy loam to clay loam, in pedon 3 surface texture of soil was sandy clay loam and in sub-surface varies from sandy clay to clay, in Pedon 4 surface texture was sandy loam and sub-surface varies from sandy loam to clay loam, in Pedon 5 surface texture was clayey and sub-surface varies from clay loam to clay, in pedon 6 surface texture of soil was sandy clay loam and in sub-surface varies from sandy clay to clay and in pedon 7 surface texture was sandy clay loam and sub-surface varies from clay loam to clayey. In Pedon 3 and 4 clay content increases upto Bt2 and Bt1 then decrease in Bt3 and Bt4C then it showed increasing trend, indicating to an extent of the advanced soil profile development.

Textural variations are mainly associated with type of parent material, degree of weathering, topography and time and similar result was reported by Sitanggang *et al*. (2006).

Clay content increased with depth in all the profiles depicted in (Fig 15) by differential accumulation under different climatic spells and internal drainage allowed fast infiltration and permeability towards lower layers.

5.4.2.2 Bulk density

It was observed that the bulk density in Pedon 4 and 6 increases with depth. Due to the severity of erosion, most of the soil material was removed leaving only the compact layer below (Bhaskar and Subbaiah., 1995). The lower bulk density in the surface horizon is due to the high organic carbon content in the surface horizons. Among the pedons higher surface bulk density was observed in pedon 1 and 4 is due to their coarser texture, clay and silt particles were eroded from the surface layer leaving well drained dense sand particles and in some cases coupled with low organic carbon (Sitanggang *et al*., 2006).

Depth wise distribution of B.D in 7-pedons have been depicted in (Fig 16), all soils showed increase in bulk density with depth owing to dominance of illuviated clay mineral in the lower horizons but surface layers with high organic matter. But in different locations the curves behaved differently owing to the difference in rate of clay illuviation, surface texture and gravelliness.

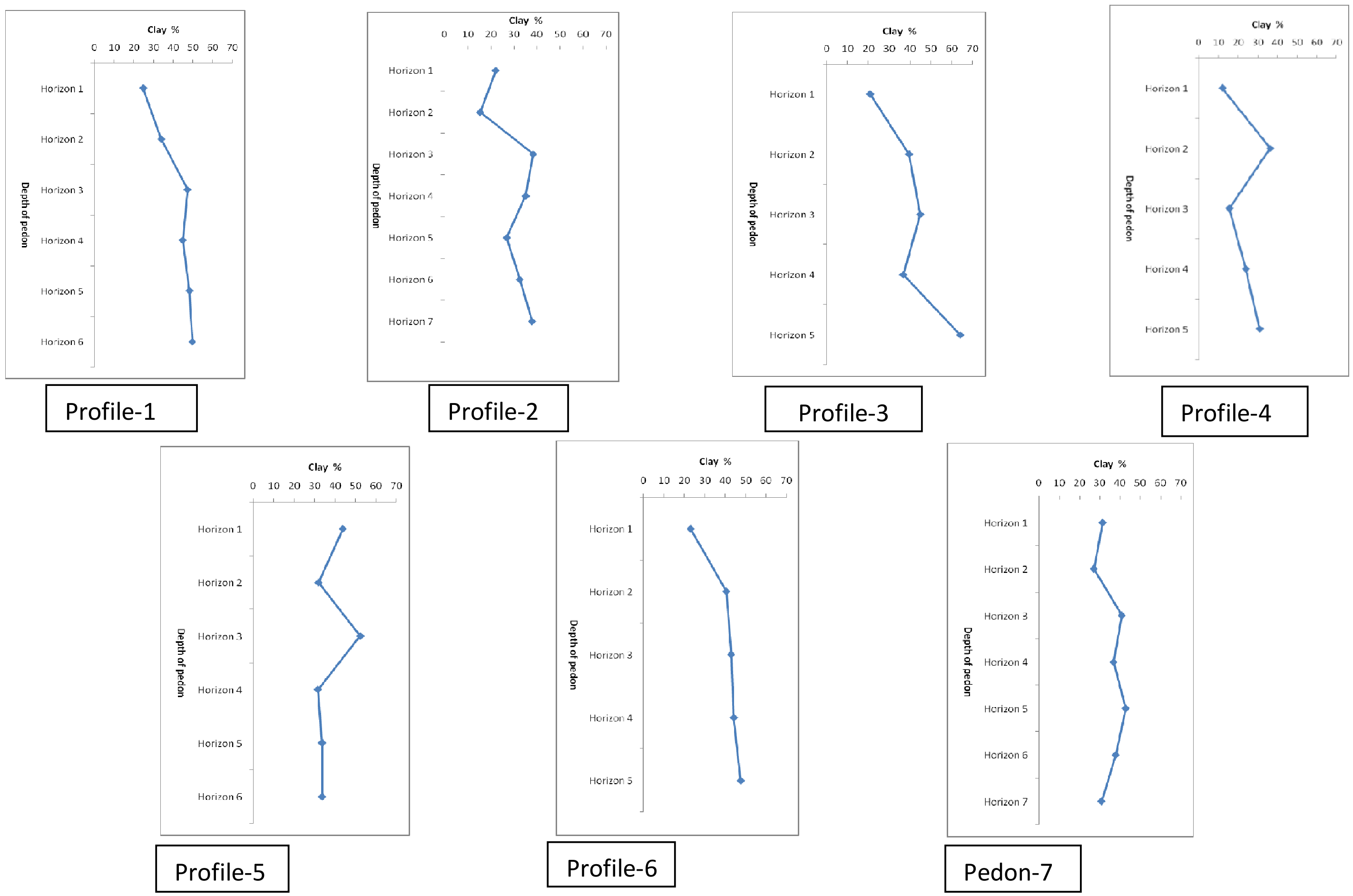


Fig 15: Depth wise distribution of Clay in pedons

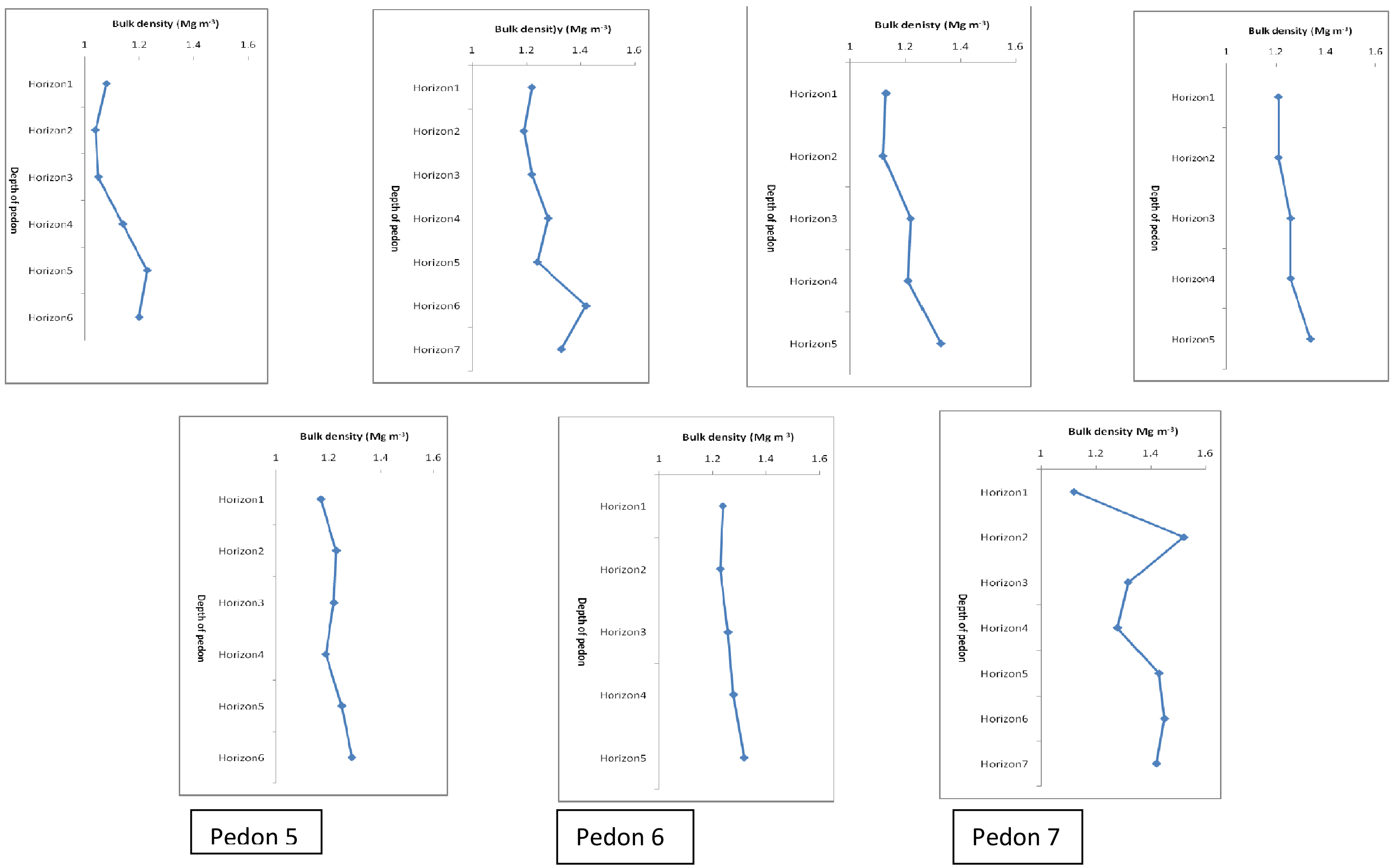


Fig 16: Depth wise distribution of B.D in pedons

5.4.3 Chemical properties

5.4.3.1 Soil organic carbon

Generally organic carbon content in surface horizon was high due to the dense forest in Western Ghats and deposition of plant litter along with the alluvium (Badrinath *et al.*, 1986). Among all the pedons-1, 2, 3 and 5 showed comparatively higher organic carbon content in the surface mainly due to these sites are under rubber cultivation which add high amount of litter to the soil. And rubber roots some times venture to the leaf litter as a mat surface above soil. Organic carbon content decreases with depth due to the leaching environment existing in the area these results are in agreement with (Patil and Dasog., 1999).

Organic carbon contents in the soils reduced with depth (Fig 17) with definite reduction near surface and with slow decrease further this may be decided by vegetation on the surface, its root growth and litter additions and high microflora associated with it, long hot dry period after cessation of rains all the accumulated organic carbon to decompose and assimilation to lower layers taking the help of high rainfall.

5.4.3.2 Cation exchange capacity

Cation exchange capacity of the soils was generally low in all the pedons and it varied from 2.1 to 15.2 cmol(+) kg^{-1} of soil. Low CEC values even with high clay content indicate the dominance of low activity clays particularly, 1:1 type clay minerals i.e. kaolinite (Walia and Chamuah., 1988). Except pedon-7, higher CEC values were observed in surface horizons, due to the influence of organic matter.

All the soil profiles except 6 showed a decreasing trend of CEC with depth by slight increase in CEC with depth has been noticed in pedon-6 (Fig 18). Dominance of low activity clays over others along

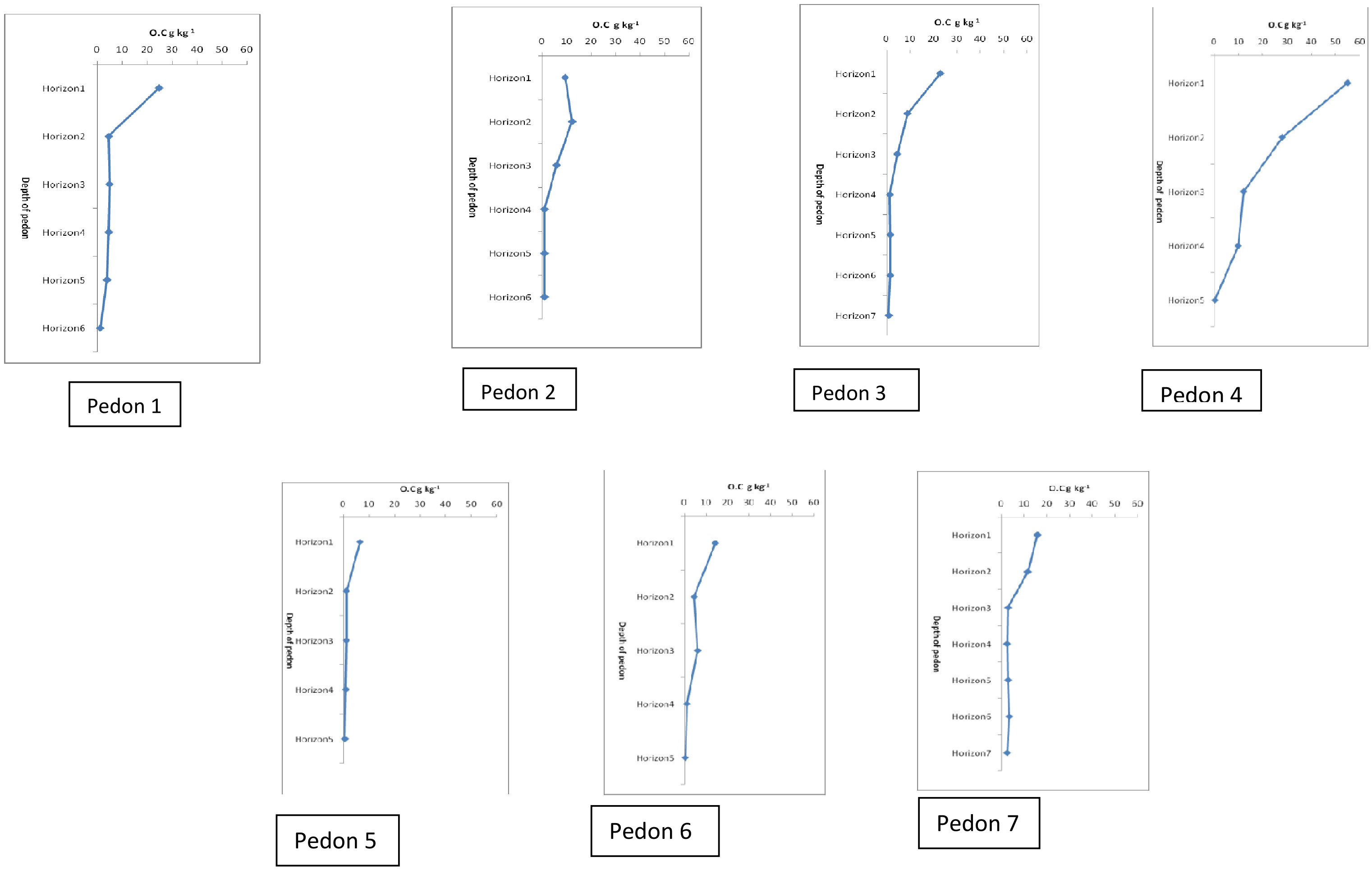


Fig 17: Depth wise distribution of O.C in pedons

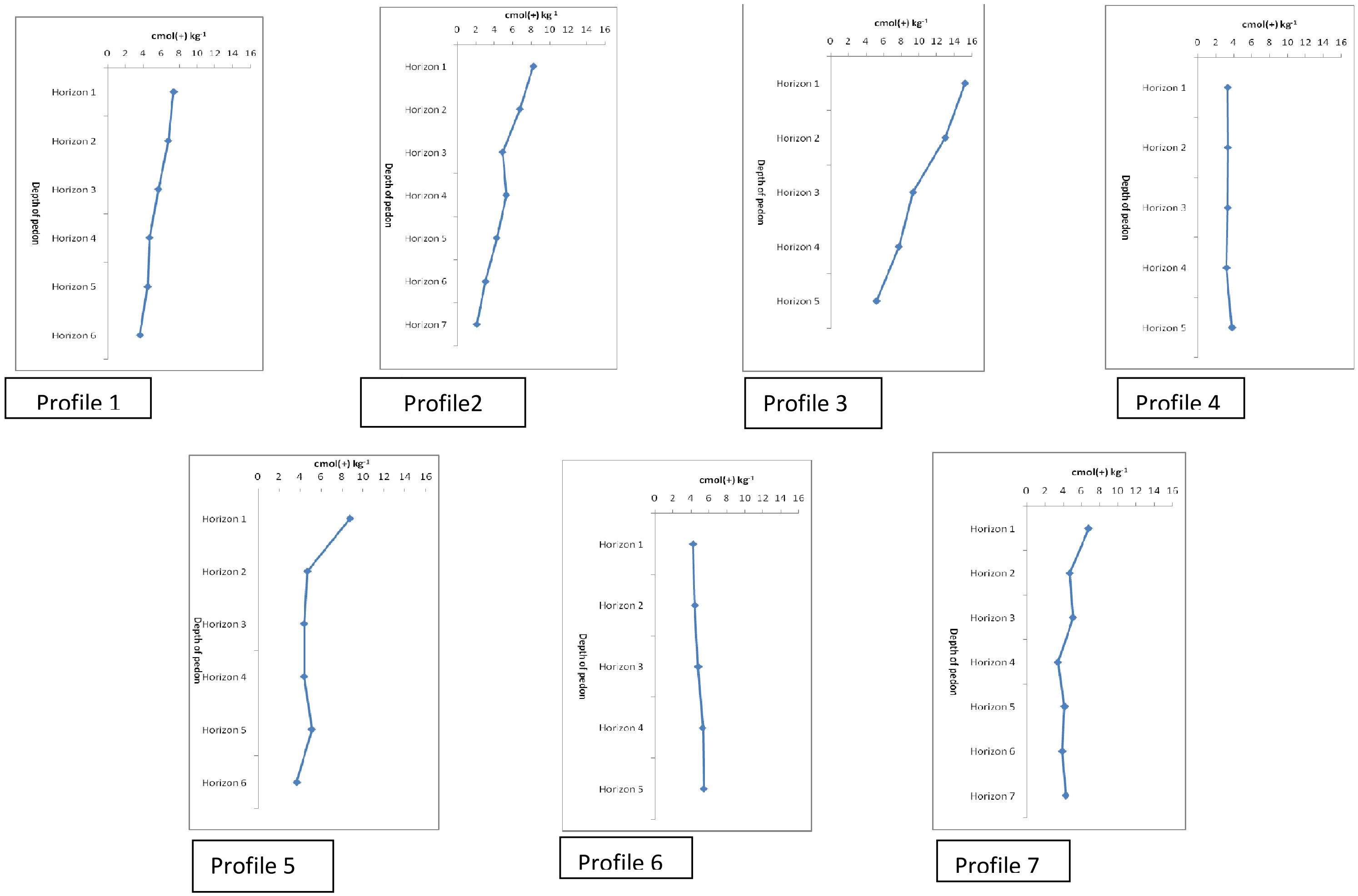


Fig 18: Depth wise distribution of CEC in pedons

with accumulation of sesquioxides and hydrated and hydroxylated forms of iron and aluminium in these soils, if leaching of bases and increase in iron and aluminium acidity also contribute to the reduction of CEC to the lower layers.

5.4.3.3 Effective cation exchange capacity

Effective cation exchange capacity was low in all the pedons and it varied from 0.9 to 7.0 cmol(+) kg^{-1}, despite high clay content and organic carbon indicating dominance of low activity clay minerals. In all the pedons ECEC was lower than the CEC due to the development of pH dependent negative charges on the exchange complex (Patil and Dasog., 1999).

5.4.3.4 Cation exchange capacity by sum of cations

Cation exchange capacity by sum of cations varied from 6.0 to 28.2 cmol(+) kg^{-1} and it was 2-4 times higher than that of ammonical acetate CEC and these results are in agreement with Patil and Dasog. (1999).

5.4.3.5 CEC Per kg clay

Cation exchange capacity clay ratio of more than 25 cmol (+) kg^{-1} clay was seen in surface horizons of pedon-1, 2, 3 and 4 due to high organic carbon content, in subsurface horizon it was less than 25 cmol (+) kg^{-1} clay and in rest of the pedons it was less than 25 cmol (+) kg^{-1} clay throughout the solum indicating presence of low activity clay (Pujari and Moharana., 1993).

5.4.3.6 Base saturation

Base saturation was low in all the pedons mainly because of leaching due to the high rainfall in the coastal areas. The base saturation was high in the surface horizons of pedon-3 and 4, due to the influence of organic matter and base saturation in these profiles, showed a tendency to increase with the depth and followed the distribution pattern of pH. In pedon-2 base saturation increases with the depth, in pedon-7 it increases with depth up to horizon Bt2C and in pedon-6 it increases with depth up to horizon Bt3. Increase in base saturation with the depth is due to the leaching of bases from the upper horizon as their deposition in the lower horizons. Sometimes it goes below solum depth vertically/horizontally beyond the soil profile along with seepage water.

5.4.4 Soil fertility characteristics of pedons

5.4.4.1 Soil pH

Soil pH varied from strongly acidic to moderately acidic. There was much variation in the pH with the depth; Increase in pH with depth might be attributed to intense and uniform leaching of bases throughout the profile (Sitanggang et al., 2006). Continues application of ammonical fertilizer for nitrogen and phosphorus will bring down pH, in case of plantations, fruits and vegetables crops, where excess nitrogen fertilizer application is common practice.

5.4.4.2 Extractable Acidity

The Barium chloride-TEA extractable acidity was several times higher than that of potassium chloride acidity in all the pedons. This suggest that most of fairly high $BaCl_2$- TEA extractable acidity of these soils can be attributed to Al (and possibly Fe) hydroxyl compounds that are held tenaciously on the exchange complex (De Alwis and Pluth 1976) and due to non-exchangeable aluminium embedded in between crystal lattices, which comes into solution due to buffering and complexing nature of $BaCl_2$-TEA (Patil and Dasog. 1999).

Higher $BaCl_2$-TEA in surface horizon compared to sub-surface horizons mainly due to high organic carbon content and high intensity of leaching as a result of high rainfall. Patil and Ananthanarayana

(1990) also attributed this to the buffering action of soils due to high organic matter and clay content of acid soils by virtue of high degree soil profile development.

5.4.4.3 Electrical Conductivity (EC)

Electrical conductivity values of all pedons ranged from 0.01 to 0.08 dS m^{-1}, which indicates that these soils are non-saline in nature. Electrical conductivity of all the pedons was very low due to the leaching caused by land slope combined with rainfall as observed by Sivasankaran *et al.* (1993).

5.4.4.4 Available nitrogen

Soil available nitrogen status was low to medium (78.4 to 423.3 kg ha^{-1}) in all the pedons except in pedon-3 and 5, similar findings were recorded by Shivaprasad *et al.*, (1998). Nitrogen content was decreasing with the depth in all the pedons (Parasuram and Jayaraj., 1982). Pedon-3 and 5 recorded high level of available nitrogen compared to all other pedons. This was due to higher clay, which can induce less leaching of bases, continuous addition of fertilizers and increased level of organic carbon content.

5.4.4.5 Available phosphorus

Soil available phosphorus was low in all the pedons low status of available phosphorous was mainly attributed to its higher removal than replenishment and also high P fixing capacity (Sathisha and Badrinath., 1994) and similar results were found by Misra and Saithantuaanga (2000) in acid soils of Mizoram.

5.4.4.6 Available potassium

Soil available potassium was low except in pedon-3 and 5 throughout the solum due to coarse texture and gravelly nature of soils which are particularly low in available potassium, possibly due to faster and deeper leaching as observed by Badrinath *et al.* (1986) in Puttur soils. The available potassium is medium to high in most of the soils of the Karnataka state, except in lateritic soils of coastal and western Ghats and in shallow red and black soils (Shivaprasad *et al.*, 1998).

In soil pedon-3 and 5 the available potassium content in surface horizon is high and it decreases in subsurface horizons, may be due to addition of Pottasic fertilizers, as it was seen in well managed rubber plantation, though the soils have low potassium resources.

5.4.4.7 Available secondary nutrients

Secondary nutrients in there availability were deficient in all the pedons. Deficiency of Ca and Mg is mainly because of leaching due to hot humid and heavy rainfall in Coastal areas. All the soils are low in sulphur content and this is also attributed to high rainfall and low content of sulphur bearing minerals (Ananthanarayanan *et al.*, 1986).

5.4.4.8 Micronutrients

The examination of the data on available micro nutrients of soils revealed that HCl extractable iron, manganese, zinc and copper varied from deficiency to near toxicity level in all pedons. Iron content in coastal cashew growing soils decreases with depth and this may be due to the low organic carbon content as observed by Badrinath *et al.* (1986). With regard to zinc, six per cent of the samples were deficient, 58 per cent marginal and remaining 36 per cent retained at adequate levels.

High rainfall and high temperature in the granite gneiss landscape and laterization assisted the accumulation of sesquioxides under redoximorphic conditions favoring high concentration of Fe and Mn ions and sometimes Cu also. Porous nature of granite gneiss i.e parent material, favoured the fast leaching of boron and zinc from solum either vertically or laterally with seepage water. This has been reported by Anita *et al.* (2011), while working in western ghats and coastal soils of Karnataka.

5.4.4.9 Soil classification

Among the soil studied 3 soil profiles belong to Humults sub order owing to very high levels of soil organic carbon in the top 50 cm (> 0.9%) and out of that two showed low CEC clay ratio of < 0.16 and low ECEC by clay ratio of <0.12 and belong to Kandihumults and Kanhaplohumults and other one belong to Kandic subgroup indicating <24 cmol(+) kg^{-1} CEC/clay these 3 soils belong to steep high hills, low hills, elongated ridges and foot hills belonging to Sullya, Beltangadi and Kollur.

Mid land lateritic plateau and mound and undulating upland soils belong to Ustults sub order indicating low soil organic carbon in the surface layer upto 50 cm and have Kandic horizon in case of soil profiles and other one having Kanhaplic subgroup with CEC per kg clay of < 24 cmol(+)kg^{-1}. Low CEC, low bases and high clay content indicate the soils belong to hot humid tropical origin and have dominance of low activity clays in tropical reported by many workers like Nair *et al.*, (2011) and Krishnan *et al.*, (2000).

5.5 Soil organic carbon stocks

Traditionally soil organic carbon content was measured as an index of soil fertility in terms of its plant nutrient supplying capacity and positive effect on soil structure and microbial activity. Land use exerts considerable influence on soil organic carbon stocks.

Among the study areas the soil organic carbon stocks of 0-100 cm was highest in pedon-3. In pedon-1, 2, 5, 6 and 7 it was medium and in pedon 4 it was low.

The SOC stock realised in pedon-2, 5 in rubber production systems and pedon-6 in cashew production system, ranged between 7.98 to 8.56 kg m^{-2}. The SOC stock was almost on par with soil organic carbon stock in rubber and cashew plantations on the foothills on western side of Western Ghats (Roni, 2005) and coconut plantation in Brahmavar (Suvana, 2012).

5.6. Soil fertility and available nutrients

In all the seven locations composite surface soil samples were collected from farmer's field in the vicinity of the soil profile representing major production system and tested for the major, secondary and micronutrients where classified under frequency distribution diagrams and classes of soil reaction and plant nutrient has been depicted (Table 28).

At Sullya, almost all the samples tested for strongly acid. About 30 per cent of samples tested for low levels of available nitrogen. About 70 per cent of samples tested for low phosphorus. About 80 per cent of samples were tested for low levels of available potassium. Almost all the samples tested for low available calcium, sulphur, copper and zinc. Available magnesium was deficient in 80 per cent of the samples. About 70 per cent of samples tested for available boron were deficient. (Fig 19)

At Beltangadi, about 90 per cent of samples tested for strongly acid and 10 per cent for moderately acid. About 70 per cent of samples were tested for low levels of available nitrogen, 90 per cent of samples tested for phosphorus were low. Cent per cent of samples were low in available potassium. Almost all samples tested for calcium and sulphur were deficient. Available magnesium was deficient in 90 per cent of the samples. About 80 per cent of samples tested for deficieny of copper. About 90 per cent for zinc and 70 per cent for boron content in samples were deficient. (Fig 20)

Table 28: Classes soil reaction and plant nutrients used for frequency distribution diagrams

Parameter	Class interval	Parameter	Class interval
Soil Reaction		**Available Magnesium**	
1 – Strongly acid	pH < 5.6	D - Deficient	Mg < 120 mg kg^{-1} soil
2 – Moderately acid	pH 5.6 to 6.0	A - Adequate	Mg > 120 mg kg^{-1} soil
3 – Slightly acid to Slightly alkaline	pH 6.1 to 7.8	**Available Sulphur**	
4 – Moderately alkaline	pH > 7.8	D - Deficient	S < 10 mg kg^{-1} soil
Available Nitrogen		A - Adequate	S > 10 mg kg^{-1} soil
L - Low	N < 280 kg ha^{-1}	**Available Copper**	
M - Medium	N 280 to 560 kg ha^{-1}	D - Deficient	Cu (DTPA) < 0.12 mg kg^{-1} soil Cu (HCl) < 1.00 mg kg^{-1} soil
H - High	N > 560 kg ha^{-1}	A - Adequate	Cu (DTPA) > 0.12 mg kg^{-1} soil Cu (HCl) > 1.00 mg kg^{-1} soil
Available Phosphorus		**Available Zinc**	
L - Low	P < 10 kg ha^{-1}	D - Deficient	Zn (DTPA) < 0.6 mg kg^{-1} soil Zn (HCl) < 1.0 mg kg^{-1} soil
M - Medium	P 11 to 24 kg ha^{-1}	A - Adequate	Zn (DTPA) > 0.6 mg kg^{-1} soil Zn (HCl) > 1.0 mg kg^{-1} soil
H - High	P > 24 kg ha^{-1}	**Available Boron**	
Available Potassium		D - Deficient	B < 0.5 mg kg^{-1} soil
L - Low	K < 115 kg ha^{-1}	A - Adequate	B > 0.5 mg kg^{-1} soil
M - Medium	K 116 to 275 kg ha^{-1}		
H - High	K > 275 kg ha^{-1}		
Available Calcium			
D - Deficient	Ca < 300 mg kg^{-1} soil		
A - Adequate	Ca > 300 mg kg^{-1} soil		

At Kollur, about 70 per cent of the samples were tested for strongly acid and 30 per cent for moderately acid. About 27.8 per cent of samples were low in available nitrogen, were as 63.6 per cent of samples were low in phosphorus. About 90.9 per cent of samples tested for low in potassium, where as almost all samples tested for Available calcium and sulphur were deficient. Available magnesium was deficient in 90.9 per cent samples, copper and zinc in 36.3 per cent and boron in 63.6 per cent. (Fig 21)

At Molahalli, about 90 per cent of the samples were tested for strongly acid and 10 per cent moderately acid. About 80 per cent of samples were tested for low levels of available nitrogen. About 80 per cent of samples tested for phosphorus were low. Cent per cent of samples tested for low levels of potassium. Almost all samples tested for Available calcium, magnesium and copper were deficient. About 90 per cent of samples tested for sulphur were deficient. About 10 per cent of the samples tested for Available zinc were deficient and 80 per cent of samples tested for boron were deficient. (Fig 22)

At Brahmavar, about 70 per cent of the samples were tested for strongly acid, 20 per cent for moderately acid and 10 per cent of samples were alkaline. Cent per cent of sample were tested for low levels of available nitrogen. About 60 per cent of samples were tested for Available phosphorus were low. About 80 per cent of samples were tested for low levels of Available potassium. About 90 per cent of samples were tested for calcium and magnesium were deficient. Almost all samples were tested for Available sulphur were deficient. About 10 per cent of samples tested for available copper were deficient. About 40 per cent of samples tested for zinc were deficient and 60 per cent of samples tested for boron were deficient. (Fig 23)

At Murdeshwar, about 60 percent of the samples tested for strongly acid, 40 per cent were moderately acid. 90 per cent of samples tested for low levels of available nitrogen. About 60 per cent of samples tested for Available phosphorus were low. Cent per cent of samples tested for low levels of Available potassium. About 90 per cent of samples tested for calcium and magnesium were deficient. Almost all samples tested for Available sulphur were deficient and 70 per cent of samples tested for boron were deficient. (Fig 24)

At Ullal, about 90 percent of the samples tested for strongly acid and 10 per cent were moderately acid. About 70 per cent of samples tested for low levels of available nitrogen. About 50 per cent of samples tested for low levels Available phosphorus. About 90 per cent of samples tested for low levels of Available potassium. Almost all samples tested for calcium and sulphur were deficient. About 90 per cent of samples tested for Available magnesium were deficient. About 90 per cent of samples tested for boron were deficient. (Fig 25)

Strongly to moderately acidic soil reaction and low in available nitrogen are mainly due to the heavy rainfall in the area, which causes leaching of bases and also may be due to heavy use of high acid forming fertilizers. In Karnataka about 10.3 per cent of soils fall under low category, 35.8 per cent under medium and 53.9 per cent under high category of available nitrogen status as reported by Shivaprasad *et al.* (1998).

Low in Available phosphorus mainly due to its fixation into insoluble form with Al^{3+} and Fe^{3+} prevalent in acid soils. Sathisha and Badrinath (1994) observed that low status of available phosphorous was mainly attributed to its higher removal than replenishment and also high P fixing capacity in Dakishna Kannada district, Karnataka. The data on the available phosphorous status in the soils of Karnataka showed that about 83 per cent of the soils are low in phosphorous and 17 per cent area is under medium category (Shivaprasad *et al.*, 1998).

Badrinath *et al.* (1986), while studying the fertility status some typical soils of coastal Karnataka, reported that Puthur soils have low

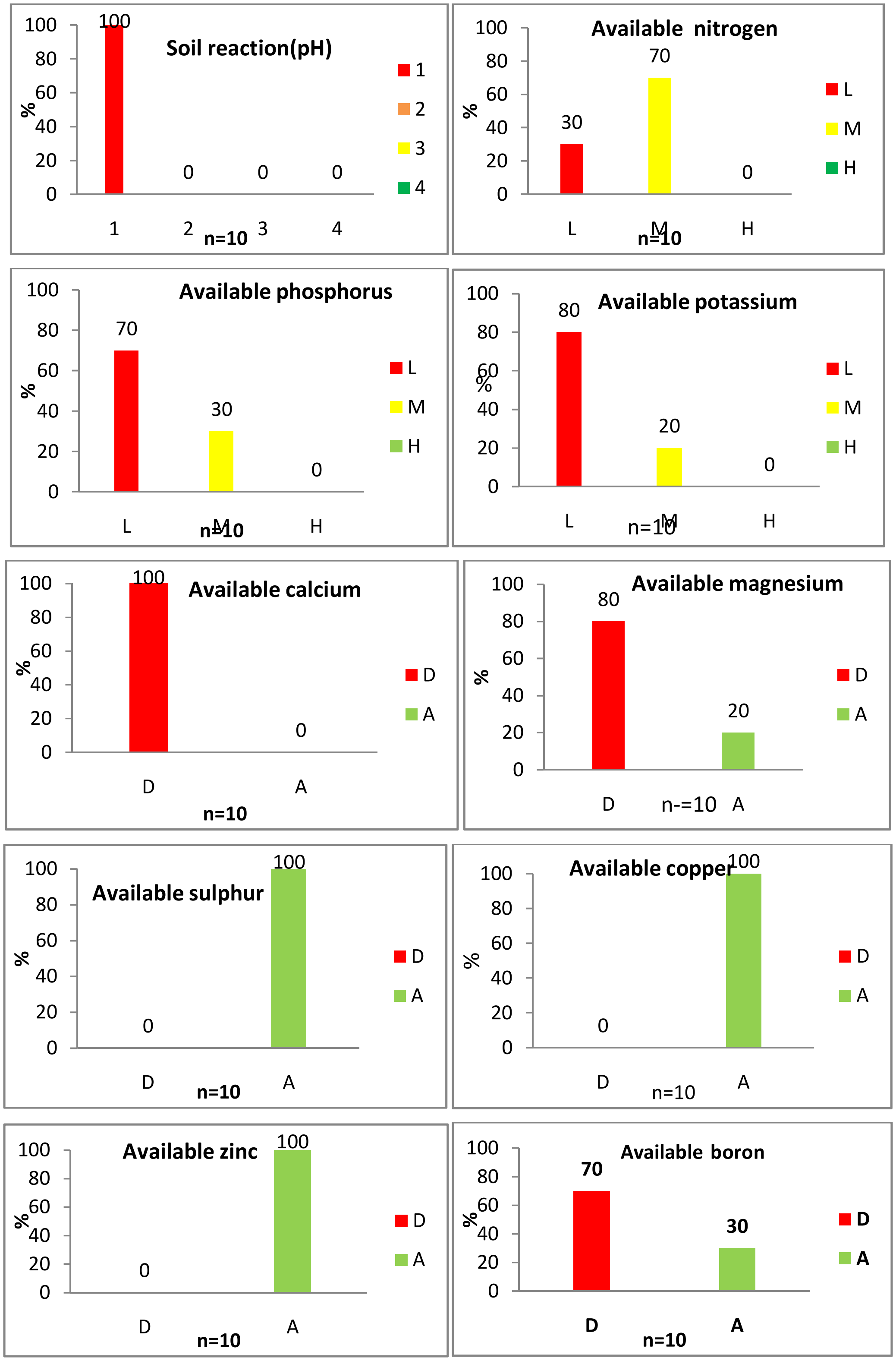


Fig 19: Frequency of soil reaction and plant available nutrient classes in surface soils of Sullya (Refer table 28 for class definitions)

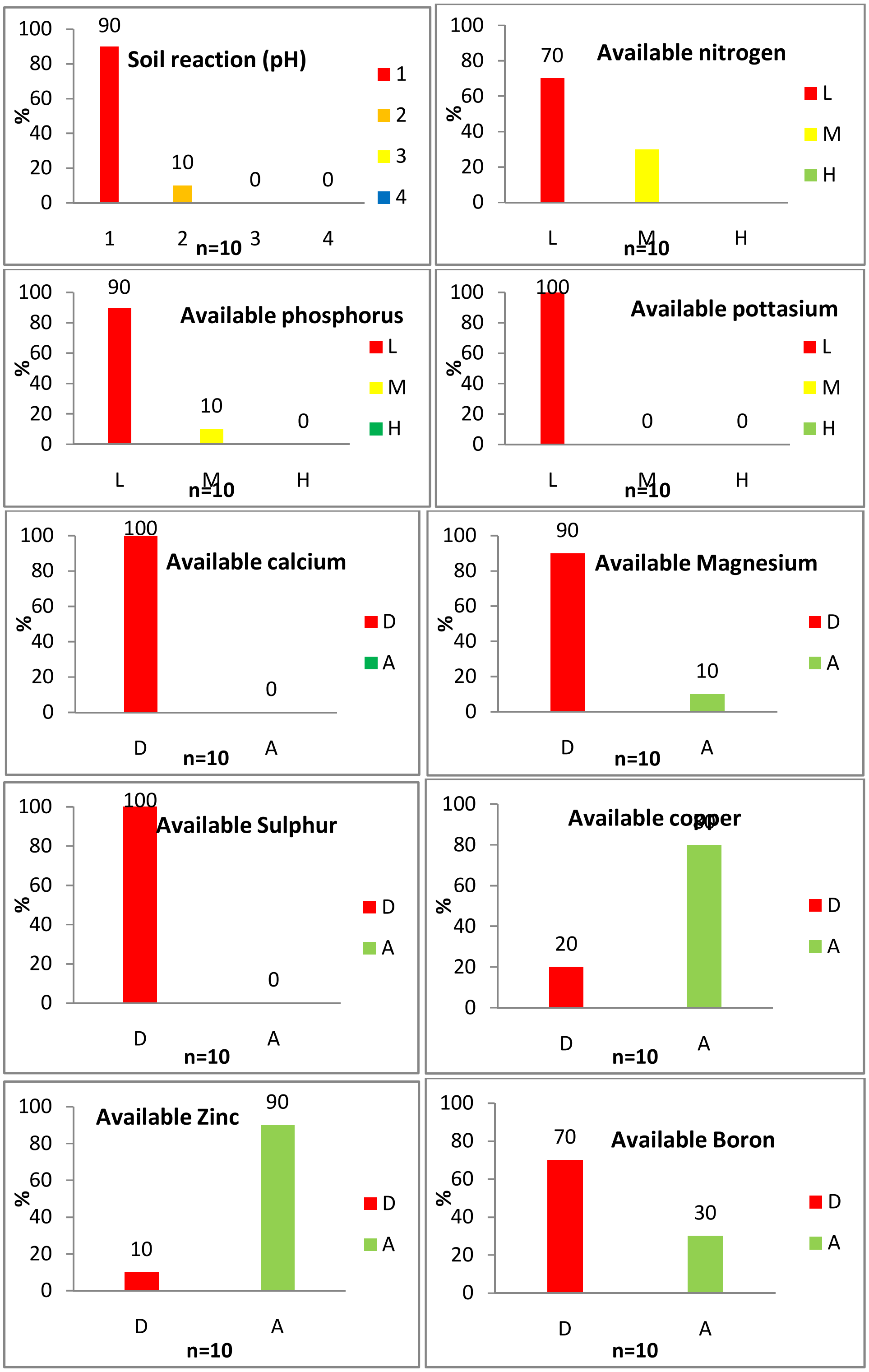


Fig 20: Frequency of soil reaction and plant available nutrient classes in surface soils of Beltangadi (Refer table 28 for class definitions)

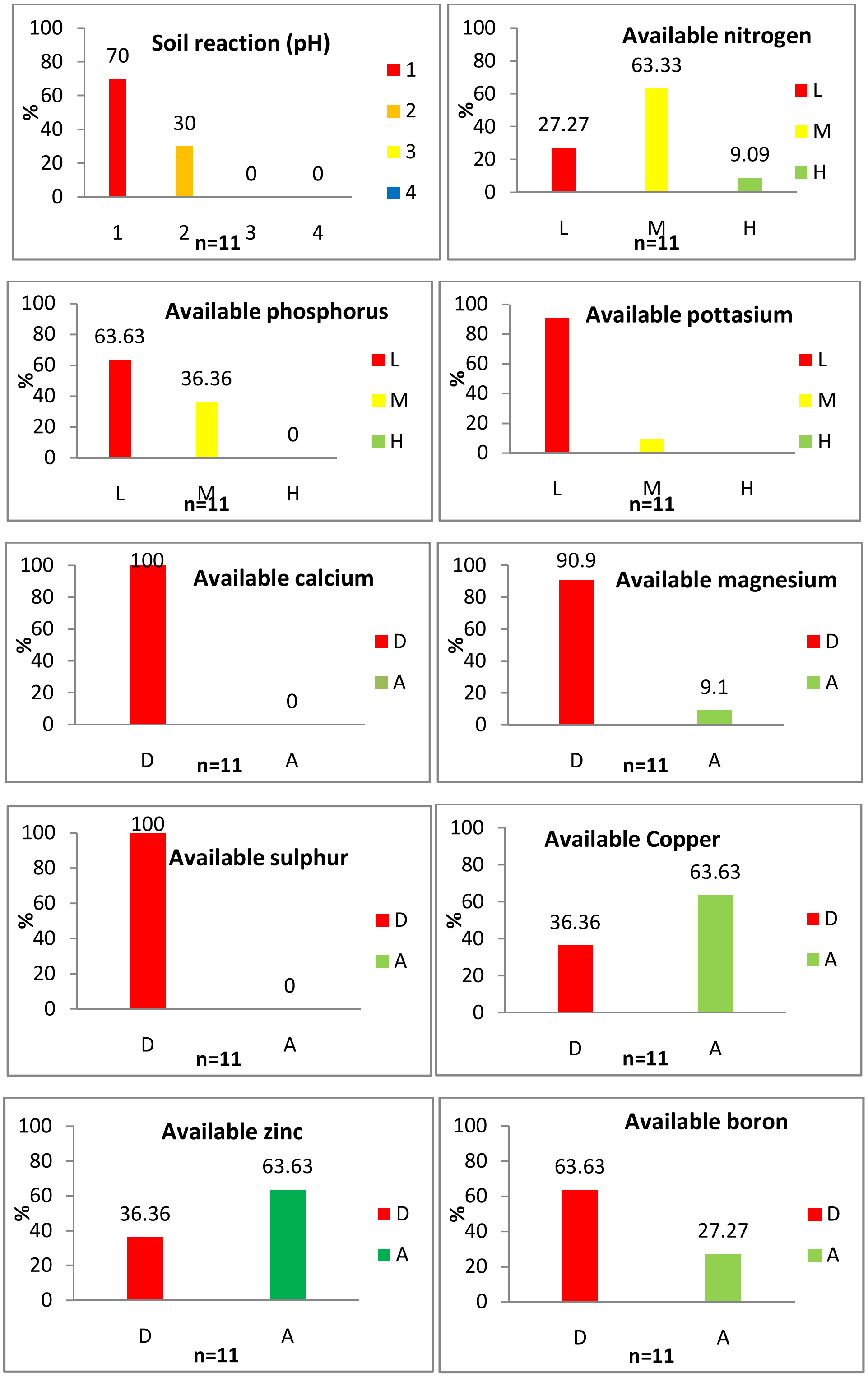


Fig 21: Frequency of soil reaction and plant available nutrient classes in surface soils of Kollur (Refer table 28 for class definitions)

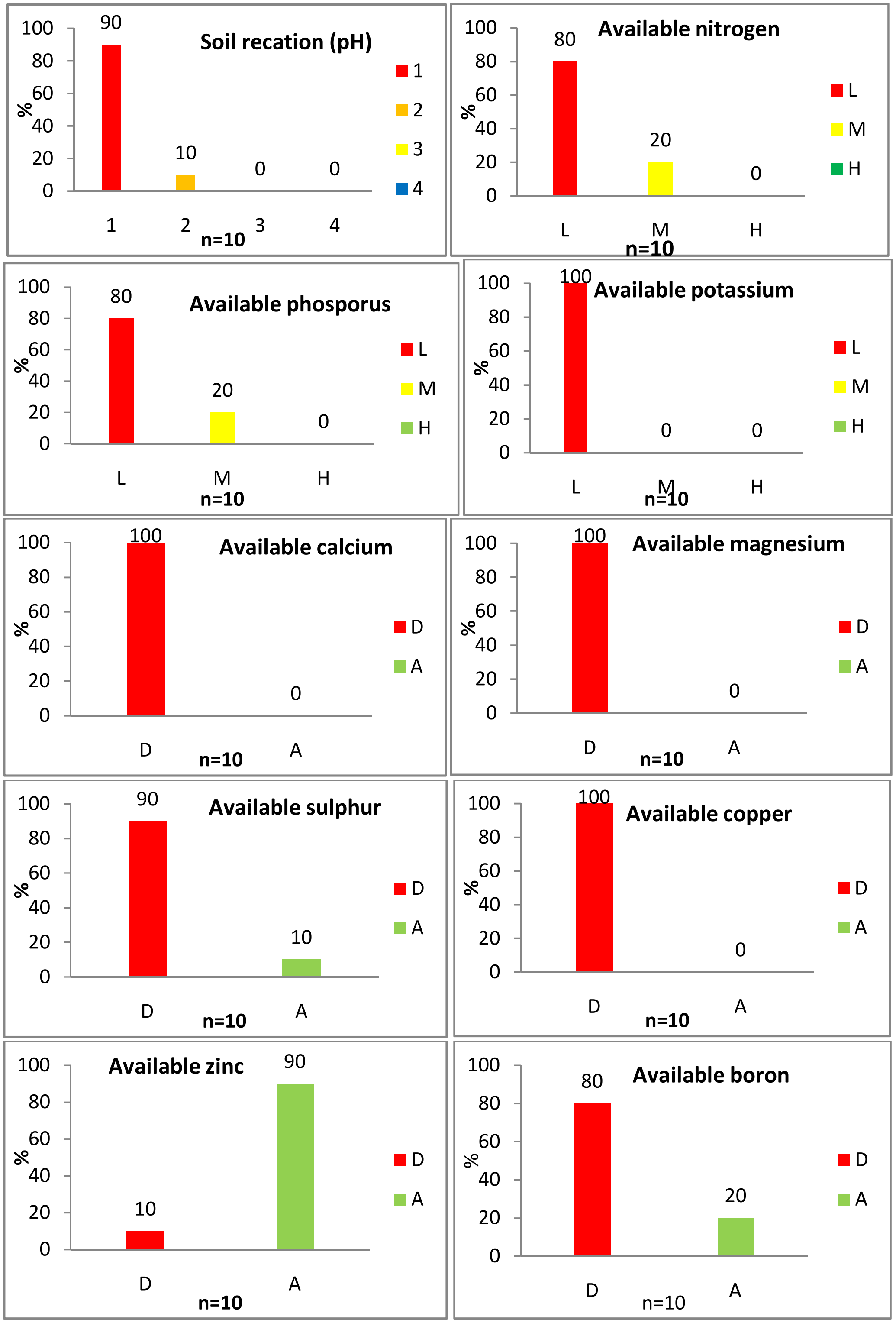


Fig 22: Frequency of soil reaction and plant available nutrient classes in surface soils of Molahalli (Refer table 28 for class definitions)

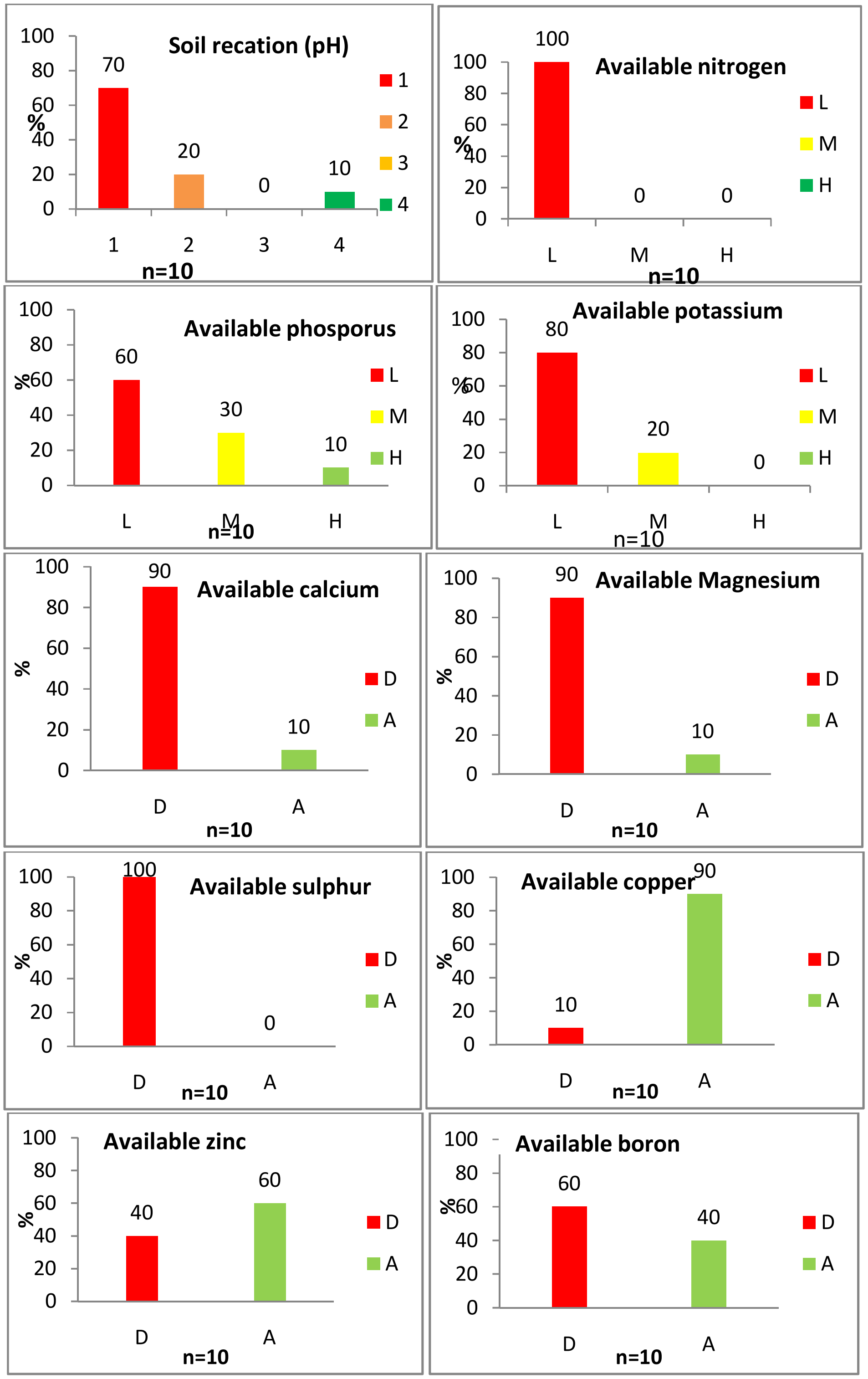


Fig 23: Frequency of soil reaction and plant available nutrient classes in surface soils of Brahmavar (Refer table 28 for class definitions)

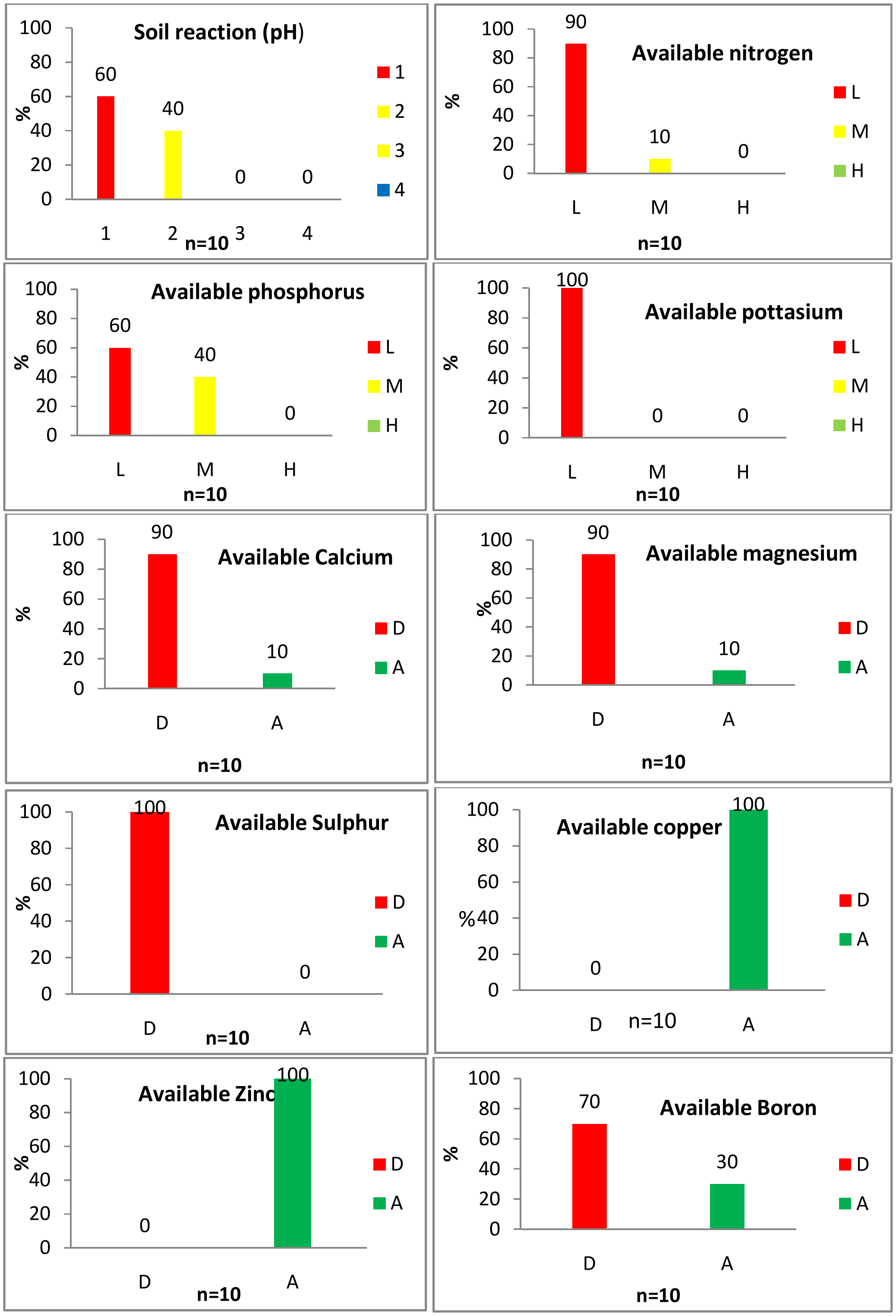


Fig 24: Frequency of soil reaction and plant available nutrient classes in surface soils of Murdeshwar (Refer table 28 for class definitions)

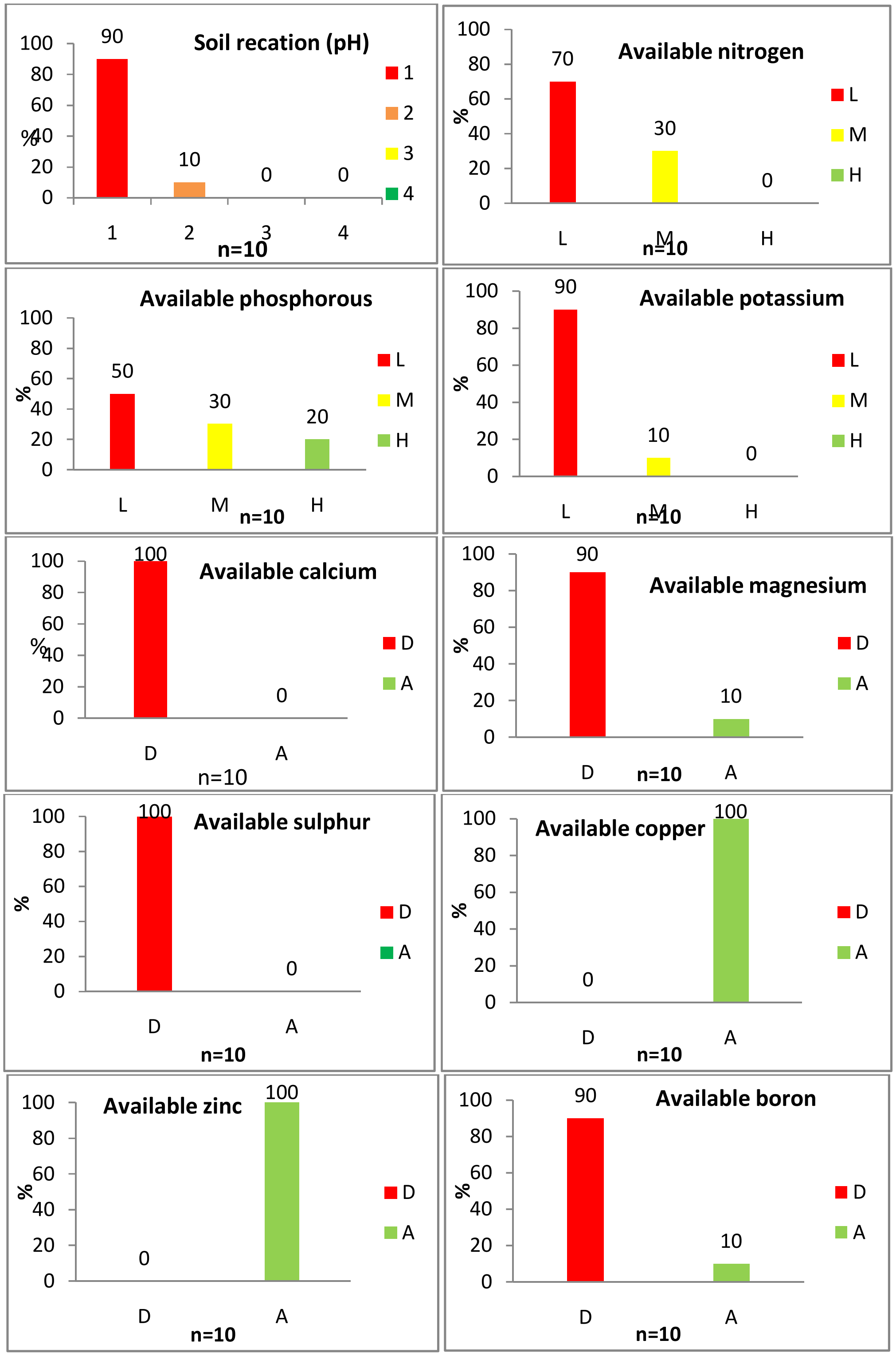


Fig 25: Frequency of soil reaction and plant available nutrient classes in surface soils of Ullal (Refer table 28 for class definitions)

potassium content. Coarse textured and gravelly soils with deeper solum are particularly low in potassium. The available potassium is medium to high in most of the soils of the Karnataka state, except in laterite soils of coastal and western Ghats and in shallow red and black soils (Shivaprasad *et al.*, 1998).

Deficiency of Available calcium and magnesium occurs in Dakshina Kannada, soils are formed from the acid parent material, granite or peninsular gneiss are inherently low in calcium. Heavy rainfall in the coastal areas causes leaching losses of the two nutrients. Deficiency of sulphur is due to low pH and low content of Sulphur bearing minerals (Ananthanarayana *et al.*, 1986).

Deficiency of micronutrients is mainly attributed to the leaching of organic matter due to the heavy rainfall in the area. Owing to high rainfall and temperature assisted high weathering process and soil development, most of the mobile micronutrients like boron and zinc are very low in the study area. Highly porous nature of tropical soils originated from granite gneiss parent material also assist fast removal of zinc and boron from the soil solum.

Available Fe and Mn has shown a different trend with their accumulation due to the tropical soil weathering environment and high acidity.

5.7 Land degradation assessment and vulnerability

The basic data collected from interpretation of image and soil study provided comprehensive information on type of degradation and soil resources under existing climatic situation. Though the data is very valuable and can be used by land users as such, the effective utilization of database depends on the extraction of relevant and required data by the concerened users and land use planners to make use of database effectively various land user friendly interpretations were carried out for the study area and their salient findings are presented below.

5.7.1 Soil depth

Soil depth indicates the depth of the Solum occurring above the parent material or hard rock. It determines the effective rooting depth of plants and the capacity of the soil to hold water and nutrients. In study area deep (100-150 cm) soils occur in Kollur, Sullya, Molahalli, Brahmavar and very deep (>150 cm) soils are observed in the Beltangadi, Ullal, Murdeshwar. The general slope in the study area was 3- 5 per cent which is responsible for deposition of the soil due to erosion and this was responsible for formation of very deep soils in the coastal plateau summits and valleys regions. Variation in depth is due to the variation in topography, physiography and slope gradient (Sitanggang *et al.*, 2006). Reduction in depth of solum owing to loss of top soil by sheet erosion, selective removal of finer particles and assorting of coarse grains and gravels on surface is giving an indication of the degradation process operating there. This is aggravated by heavy rainfall and high temperature, steep slopes and soil surface devoid of vegetation cover.

5.7.2 Soil drainage

The term drainage indicates how fast rain water reaching the soil, will get infiltered into the soil and get percolated later to ground water. Drainage is an important parameter affecting crop productivity and soil management. Site and soil characteristics, particularly the slope of the area, texture of the soil and depth of the ground water affect soil drainage. The two drainage classes identified in study area are well drained (pedon-1, 2, 3, 4, 5 and 6) and moderately well drained (pedon-7).

In study area the soils occurring on very gently and gently sloping land are well drained and gently sloping low land is moderately well drained. Well drained soils occur in larger extent followed by moderately well drained. Moderately well drained soils showed mottles at depth of 21 cm in soil. If surface soils are coarse textured underlain by heavy textured soil, the rain water infiltrate immediately, and percolate down from surface towards subsurface and retain in the fine textured solum for future use.

Soils should need sufficient water retention capacity for which the soil drainage is an important criterion. If the surface is of crusted and compacted the rain water after reaching on the surface won't infiltrate to subsurface and go as surface creep along with dissolved finer particles which are taken by rain drop impact and with dissolution on the bare soil surface.

5.7.3 Slope

Slope plays an important role in the formation of soils, controls the process of erosion and alters the overall use of the land.

Among the seven locations studied the slope per cent varied in pedon-2, 3, 4, 5, 6 and 7 it was 1-3 per cent and it was 3-5 per cent in pedon-1

Per cent of slope and slope length apart from slope aspect are the important indicators of vulnerability to land degradation.

Tree cover is important in areas having steeper slopes so that it can protect rain drop impact as well as the roots of it will bind the soil against the flowing water in the direction of slope.

Contour ploughing, contour planting, contour bunding, bench terracing, check dam making, stone pitting on drainage channels and grassed water ways etc can ensure better use of sloping lands without leaving for chemical degradation.

5.7.4 Soil erosion

The detachment and removal of soil particles by water or wind are known as soil erosion. It is influenced by topography of the land scape, rainfall, soil type, vegetative cover and any interference or disturbance, which aids in removal of particles from the earth's surface.

In study area water is the major agent responsible for soil erosion. In pedon-2, 3, 5 and 7 soils were slightly eroded, in pedon-4 and 6 soils were moderately eroded and pedon-1 it was severely eroded. Sheet erosion is the dominant type of soil erosion observed in the study area because of slope particularly in the granite were large quantities of finer silt and clay particles will get washed away from the top soil. If the erosion is not checked, then the soil becomes coarser and unproductive over a period of time. In the upland the sheet erosion is severe and mainly responsible for the presence of coarser textured surface soil (Balak Ram and Chauhan., 1992).

Sheet erosion occurs more in soils, which have little or no ground cover. If exposed, soils are more prone to sheet erosion in which finer particles gets removed first, make rill formation and further leads to formation of gullies and ravines later if unattended. The lateritic mid lands and the lateritic plains with iron stone cover in patches with grass or scrub vegetation are prone to high risk of soil erosion, which are favoured by hot humid tropical climate.

5.7.5 Surface soil texture

Soil texture indicates the relative proportion of sand, silt and clay fractions present in the soil. The texture of the surface layer or plough layer plays an important role in influencing the growth and yield of crops.

In the study area the texture of the surface layer varies from sandy loam to sandy clay loam in all the pedons except pedon-5. The removal of finer particles by erosion is responsible for the occurrence of coarse textured soil in the uplands (Dutta *et al.*, 2001). Pedon-7 had clay texture and this was under puddle condition were in paddy was grown.

Surface texture of fine loamy is better than coarse loamy or sandy texture in which water falls on surface will drain away fast and get removed vertically downwards. Soils with fine texture will need more time for water to penetrate through the fine pore space. By that time the soil gets eroded with dissolved finer particles moving laterally as surface creep. In soils of finer texture, overlain by slightly coarse surfaces allow rain water to infiltrate fast to the lower horizons and gets percolated and stored at lower depth having finer textures

5.7.6 Coarse fragments

Coarse fragments refer to particles present in the soil having more than 2 mm diameter. The presence of rock fragments in the soil hinders plant growth directly through reducing the volume of soil from which it drawn water and nutrients. In clay soils, presence of coarse fragments helps in free movement of water and air and upto some amount they are not constraint for cultivation.

Coarse fragments get assorted and remaining on surface will not allow rain water to infiltrate to the soil below. If grass cover is there above coarse fragment layer, rain water will remain there for sufficient time to get infiltrated and percolated below will reduce soil erosion by helping to reduce the impact of rain drops and allowing rain water to percolate below at the same time.

In study area, coarse fragments were present almost throughout the depth in all the pedons except pedon-7 were in coarse fragments were seen from 47 cm depth. In study area due to the erosion it removes the sand, silt and clay particles leaving the coarse fragments to deposit on the surface.

In fine textured gravelly soil, coarse fragments will favour the physical condition of soil to have a better internal drainage and soil-air-water-plant root relationship and leads to better productivity than non gravelly soils.

5.7.7 Soil reaction

In study area soil reaction varied from strongly acidic to moderately acidic. This is mainly due to the leaching of bases because of heavy rainfall.

Soil reaction turning towards high acidic range is typical in hot humid tropical climate in the study area, where in soil degradation occurs due to accumulation of Fe, Mn and Al^{3+} assisted toxicity some times. Soil reaction was alkaline (pH 7.8) in the surface soils of St. Mary's island in study area where available calcium was very high owing to the origin of the landscape from coral reef.

5.7.8 Cation exchange capacity

CEC of the soils was generally low in all the pedons and it varied from 2.14 to 15.21 cmol(+) kg^{-1} of soil. Except pedon 6 the higher CEC values were observed in surface horizons, due to the influence of organic matter. Low CEC values even with high clay content indicate the dominance of low activity clay particularly, 1:1 type clay minerals i.e. kaolinite (Walia and Chamuah, 1988). Low CEC of soils is an indication of low activity clays and these soils are low in bases and have low inherent soil fertility.

5.7.9 Base saturation

Base saturation was low in all the pedons mainly because of leaching due to the high rainfall in the coastal areas. The base saturation was high in the surface horizons in some areas due to high organic carbon content. Low base saturation is also an indication of poor supply of available K, Ca and Mg and low inherent soil fertility owing to hot humid tropical climate.

5.7.10 Organic carbon

Soil organic carbon was high in the surface horizons in all the pedons and it decreased with the depth. Soil organic carbon helps the soil to have better aggregation and buffering capacity and adds to inherent soil fertility. It also helps to maintain good stand of beneficial microbial population of soil. If organic carbon contents are low there is a tendency of crusting and compaction which leads to impeding of structure and poor permeability. Soil organic carbon will decide the Soil nutrient concentration and buffering action apart from high water retention capacity.

5.7.11 Soil organic carbon stocks

The organic carbon is considered as an important attribute of soil quality. There is an increase in soil organic carbon through C sequestration into the pedosphere and it enhance the soil quality and improves soil regulatory capacity. In the study area soil organic carbon stocks of 0-100 cm was high in pedon-3. In pedon-4 it was low and in rest of the pedons it was medium. Soil organic carbon status is an indicator of quality of land and how best it can sustain crop production at profitable and sustainable level.

5.7.12 Available plant nutrients

Among the major nutrients, available N was high in pedon-3 and 5 and in rest of the pedons it was low. Available P was found to be low in almost all the pedons. Available K was medium in pedon-3 and 5 and it was low in rest of the pedons. Available secondary nutrients were low in all the pedons.

Available micronutrients of soils revealed that HCl extractable iron, manganese, zinc and copper varied from deficiency to toxicity level in all pedons.

As study area belongs to humid tropical belt, the associated soils are prone to have multinutrient deficiency, poor in bases, high acidity and low CEC. Apart from this the soils show deficiency of N, P, K, Ca, Mg, S, Zn and B and also have chances of Fe and Al^{3+} toxicity.

5.7.13 Physical deterioration

5.7.13.1 Water logging

Physical deterioration of soils associated with wetness, water logging or flooding of soils for considerable period and leading to poor soil-air-water-plant root relationships. Continuous flooding of soils can bring the pH to neutrality but in tropical hot humid climate it may not reach neutrality but have problems of Fe and Al^{3+} toxicity to roots and there is chance of dominance of disease causing fungi against beneficial microbes like bacteria which help in nutrient mineralization processes. In reality physical deterioration of soil is due to water logging is one of the reason for the epidemics of root wilt, bud rot and button shedding in coconut, abnormal leaf fall of rubber, Mahalia or kolae roga disease of arecanut and rhizome rot of ginger etc in the study area.

5.7.13.2 Crusting and Compaction

Crusting and compaction is a serious problem in exposed red and lateritic soils having low organic carbon and dominance of fine sand, silt and clay. This makes clogging of micro and macro pores against water and air penetration using the help of hydroxylated/hydrated Fe, Mn and Al^{3+} oxides. Crusting and compaction makes sealing of surface leading to higher run off and forcefull dissolution of finer particle due to rain drop impact causes physical decoration of soils and makes disturbance to cultural operation for crop production.

5.7.14 Chemical deterioration

Chemical deterioration is associated with acidification and Fe, $Al^{3+}$and Mn- toxicity, poor organic carbon, poor base status due to excessive leaching associated heavy rainfall, high temperature and extended dry period. Apart from these natural processes, human induced chemical degradation processes associated with excessive and imbalanced fertilizer application to crop and plant protection chemicals can cause deleterious effects to the beneficial microflora and soil health apart from reducing crop productivity.

Another form of chemical decoration is pollution due to heavy metals like As, Pb, Cr and Ni etc through fertilizers and plant protection chemicals and due to excessive use of ground water.

Formation of iron stone capping in exposed lateritic areas is an after effect of natural chemical deterioration on land quality.

Quarrying and open cast mining are the other reasons for chemical deteriorsation of land if done without rehabilitation processes.

5.8 Soil degradation mapping

Soil degradation status map of the study area has been generated (Fig 26) considering and adding scores prescribed for each land degradation indicator classes. The areas receiving a lowest score of < 0.55 has been considered as having very low degree of degradation and represented by Kollur soil profile and surrounding areas followed by low degree of degradation having scores of 0.55-0.6 represented by Bramhawar, medium degree of degradation having scores of 0.6-0.7 represented by Beltangadi area, while Sullya and ullal, shown moderate degree of degradation with score 0.7-0.75 and high degradation has been depicted in Molahalli and Murdeshwar areas, it has score > 0.75. (Table 29)

In west coast of southern Karnataka high degree of degradation is noticed in larger proportion of area followed by the other four. Among the indicators low organic carbon, less thickness of surface horizon, high bulk density and gravelly surface horizon and low CEC of control section and surface base saturation are the major ones in study area. High torrential rainfall also contributing to the higher degree of degradation.

5.8.1 Combating land degradation

High land degradation was noticed in Molahalli and Murudeshwar, were reduction in soil depth and increasing gravelliness was noticed occurring to removal of finer particles associated with low organic matter. To combat land degradation the coastal lateritic plateau and undulating uplands covering these places has to be put under tree species based cropping system with cashew and/ or jack tree with provision of enough surface cover and mulch to arrest crusting and compaction active there.

In case of Sullya and Ullal were moderate degradation is noticed. Here the area can be brought under plantation like rubber after doing bench terracing and making small check dams for reducing forces of erosion for conserving moisture for irrigation. The areas where demographic pressure is not there can be brought under protected forest with sufficient soils and water conservation measures to protect soil from erosive forces of running water.

In case of Beltangadi where medium land degradation was noticed owing to steep slopes and torrential rainfall, these areas bench terracing and cultivation of plantation crops like rubber/keeping the area under forestry with required soil and water conservation

Table 29: Soil degradation status of study area and associated properties

	Rainfall (mm)	Dry months	Thickness of surface horizon	Surface texture	B.D of surface horizon	OC % of surface horizon	CEC/clay of control section	B.S/Sum of cations surface horizon	Status of Land degradation
Sullya	3738 (1)	4.2 (1)	10 (3)	gscl (2)	1.08 (1)	0.94 (3)	18-12 (3)	10.5 (4)	18/25= 0.72 (4)
Beltangadi	4485 (2)	4.5 (1)	41 (1)	gscl (2)	1.22 (2)	2.30 (2)	12-16 (2)	3.8 (5)	17/25= 0.68 (3)
Kollur	3860 (1)	5.4 (2)	10 (3)	gscl (2)	1.13 (1)	5.40 (1)	> 16 (1)	23.9 (2)	13/25= 0.52 (1)
Molahalli	3887 (1)	5.6 (3)	10 (3)	gsl (3)	1.24 (2)	0.66 (4)	>16 (1)	20.5 (3)	20/25= 0.80 (4)
Brahmavar	3887 (1)	5.2 (2)	10 (3)	gc (2)	1.07 (1)	2.40 (2)	12-16 (2)	23.5 (2)	15/25= 0.60 (2)
Murdeshwar	3237 (2)	5.2 (2)	20 (2)	gscl (2)	1.24 (2)	1.45 (3)	8-12 (3)	8.6 (4)	20/25= 0.86 (4)
Ullal	3769 (1)	5.2 (2)	10 (3)	scl (1)	1.12 (1)	0.52 (4)	8-12 (3)	12.3 (4)	17/25= 0.68 (4)
	3500-4000= (1)	< 5=1	> 20 = 1	scl= 1	<1.2 = 1	>2.5 = very high(1)	> 16 =1	> 30 = 1	<0.55 = Very Low
	>4000 =(2)	5-5.5=2	10-20 = 2	gscl= 2	> 1.2 =2	1.5-2.5 = high (2)	12- 16 = 2	22.5-30 =2	0.55-0.60 = Low
	<3500 =(2)	5.5-6.0=3	< 10 = 3	gc= 2		0.75-1.5 = Medium (3)	8-12=3	15-22.5 =3	0.60-0.70 = Medium
				gsl= 3		> 0.75 = low (4)		7.5-15=4	0.70-0.75 = Moderate
								<7.5= 5	<0.75= High

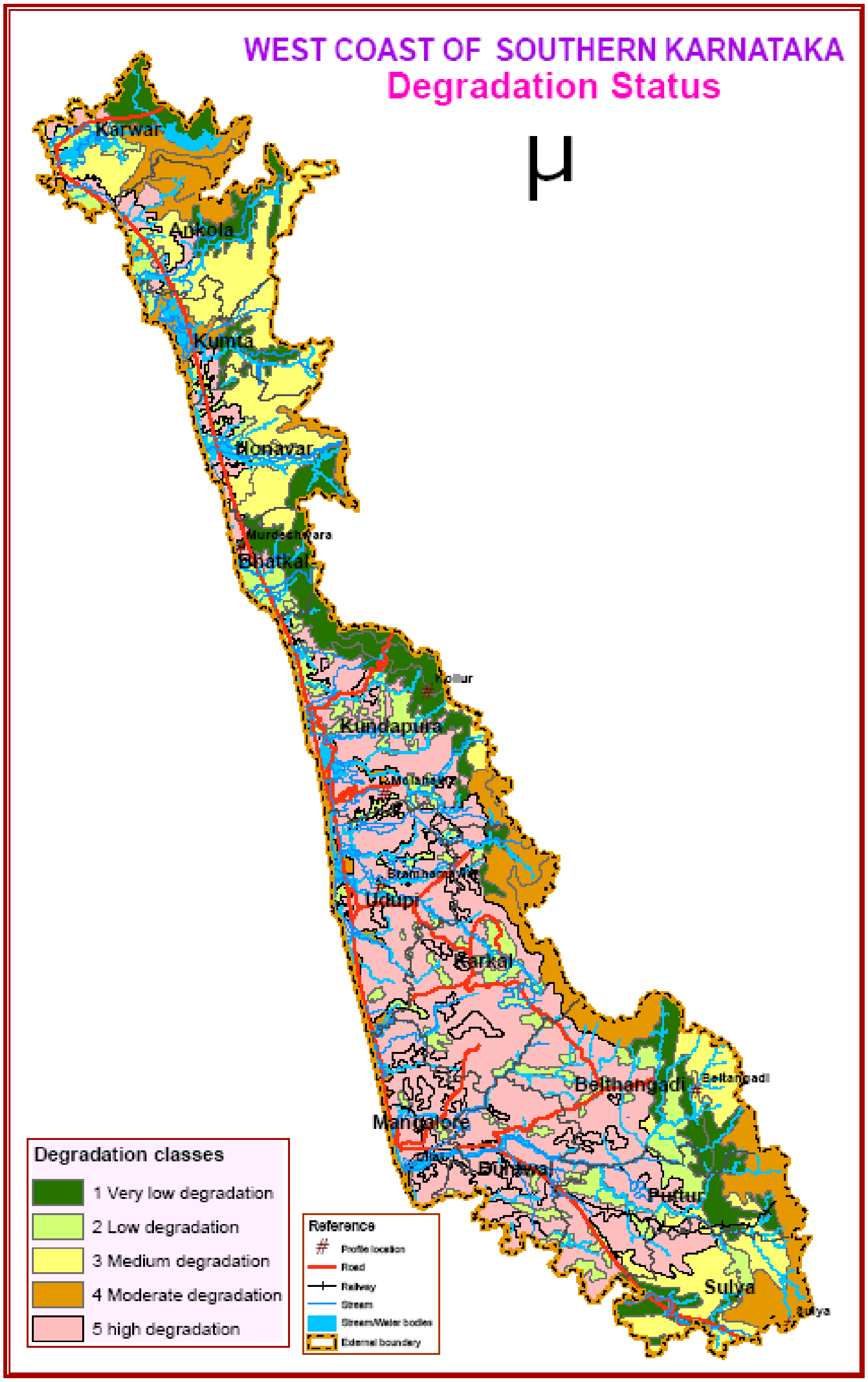


Fig 26: Soil degradation status map prepared after study

measures to arrest the present pace of land degradation and to bring back to its original form.

In case of Brahmavar low land degradation is noticed owing to acidification and depletion of nutrient required for plant growth. These areas has to be brought under intensive agriculture with tree crops like coconut with intercrops like banana, nutmeg, pineapples and cocoa with separate fertilization each along with liming and mulching without allowing for crusting and compaction of surface soil.

In case of Kollur were very low degradation is noticed with very high soil organic carbon stock covered by elongated ridges and foot hills planted with rubber under good management, here also bunding and terracing is practiced to avoid erosion by flowing water and mulching to protect the degrading effect of rain drops and to conserve moisture. These areas can be utilized for intensive agriculture after protecting from erosive and degrading forces.

VI. SUMMARY

An assessment of land degradation was carried out in west coast of southern Karnataka. The objective of study were to characterize soils of west coast of Southern Karnataka to assess land quality and to assess the extent of land degradation in the study area by field studies and using satellite imageries and toposheets.

Land attributes like elevation, topography and drainage, climatic factors such as rainfall, temperature, soil attributes like soil depth, soil texture, soil structure, coarse fragments, soil reaction, electrical conductivity, CEC, base saturation, organic carbon, organic carbon stock and plant nutrients were selected as indicators of land qualities, which may be responsible for land degradation.

To identify the degraded land and type, extent and degree of degradation in the study area imageries were collected from Karnataka State Remote Sensing Application Centre. Imageries were interpreted based on tone, colour, shape and pattern and slope characteristics from toposheets, soil physiographic divisions map, soil units map and soil degradation types map generated from the toposheets, imagery and SRM database of Karnataka state.

A field traverse was conducted in the study area, seven soil profiles were selected viz. Sullya, Beltangadi, Kollur, Molahalli, Bramhawar, Murdeshwar and Ullal to represent all physiographic divisions covering the study area. Horizon wise samples were collected from all the pedons for analysis and core samples for bulk density and gravel volume determination and composite surface samples were collected from farmers' fields surrounding each location representing all major farming systems of that physiographic division.

For the profile samples analysis of physicochemical properties such as pH, EC, organic carbon, particle size distribution, CEC, base saturation and macro, secondary and micro nutrient analysis were conducted.

Composite surface samples were analysed for pH, EC and available, macro, secondary and micro nutrient analysis were conducted and concluded for all the seven pedon locations.

Soil morphological studies indicated that all the soils studied were deep to very deep. Soil colour varied from dark reddish brown to reddish brown in surface and yellowish red to dark red in lower horizons. Clay illuviation was noticed in subsurface layers and indicated by the presence of clay cutans.

Physical and chemical characterization of the soils studied indicated an increase in bulk density with depth in almost all pedons. Soil reaction was strongly to moderately acid, organic carbon stocks varied with the pedons locations and its agro-ecology, cation exchange capacity was generally low and exchange complex dominated by calcium and magnesium, low base saturation was noticed in all the pedons. Available primary and secondary nutrients where low in status and among the micronutrients Fe, Mn and Cu remained high, while Zn medium to low and B uniformly low.

- Soil organic carbon stock was high in the pedon-3 situated in foot hills of Kollur.

- CEC per kg clay in pedon-5, 6 and 7 was less than 25 cmol (+) kg^{-1} in surface horizon indicating presence of low activity clays.
- The Barium chloride-TEA extractable acidity (4.5-19.2 cmol (+) kg^{-1}) was several times higher than that of potassium chloride acidity (0.12-0.28 cmol (+) kg^{-1}) in all the pedons.
- Soil degradation vulnerability and status was assessed and mapped by assigning scores to each land quality, which favour degradation and the ratings made adding all scores and dividing by total possible score in a numerical scale ranging from 0 to 1.

Kollur soils showed very low vulnerability and status (<0.48) followed by Brahmavar with low status (0.60) and high vulnerability and status was noticed in case of Molahalli and Murdeshwar (0.80).

VII. REFERENCES

ADEL, S. AND RYUTARO, T., 2007, Remote sensing and GIS for mapping and monitoring land cover and land-use changes in the Northwestern coastal zone of Egypt. *Applied Geography.*, **27**:28–41.

ADEMOLA, O. AND ALABI, S.,2011, A Study of Land Degradation Pattern in the Mahin Mud-beach Coast of Southwest Nigeria with Spatial-statistical Modelling Geostatistics. *J. geography and geology*, **3**:141-159

ANITHA, M.S., ANIL KUMAR, K.S., NAIR, K.M., C.R. SHIVAPRASAD, NAIDU, L.G.K. AND DIPAK SARKAR., 2012. Soil boron and its fractions in agro-climatic zones of Karnataka, Paper presented (T-4/7) in 17th Annual Convention and National symposium of Applications of clay Science: Agriculture, Environment and Industry by Clay Mineral Society of India at NBSS and LUP, Kolkatta, 39p

BADRINATH, M.S., KRISHNAN, A.M., PATIL, B.N., KENCHAIAH, K. AND BALAKRISHNA RAO, K., 1986, Fertility status of some typical soils of coastal Karnataka. *J. Indian Soc.Soil Sci.*, **34**: 436-438

BALAK RAM AND CHAUHAN, J.S., 1992. Remote sensing in mapping the vulnerability and dynamic of the gullied land in Sikar district, Rajasthan. *Indian Cartographer*, **12**:47-50.

BHASKAR, B.P., MISHRA, J.P., BARUAH, UTPAL., VADIVELLU, S., SEN, T.K., BUTTE, P.S. AND DUTTA, D.P., 2004, Soils of Jhum cultivated hill slopes of Narang-Kongripara watershed in Meghalaya. *J. Indian Soc.Soil Sci.*, **52**: 125-133.

BHASKAR, B.P. AND SUBBAIAH, G.V., 1995, Genesis, Characterization and Classification of laterites and associated soils along the east coast of Andhra Pradesh. *J. Indian Soc.Soil Sci.*, **43**: 107-112.

CHALLA, O., BHASKAR, B.P., ANANTWAR, S.G. AND GAIKAWAD, M.S., 2000, Characterization and classification of some problematic vertisols in semi arid ecosystem of Maharastra plateau. *J. Indian Soc.Soil Sci.*, **48**(1): 139-145.

DAS, M, SINGH, B.P, RAM, M, DWIVEDI, B.S AND PRASAD, R.N, 1991, Influence of organic manures on native plant nutrient availability in an acid Alfisols. *J. Indian Soc. Soil Sci.*, **45**: 456-465.

DAS, P.K., SAHU, G.C. AND NANDHA, S.S.K., 1992, Nature of acidity and exchange chemistry of some lateritic soils of orissa. *J. Indian Soc.Soil Sci.*, **40**: 425-430.

DATTA, M., SAHA, P.K. AND CHAUDHARY, H.P., 1990, Erodibility Characteristics of Soils in relation to soil characteristics and topography. *J. Indian Soc.Soil Sci.*, **38**: 495-498.

DEALWIS, K.A. AND PLUTH, D.J., 1976, The red Latosols of Sri Lanka. I. Macromorphologoical, physical and chemical properties, genesis and classification. *Soil Science Society of American Journal,* **40**: 912-920.

DUTTA, D., RAY, S.K., REDDY, R.S. AND BUDHIHAL, S.L., 2001, Characterization and classification of Paleosols in part of south India. *J. Indian Soc. Soil Sci.*, **49**(4):726-734.

FOOD AND AGRICULTURAL ORGANIZATION., 1979, Frame work for land evaluation purposes. *Soil bull.* No **32**, FAO, Rome.

GANGOPADHYAY, S. K., BHATTACHARYA, T. AND SARKAR, D., 2001, Rubber growing soils of tripura their characteristics and classification. *J. Indian Soc. Soil Sci.*, **49**(1):164-170.

GAN-LIN ZHANG, HUA ZHANG, YU-GUO ZHAO, WEN-JUN ZHAO, ZHI-PING Q., 2007, Chemical degradation of a Ferralsol (Oxisol) under intensive rubber (Hevea brasiliensis) farming in tropical China. *Soil & Till.* Res., **93** : 109–116.

GHOSH, G.K. AND SARKAR, A.K., 1994, Availability of sulphur and some micronutients in acid sedentary soils of Chhotanagpur region. *J. Indian Soc. Soil Sci.*, **42**:464-466.

GHOSH, T.K., SHAH, S.D. AND TRIPATHY, K.K., 1996, Monitoring of desertification process in Karnataka state of India using multitemporal remote sensing and ancillary information using GIS. International Journal of Remote Sensing., **17**(12): 2243-2257.

GROSSMAN, R.B., HARMS, D.S., KINNGSBURY, D.F., SHAW, R.K. AND JENKINS, A.B., 2001, Assesment of soil organic carbon using the U.S Soil Survey. In: Assessment Methods for Soil Carbon. Ed by R.Lal, J. Kimble, R.F. Follet and Stewart, B.A., CRC press. Boca Raton, pp. 87-102.

GUPTA, J.P., SHARMA, M.P. AND GUPTA, G.D., 2001, Characterization and classification of Kandi belt soils of Jammu region as affected by different land used patterns. *J. Indian Soc. Soil Sci.*, **49**(4):770-773.

GUPTA, U.C., 1967, A simplified method for determining hot-water soluble boron in podzol soils. *Soil Sci.* **103:** 424-428.

HESSE, P. R., 1994, A Text Book of soil chemical Analysis, CBS publishing House, NEW Delhi, India. pp. 720-728.

JACKSON, M.L., 1973, *Soil Chemical Analysis*. Prentice Hall of India (pvt) Ltd., New Delhi.

JOSHI, A.B., 1995, Coastal erosion – An overview. In: Course Manual on Coastal Erosion, Protection and Coastal Zone Management, Vol.II. Bench Erosion Board, Ministry of Water Resources, Govt. of India, New Delhi, pp. 1-26.

KELLOGG, C.E., 1950, Tropical soils. *Transactions 4th International Congress of Soil Science*, **3**: 266-276.

KRISHNAMOORTHY, P. AND GOVINDARAJAN, P.V., 1977, Genesis and classification of associated red and black soils under Rajolihunda diversion irrigation scheme (Andra Pradesh). *J. Indian Soc. Soil Sci.*, **25**(3):239-246.

KRISHNAN, P., VENUGOPAL, K.R., AND NAIR, K.M., 2000, Morphology, characteristics and classification of low activity clay soils of Kerala. *J. Ind. Soc. Soil.Sci.,* **48**(4): 819-823.

LAL, R. AND STEWART, B.A., 1990, Soil degradation: A global threat. Advances in Soil Sci., **11**:XIII- XVII.

LILLESAND, T.M. AND KIEFER, R.W., 1994*, Remote sensing and image interpretation.* **2**nd Edn., Willey j and Sons, New York,pp.721.

LINSDAY, W.L., PEECH, M. AND CLARK, J.S., 1959, Determination of Aluminium ion activity in soil extracts. Proc. *Soil Sci. Soc.Am.*, **23**: 266-269.

MAHAPATRA, S.K., WALIA, C.S., SIDHU, G.S., RANA, K.P.C. and TARSEM LAL, 2000, Characterization and classification of the soils of different physiographic units in the subhumid ecosystem of kashmir region .*J. Indian Soc. Soil Sci.*, **48**(3):572-577.

MAJI, A.K., OBIREDDY, G.P. AND DEEPAK SARKAR 2010, Degraded and waste lands of India; status and spatial distribution, pub: ICAR p158.

MALLIK, R.P., SACHDEV, C.B., RANA, K.P.C., KUHAD, M.S. AND LOHAN, H.S., 1990, Use of Landsat imagery FCC for preparing land resource map of Sirsa district for optimum land use planning and environmental conservation. Proc. Natn. Symp. Remote sensing for agricultural applications, dec. 6-8, New Delhi: pp 58-65.

MINI, V. PATIL, P.L. AND DASOG, G.S., 2007, Characterisation and classification of soils of a pilot site in coastal agro ecosystem of North Karnataka. *Agropedology*, **17**(1): 59-67.

MISRA, U.K., 2004. Acid soil and its management. *J. Indian Soc. Soil Sci.*, **52**: 332-343.

MISRA, U.K., AND SAITHANTUAANGA, H., 2000, Characterization of acid soils of Mizoram. *J. Indian Soc. Soil Sci.*, **48**(3):437-446.

MISRA, U.K., SATAPATHY, S AND PANDA, N.N., 1989, Characterization of some acid soils of orissa I. nature of soil acidity. *J. Indian Soc. Soil Sci.*, **37**:22-28.

MORTVEDT, J.J., COX, F.R., SHUMAN, L.M AND WELCH, R.M., 1991, Micronutrients in agriculture. Second edtion, No. **4,** *Soil Science Society of American Book series*, SSSA, Madison, Wisconsin, USA.

NAIR, K.M, ANIL KUMAR, K.S., KRISHNAN, P., NAIDU, L.G.K. AND DIPAK SARKAR., 2011. Variability of Lateritic Soil Development in Humid Tropical Environment, *Clay Research*. **30**(2): 12-20.

NARAYANA RAO, K., DASOG, G.S. AND SATYANARAYANA, T., 1993, Characterization and classification of some laterite soils of north karnataka. NBSS AND LUP, Nagpur, Publ., P. 39.

NATRAJAN, A., REDDY, R.S., NAIR, K.M. AND KRISHNAN, P., 2005, Assessment and monitoring of land qualities in southern states of India. Proc. Nat. Workshop on managing Land quality for sustainable Agriculture. P. 24-38.

NIRMALYA BALA AND SAHU, G.C., 1993, Characterization and classification of soils of hill slope of middle Andaman island. *J. Indian Soc. Soil Sci.*, **41**:133-137.

NIZEYMANA., EGIDE. AND PETERSEN, G.W., 1998, Remote sensing application to soil degradation assessments. In: Advance in soil science (Eds.) Lal., Blum, W.H., Valentine, c. and Stewart, B.A., CRC Press Inc., New York, pp. 393-405.

OLDEMAN, L.R., 1991, Global extent of soil degradation. Bi-annual Report, ISRIC, Wageningen. The Netherlands, pp. 19-35.

PAGE, A.L., MILLER, R.H. AND KENNY, D.R., 1982, Methods of soil Analysis, part-2. Chemical and Microbiological properties. *American Society of Agronomy*. Inc., Madison, Wisconson, USA, pp. 234-236.

PAL, D.K., NATH, S., BANERJEE, S.K. AND SHARMA, S. K., 1985, Characterization of some forest soil of Darjeeling, Himalayan region under Pinus patula. *J. Indian Soc. Soil Sci.*, **33**:84-95.

PARASURAM, S. AND JAYRAJ, S., 1982, Distribution of total and available N, P and K of the major soil series of profiles of black soils of coimbatore district, Tamil Nadu. *Madras Agric. J.*, **69**:825-829.

PATIL, P.L. AND ANANTHANARAYANA, R., 1990, Determination of lime requriment of some acid soils of uttara Kannada District, Karnataka. *Karnataka Journal of Agricultral Science*, **3**: 161-170.

PATIL, P.L. AND DASOG, G.S., 1999, Genesis and classification of ferruginous soils in Western Ghats and Coastal region of North Karnataka., *Agropedology*. **9**, 1-15.

PIPER, C.S., 1942, soil. *Pl anal, Hans*. Publ. Bombay.

PRAKASH, N.B., KENCHANAGOWDA, S.K. AND SIDDARAMAPPA, R., 1993, Phosphorous adsorption and desorption in Alfisols of Karnataka. NBSS AND LUP, Nagpur, Publ. **37** P.205.

PRASAD, SHIVA, REDDY, R.S, SEHGAL, J AND VELAYUTHAM, M., 1998, Soil of Karnataka for optimizing land use. NBSS, Publ. **47b**. (soils of India series) National Bureau of soil survey and land use planning, Nagpur, India.

PUJARI, K.L. AND MOHARANA, G., 1993, Characterization and classification of some lateritic soils of Orissa. In 'Red and lateritic soils of India Resource Apprisal and Management' (Eds. Sehgal *et al.*) pp. 46-52. *NBSS Publ.* **37**, NBSS&LUP, Nagpur, India.

RAJAMANNAR, A. AND KRISHNAMOORTHY, K.K., 1978, A note on the influence of altitude on the physico-chemical characters of forest soils. *J. Indian Soc. Soil Sci.*, **26**(4):399-400.

REDDY, D.R., RAO, A.E.V. AND RAGHUMOHAN, N.G., 1993, Morphology and Physico-Chemical properties of red soils (Alfisols) under irrigated and unirrigated condition of Nagarjuna Sagar Project area of Andhra Pradesh, Red and laterites soils of India- resource applied and management. NBSS Publ., **37**:106-110.

RONI, V., 2005, Soil organic Carbon Sequestration Under Forestry and Plantation Land Systems in South Karnataka. M.Sc (Agri) Thesis, University of agricultural sciences, Banglore.

RUDRMURTHY, H.V. AND DASOG, G.S., 2001, Properties and Genesis and classification of associated red and black pedons of north Karnataka. *Mysore J. agric. Sci.*, **49** (2): 301-309.

SAHA, R. AND MISHRA, V.K., 2007, Long term effect of various land use systems on physical properties of silty clay loam soil of north eastern hills. *J. Indian Soc. Soil Sci.*, **55**:112-118.

SAHU, G. C. PATNAIK, S. N. AND DAS, P. K. 1990, Morphology, genesis, mineralogy and classification of soils of northern plateau zone of Orissa. *J. Indian Soc. Soil Sci.*, **38** (1): 116.

SAHU, G.C. AND MISHRA, K.N., 1997, Morphology, Characteristics and classification of soils of an irrigated river flood plain in the eastern coastal region. *J. Indian Soc. Soil Sci.*, **45**(1):152-156.

SARMA, V.A.K, KRISHNAN, P. AND BUDIHAL, S.L., 1987, Labrotary methods. NBSS Pub. **14**, Technical Bulletin, National Bureau of soil survey and land use planning, Nagpur.

SARMA, V.A.K., BORDOLI, P.K., BARUAH, T.C., DAS, K.N. AND BORAH, N., 1997, Physico-Chemical characteristics of two soils (Alfisols and Inceptisols) from different command areas of Assam. *J. Indian Soc. Soil Sci.*, **45**(4): 709-712.

SARMA, V.A.K., KRISHNAN, P. AND BUDIHAL, S.L., 1987, Labrotary methods, NBSS Publn. No. **14**, Tech. Bull., NBSS and LUP, Nagpur, India.

SATHISHA G.C., 1991, physical and chemical characteristics of two soils different agricultural situation in dhakshina Kannada district of Karnataka. M. Sc. (Ag) thesis, university of agricultural sciences, Bangalore.

SATHISHA G.C., AND BADRINATH, M.S., 1994, Characterization of soils of western ghats in dakshina Kannada district, Karnataka. *Agropedology*, **4**: 45-48.

SEN, T.K., DUBEY, P.N. AND CHAMUAH, G.S., 1997, Characteristics and Classification of some soils of Barak valley in Assam. *J. Indian Soc. Soil Sci.*, **44**(3): 470-475.

SEN, T.K., NAYAK, D.C., MAJI, A.K. AND CHAMUAH, G.C., 1993, Pedogenic characteristics of some red soils of Manipur. NBSS publ., **37**: P.62.

SHARADA, N., 2011. Strategies for arresting land degradation in India (SAARC), p. 6-8

SHARMA, S.P., SHARMA, P.D. AND MINHAS, R.S., 1993, Characterization of soam river valley in lower shiwaliks of Himachal Pradesh. I hill soils. *J. Indian Soc. Soil Sci.*, **38**(3): 714-719.

SHARMA, S.P., SHARMA, P.K AND TRIPATHI, B.R., 1990, Formation of acidity in some acid soils of India. *J. Indian Soc. Soil Sci.*, **41**(2): 326-330.

SHARMA, S.S., TOTAWAT, K.L. AND SHYAMPURA, R.L., 1996, Characterization and Classification of soils in a toposequence over basaltic terrain. *J. Indian Soc. Soil Sci.*, **44**(3): 470-475.

SHIVAPRASAD, C. R., REDDY, R.S., SEGHAL, J. AND VELAYUTHAM, M., 1998, soils of Karnataka for optimizing land use. National Bureau of Soil Survey and Land Use Planning, Nagpur, publ. **47** p.15.

SIDHU, G.S., RANA, K.P.C., LAL, TARSEM, MAHAPATRA, S.K., VERMA, T.P. AND RAO, R.V.S., 2007, Soils of Himachal Pradesh: Land capability classification and assessment of soil degradation status for suggested land use. *J. Indian Soc. Soil sci.*, **55**: 335-339.

SINGH, O.P., DATTA, B. AND RAO, C.N., 1991, Pedochemical characterization and genisis of soils in relation to altitude in mizoram. *J. Indian Soc. Soil Sci.*, **39**: 739-750.

SINGH, R.N., DIWAKAR, D.P.S. AND SINGH, A.K., 1993, Nature of acidity development on granite gneiss and mahananda alluvium. *J. Indian Soc. Soil Sci.*, **41**(2): 29-32.

SITANGGANG, MASRI, RAO, V.S., AHMED, NAYAN AND MAHAPATRA, S.K., 2006, Characterization and Classification of soils in watershed area of Shikolpur, Gurgaon district, Haryana. *J. Indian Soc. Soil Sci.*, **54**:106-110.

SIVASANKARAN, K., MITHYANTHA, M.S., NATESAN, S. AND SUBBRAYAPPA, C.T., 1993, Physico-Chemical properties and nutrient management of red and laterite soils under plantation crops in southern India. NBSS AND LUP, Nagpur, Publ., **37**, P.280.

SRINIVASAN., 2009, Characterization and classification of cashew growing soils of Karnataka using remote sensing technique. M.Sc (Agri) Thesis, University of agricultural sciences, Banglore.

SUVANA., 2012, Study of Variability for Assessment of soil Quality in selected Agro-Ecosystem of Southern Karnataka. M.Sc (Agri) Thesis, University of agricultural sciences, Banglore.

TAMGADGE, D.B., GAIKAWAD, S.T., GAJBHIYE, K.S. AND GAIKAWAD, M.S., 2000, Soil land form relationship of granite/gneissic terrain in Deccan Plateau, Satpura range, Madhya Pradesh. *J. Indian soc. Soil sci.*, **33**: 272-280.

THORNTHWAITE, C.W. AND MATHER, J.R., 1955, The water balance publication in Climatology (8) 1 Drexel Institute of

Technology, Laboratory of Climatology, centerten, New Jersey, Us, 10p.

VELAYUTHAM, M., MANDAL, D.K., CHAMPA, M. AND SEHGAL, J., 1999, Agro-ecological subregions of India. NBSS Pub.**35**: 340.

WAKLEY AND BLACK, C.A., 1934, An examination of digestion method for determining organic carbon in soil, effect of variations in digestion conditions and of inorganic soil constituents, *soil.sci.* **63**: 251-263.

WALIA, C. S. AND RAO, Y. S., 1996, Genesis, characterisitation and taxonomic classification of some red soils of Bundelkhand region of UP. *J. Indian Soc. Soil Sci.*, **44**(3): 476-581.

WALIA, C. S. AND RAO, Y. S., 1997, Genesis, characterisitation and taxonomic classification of some red soils of Bundelkhand region of UP. *J. Indian Soc. Soil Sci.*, **44**(3): 476-581.

WALIA, C.S. AND CHAMUAH, G.S., 1988, Influence of topography on cantery soils in old flood plain Assam. *J. Indian Soc. Soil Sci.*, **44**(3): 476-581.

YASSER, M. AYAD., 2005, Remote sensing and GIS in modeling visual landscape change: a case study of the northwestern arid coast of Egypt. Landscape and Urban Planning, **73**: 307–325.

APPENDIX 1

Soil climatic water balance of Sullya

Rainfall	PET	1/2 PET	AET
2.9	30.7	15.4	12.6
2.1	30.7	15.4	10.4
0.0	30.7	15.4	7.4
0.0	30.7	15.4	5.9
0.5	32.6	16.3	5.6
9.1	34.0	17.0	12.3
2.5	34.0	17.0	5.9
6.1	34.0	17.0	8.6
4.4	35.7	17.9	6.7
10.8	37.0	18.5	12.4
6.4	37.0	18.5	7.9
16.1	37.0	18.5	17.0
17.0	36.9	18.5	17.7
11.1	35.9	18.0	11.9
20.2	35.9	18.0	20.6
17.1	35.9	18.0	17.6
26.2	35.9	18.0	26.4
30.1	32.4	16.2	30.1
28.4	31.8	15.9	28.5
32.2	31.8	15.9	31.8
28.7	31.8	15.9	28.8
69.9	27.8	13.9	27.8
133.8	22.4	11.2	22.4
210.1	22.4	11.2	22.4
240.9	22.4	11.2	22.4
256.8	22.1	11.1	22.1
199.6	20.5	10.3	20.5
237.1	20.5	10.3	20.5

252.6	20.5	10.3	20.5
257.5	20.5	10.3	20.5
247.0	21.2	10.6	21.2
196.5	21.5	10.8	21.5
206.3	21.5	10.8	21.5
165.6	21.5	10.8	21.5
109.2	22.0	11.0	22.0
90.8	23.3	11.7	23.3
66.5	23.3	11.7	23.3
52.9	23.3	11.7	23.3
63.2	23.3	11.7	23.3
75.9	24.6	12.3	24.6
71.3	24.6	12.3	24.6
51.5	24.6	12.3	24.6
59.5	24.6	12.3	24.6
44.5	26.0	13.0	26.0
41.8	27.1	13.6	27.1
23.9	27.1	13.6	27.1
11.3	27.1	13.6	25.9
2.6	27.6	13.8	22.9
3.2	28.9	14.5	20.8
4.0	28.9	14.5	18.5
1.0	28.9	14.5	14.5
7.9	28.9	14.5	16.6

APPENDIX 2

Soil climatic water balance of Beltangadi

Week	Rainfall	PET	1/2 PET	AET
1	0.2	30.7	15.4	6.5
2	2.3	30.7	15.4	6.7
3	1.1	30.7	15.4	4.5
4	0.0	30.7	15.4	2.6
5	0.0	32.6	16.3	2.0
6	13.2	34.0	17.0	14.2
7	2.6	34.0	17.0	3.8
8	6.8	34.0	17.0	7.5
9	5.2	35.7	17.9	5.8
10	6.2	37.0	18.5	6.7
11	9.3	37.0	18.5	9.6
12	16.9	37.0	18.5	17.1
13	13.0	36.9	18.5	13.2
14	22.0	35.9	18.0	22.1
15	22.7	35.9	18.0	22.7
16	16.4	35.9	18.0	16.5
17	15.6	35.9	18.0	15.7
18	16.6	32.4	16.2	16.6
19	18.7	31.8	15.9	18.8
20	29.6	31.8	15.9	29.6
21	35.8	31.8	15.9	31.8
22	78.6	27.8	13.9	27.8
23	160.7	22.4	11.2	22.4
24	258.0	22.4	11.2	22.4
25	279.2	22.4	11.2	22.4
26	304.7	22.1	11.1	22.1
27	269.2	20.5	10.3	20.5
28	296.8	20.5	10.3	20.5

29	330.0	20.5	10.3	20.5
30	295.2	20.5	10.3	20.5
31	281.1	21.2	10.6	21.2
32	275.7	21.5	10.8	21.5
33	260.9	21.5	10.8	21.5
34	200.2	21.5	10.8	21.5
35	126.2	22.0	11.0	22.0
36	115.2	23.3	11.7	23.3
37	93.6	23.3	11.7	23.3
38	67.9	23.3	11.7	23.3
39	81.4	23.3	11.7	23.3
40	96.3	24.6	12.3	24.6
41	69.9	24.6	12.3	24.6
42	53.6	24.6	12.3	24.6
43	52.8	24.6	12.3	24.6
44	41.2	26.0	13.0	26.0
45	36.3	27.1	13.6	27.1
46	33.2	27.1	13.6	27.1
47	15.6	27.1	13.6	26.5
48	1.0	27.6	13.8	21.8
49	4.3	28.9	14.5	19.2
50	2.5	28.9	14.5	14.9
51	1.7	28.9	14.5	11.4
52	2.6	28.9	14.5	9.9

APPENDIX 3

Soil climatic water balance of Kollur

WEEK	Rainfall	PET	1/2 PET	AE	FC	PPE	APWL	ST	DS	MI
1	0.0	31.6	15.8	3.3	101.0	-31.6	-245.0	8.9	-3.3	10.4
2	0.4	31.6	15.8	2.7	101.0	-31.2	-276.2	6.6	-2.3	8.5
3	0.0	31.6	15.8	1.8	101.0	-31.6	-307.8	4.8	-1.8	5.7
4	0.0	31.6	15.8	1.3	101.0	-31.6	-339.4	3.5	-1.3	4.1
5	0.7	31.7	15.9	1.6	101.0	-31.0	-370.4	2.6	-0.9	5.0
6	0.0	31.8	15.9	0.7	101.0	-31.8	-402.2	1.9	-0.7	2.2
7	0.0	31.8	15.9	0.5	101.0	-31.8	-434.0	1.4	-0.5	1.6
8	0.0	31.8	15.9	0.4	101.0	-31.8	-465.8	1.0	-0.4	1.3
9	0.0	33.2	16.6	0.3	101.0	-33.2	-499.0	0.7	-0.3	0.9
10	0.0	34.3	17.2	0.2	101.0	-34.3	-533.3	0.5	-0.2	0.6
11	0.0	34.3	17.2	0.1	101.0	-34.3	-567.6	0.4	-0.1	0.3
12	0.6	34.3	17.2	0.7	101.0	-33.7	-601.3	0.3	-0.1	2.0
13	0.7	34.8	17.4	0.8	101.0	-34.1	-635.4	0.2	-0.1	2.3
14	3.2	37.3	18.7	3.3	101.0	-34.1	-669.5	0.1	-0.1	8.8
15	7.4	37.3	18.7	7.4	101.0	-29.9	-699.4	0.1	0.0	19.8
16	1.5	37.3	18.7	1.5	101.0	-35.8	-735.2	0.1	0.0	4.0
17	3.0	37.3	18.7	3.1	101.0	-34.3	-769.5	0.0	-0.1	8.3
18	13.7	37.8	18.9	13.7	101.0	-24.1	-793.6	0.0	0.0	36.2
19	16.7	37.9	19.0	16.7	101.0	-21.2	-814.8	0.0	0.0	44.1
20	33.2	37.9	19.0	33.2	101.0	-4.7	-819.5	0.0	0.0	87.6
21	48.4	37.9	19.0	37.9	101.0	10.5	-228.6	10.5	10.5	100.0
22	67.8	36.5	18.3	36.5	101.0	31.3	-89.1	41.8	31.3	100.0
23	227.2	34.5	17.3	34.5	101.0	192.7	0.0	101.0	59.2	100.0
24	296.7	34.5	17.3	34.5	101.0	262.2	0.0	101.0	0.0	100.0
25	230.5	34.5	17.3	34.5	101.0	196.0	0.0	101.0	0.0	100.0
26	270.5	33.8	16.9	33.8	101.0	236.7	0.0	101.0	0.0	100.0
27	226.1	29.6	14.8	29.6	101.0	196.5	0.0	101.0	0.0	100.0
28	286.2	29.6	14.8	29.6	101.0	256.6	0.0	101.0	0.0	100.0
29	268.6	29.6	14.8	29.6	101.0	239.0	0.0	101.0	0.0	100.0
30	290.5	29.6	14.8	29.6	101.0	260.9	0.0	101.0	0.0	100.0
31	204.6	29.4	14.7	29.4	101.0	175.2	0.0	101.0	0.0	100.0

32	231.4	29.4	14.7	29.4	101.0	202.0	0.0	101.0	0.0	100.0
33	253.6	29.4	14.7	29.4	101.0	224.2	0.0	101.0	0.0	100.0
34	198.6	29.4	14.7	29.4	101.0	169.2	0.0	101.0	0.0	100.0
35	131.2	30.4	15.2	30.4	101.0	100.8	0.0	101.0	0.0	100.0
36	89.9	33.1	16.6	33.1	101.0	56.8	0.0	101.0	0.0	100.0
37	61.4	33.1	16.6	33.1	101.0	28.3	0.0	101.0	0.0	100.0
38	58.6	33.1	16.6	33.1	101.0	25.5	0.0	101.0	0.0	100.0
39	71.7	33.1	16.6	33.1	101.0	38.6	0.0	101.0	0.0	100.0
40	80.6	32.1	16.1	32.1	101.0	48.5	0.0	101.0	0.0	100.0
41	33.1	32.1	16.1	32.1	101.0	1.0	0.0	101.0	0.0	100.0
42	17.9	32.1	16.1	31.1	101.0	-14.2	-14.2	87.8	-13.2	96.9
43	25.5	32.1	16.1	31.1	101.0	-6.6	-20.8	82.2	-5.6	96.9
44	22.5	31.9	16.0	29.8	101.0	-9.4	-30.2	74.9	-7.3	93.4
45	21.7	31.7	15.9	28.8	101.0	-10.0	-40.2	67.8	-7.1	90.9
46	23.8	31.7	15.9	28.9	101.0	-7.9	-48.1	62.7	-5.1	91.2
47	5.7	31.7	15.9	19.9	101.0	-26.0	-74.1	48.5	-14.2	62.8
48	0.6	31.6	15.8	13.4	101.0	-31.0	-105.1	35.7	-12.8	42.4
49	7.9	31.2	15.6	15.3	101.0	-23.3	-128.4	28.3	-7.4	49.0
50	3.0	31.2	15.6	9.9	101.0	-28.2	-156.6	21.4	-6.9	31.7
51	2.5	31.2	15.6	7.8	101.0	-28.7	-185.3	16.1	-5.3	25.0
52	3.1	31.2	15.6	7.0	101.0	-28.1	-213.4	12.2	-3.9	22.4

APPENDIX 4

Soil climatic water balance of Molahalli

WEEK	Rainfall	PET	1/2 PET	AE	FC	PPE	APWL	ST	DS	MI
1	0.0	31.6	15.8	0.7	60.0	-31.6	-244.7	1.0	-0.7	2.2
2	0.1	31.6	15.8	0.5	60.0	-31.5	-276.2	0.6	-0.4	1.6
3	0.6	31.6	15.8	0.8	60.0	-31.0	-307.2	0.4	-0.2	2.5
4	0.0	31.6	15.8	0.2	60.0	-31.6	-338.8	0.2	-0.2	0.6
5	0.8	31.7	15.9	0.9	60.0	-30.9	-369.7	0.1	0.1	2.8
6	0.4	31.8	15.9	0.4	60.0	-31.4	-401.1	0.1	0.0	1.3
7	0.8	31.8	15.9	0.9	60.0	-31.0	-432.1	0.0	0.1	2.8
8	0.0	31.8	15.9	0.0	60.0	-31.8	-463.9	0.0	0.0	0.0
9	0.0	33.2	16.6	0.0	60.0	-33.2	-497.1	0.0	0.0	0.0
10	2.1	34.3	17.2	2.1	60.0	-32.2	-529.3	0.0	0.0	6.1
11	0.1	34.3	17.2	0.1	60.0	-34.2	-563.5	0.0	0.0	0.3
12	0.5	34.3	17.2	0.5	60.0	-33.8	-597.3	0.0	0.0	1.5
13	1.3	34.8	17.4	1.3	60.0	-33.5	-630.8	0.0	0.0	3.7
14	5.5	37.3	18.7	5.5	60.0	-31.8	-662.6	0.0	0.0	14.7
15	4.0	37.3	18.7	4.0	60.0	-33.3	-695.9	0.0	0.0	10.7
16	4.8	37.3	18.7	4.8	60.0	-32.5	-728.4	0.0	0.0	12.9
17	3.7	37.3	18.7	3.7	60.0	-33.6	-762.0	0.0	0.0	9.9
18	7.0	37.8	18.9	7.0	60.0	-30.8	-792.8	0.0	0.0	18.5
19	20.6	37.9	19.0	20.6	60.0	-17.3	-810.1	0.0	0.0	54.4
20	27.8	37.9	19.0	27.8	60.0	-10.1	-820.2	0.0	0.0	73.4
21	42.1	37.9	19.0	37.9	60.0	4.2	-159.6	4.2	4.2	100.0
22	81.1	36.5	18.3	36.5	60.0	44.6	-12.4	48.8	44.6	100.0
23	231.9	34.5	17.3	34.5	60.0	197.4	0.0	60.0	11.2	100.0
24	303.4	34.5	17.3	34.5	60.0	268.9	0.0	60.0	0.0	100.0
25	251.0	34.5	17.3	34.5	60.0	216.5	0.0	60.0	0.0	100.0
26	293.3	33.8	16.9	33.8	60.0	259.5	0.0	60.0	0.0	100.0
27	221.5	29.6	14.8	29.6	60.0	191.9	0.0	60.0	0.0	100.0
28	287.5	29.6	14.8	29.6	60.0	257.9	0.0	60.0	0.0	100.0
29	267.5	29.6	14.8	29.6	60.0	237.9	0.0	60.0	0.0	100.0
30	261.4	29.6	14.8	29.6	60.0	231.8	0.0	60.0	0.0	100.0
31	223.7	29.4	14.7	29.4	60.0	194.3	0.0	60.0	0.0	100.0
32	234.9	29.4	14.7	29.4	60.0	205.5	0.0	60.0	0.0	100.0

33	213.6	29.4	14.7	29.4	60.0	184.2	0.0	60.0	0.0	100.0
34	170.7	29.4	14.7	29.4	60.0	141.3	0.0	60.0	0.0	100.0
35	114.1	30.4	15.2	30.4	60.0	83.7	0.0	60.0	0.0	100.0
36	84.8	33.1	16.6	33.1	60.0	51.7	0.0	60.0	0.0	100.0
37	63.9	33.1	16.6	33.1	60.0	30.8	0.0	60.0	0.0	100.0
38	62.0	33.1	16.6	33.1	60.0	28.9	0.0	60.0	0.0	100.0
39	57.0	33.1	16.6	33.1	60.0	23.9	0.0	60.0	0.0	100.0
40	68.0	32.1	16.1	32.1	60.0	35.9	0.0	60.0	0.0	100.0
41	58.2	32.1	16.1	32.1	60.0	26.1	0.0	60.0	0.0	100.0
42	22.0	32.1	16.1	31.3	60.0	-10.1	-10.1	50.7	-9.3	97.5
43	25.0	32.1	16.1	30.7	60.0	-7.1	-17.2	45.0	-5.7	95.6
44	22.6	31.9	16.0	29.0	60.0	-9.3	-26.5	38.6	-6.4	90.9
45	24.0	31.7	15.9	28.7	60.0	-7.7	-34.2	33.9	-4.7	90.5
46	18.4	31.7	15.9	25.1	60.0	-13.3	-47.5	27.2	-6.7	79.2
47	11.3	31.7	15.9	19.2	60.0	-20.4	-67.9	19.3	-7.9	60.6
48	1.0	31.6	15.8	8.7	60.0	-30.6	-98.5	11.6	-7.7	27.5
49	7.4	31.2	15.6	11.2	60.0	-23.8	-122.3	7.8	-3.8	35.9
50	0.8	31.2	15.6	3.9	60.0	-30.4	-152.7	4.7	-3.1	12.5
51	1.8	31.2	15.6	3.6	60.0	-29.4	-182.1	2.9	-1.8	11.5
52	0.2	31.2	15.6	1.4	60.0	-31.0	-213.1	1.7	-1.2	4.5

APPENDIX 4

Soil climatic water balance of Beltangadi

Week	Rainfall	PET	1/2 PET	AET
1	0.2	30.7	15.4	6.5
2	2.3	30.7	15.4	6.7
3	1.1	30.7	15.4	4.5
4	0.0	30.7	15.4	2.6
5	0.0	32.6	16.3	2.0
6	13.2	34.0	17.0	14.2
7	2.6	34.0	17.0	3.8
8	6.8	34.0	17.0	7.5
9	5.2	35.7	17.9	5.8
10	6.2	37.0	18.5	6.7
11	9.3	37.0	18.5	9.6
12	16.9	37.0	18.5	17.1
13	13.0	36.9	18.5	13.2
14	22.0	35.9	18.0	22.1
15	22.7	35.9	18.0	22.7
16	16.4	35.9	18.0	16.5
17	15.6	35.9	18.0	15.7
18	16.6	32.4	16.2	16.6
19	18.7	31.8	15.9	18.8
20	29.6	31.8	15.9	29.6
21	35.8	31.8	15.9	31.8
22	78.6	27.8	13.9	27.8
23	160.7	22.4	11.2	22.4
24	258.0	22.4	11.2	22.4
25	279.2	22.4	11.2	22.4
26	304.7	22.1	11.1	22.1
27	269.2	20.5	10.3	20.5
28	296.8	20.5	10.3	20.5

29	330.0	20.5	10.3	20.5
30	295.2	20.5	10.3	20.5
31	281.1	21.2	10.6	21.2
32	275.7	21.5	10.8	21.5
33	260.9	21.5	10.8	21.5
34	200.2	21.5	10.8	21.5
35	126.2	22.0	11.0	22.0
36	115.2	23.3	11.7	23.3
37	93.6	23.3	11.7	23.3
38	67.9	23.3	11.7	23.3
39	81.4	23.3	11.7	23.3
40	96.3	24.6	12.3	24.6
41	69.9	24.6	12.3	24.6
42	53.6	24.6	12.3	24.6
43	52.8	24.6	12.3	24.6
44	41.2	26.0	13.0	26.0
45	36.3	27.1	13.6	27.1
46	33.2	27.1	13.6	27.1
47	15.6	27.1	13.6	26.5
48	1.0	27.6	13.8	21.8
49	4.3	28.9	14.5	19.2
50	2.5	28.9	14.5	14.9
51	1.7	28.9	14.5	11.4
52	2.6	28.9	14.5	9.9

APPENDIX 5

Soil climatic water balance of Bramhavar

WEEK	Rainfall	PET	1/2 PET	AE	FC	PPE	APWL	ST	DS	MI
1	0.0	31.6	15.8	3.2	101.0	-31.6	-244.7	9.0	-3.2	10.1
2	0.1	31.6	15.8	2.5	101.0	-31.5	-276.2	6.6	-2.4	7.9
3	0.6	31.6	15.8	2.4	101.0	-31.0	-307.2	4.8	-1.8	7.6
4	0.0	31.6	15.8	1.3	101.0	-31.6	-338.8	3.5	-1.3	4.1
5	0.8	31.7	15.9	1.7	101.0	-30.9	-369.7	2.6	-0.9	5.4
6	0.4	31.8	15.9	1.1	101.0	-31.4	-401.1	1.9	-0.7	3.5
7	0.8	31.8	15.9	1.3	101.0	-31.0	-432.1	1.4	-0.5	4.1
8	0.0	31.8	15.9	0.4	101.0	-31.8	-463.9	1.0	-0.4	1.3
9	0.0	33.2	16.6	0.3	101.0	-33.2	-497.1	0.7	-0.3	0.9
10	2.1	34.3	17.2	2.3	101.0	-32.2	-529.3	0.5	-0.2	6.7
11	0.1	34.3	17.2	0.2	101.0	-34.2	-563.5	0.4	-0.1	0.6
12	0.5	34.3	17.2	0.6	101.0	-33.8	-597.3	0.3	-0.1	1.7
13	1.3	34.8	17.4	1.4	101.0	-33.5	-630.8	0.2	-0.1	4.0
14	5.5	37.3	18.7	5.6	101.0	-31.8	-662.6	0.1	-0.1	15.0
15	4.0	37.3	18.7	4.0	101.0	-33.3	-695.9	0.1	0.0	10.7
16	4.8	37.3	18.7	4.8	101.0	-32.5	-728.4	0.1	0.0	12.9
17	3.7	37.3	18.7	3.7	101.0	-33.6	-762.0	0.1	0.0	9.9
18	7.0	37.8	18.9	7.1	101.0	-30.8	-792.8	0.0	-0.1	18.8
19	20.6	37.9	19.0	20.6	101.0	-17.3	-810.1	0.0	0.0	54.4
20	27.8	37.9	19.0	27.8	101.0	-10.1	-820.2	0.0	0.0	73.4
21	42.1	37.9	19.0	37.9	101.0	4.2	-321.2	4.2	4.2	100.0
22	81.1	36.5	18.3	36.5	101.0	44.6	-73.5	48.8	44.6	100.0
23	231.9	34.5	17.3	34.5	101.0	197.4	0.0	101.0	52.2	100.0
24	303.4	34.5	17.3	34.5	101.0	268.9	0.0	101.0	0.0	100.0
25	251.0	34.5	17.3	34.5	101.0	216.5	0.0	101.0	0.0	100.0
26	293.3	33.8	16.9	33.8	101.0	259.5	0.0	101.0	0.0	100.0
27	221.5	29.6	14.8	29.6	101.0	191.9	0.0	101.0	0.0	100.0
28	287.5	29.6	14.8	29.6	101.0	257.9	0.0	101.0	0.0	100.0
29	267.5	29.6	14.8	29.6	101.0	237.9	0.0	101.0	0.0	100.0
30	261.4	29.6	14.8	29.6	101.0	231.8	0.0	101.0	0.0	100.0

31	223.7	29.4	14.7	29.4	101.0	194.3	0.0	101.0	0.0	100.0
32	234.9	29.4	14.7	29.4	101.0	205.5	0.0	101.0	0.0	100.0
33	213.6	29.4	14.7	29.4	101.0	184.2	0.0	101.0	0.0	100.0
34	170.7	29.4	14.7	29.4	101.0	141.3	0.0	101.0	0.0	100.0
35	114.1	30.4	15.2	30.4	101.0	83.7	0.0	101.0	0.0	100.0
36	84.8	33.1	16.6	33.1	101.0	51.7	0.0	101.0	0.0	100.0
37	63.9	33.1	16.6	33.1	101.0	30.8	0.0	101.0	0.0	100.0
38	62.0	33.1	16.6	33.1	101.0	28.9	0.0	101.0	0.0	100.0
39	57.0	33.1	16.6	33.1	101.0	23.9	0.0	101.0	0.0	100.0
40	68.0	32.1	16.1	32.1	101.0	35.9	0.0	101.0	0.0	100.0
41	58.2	32.1	16.1	32.1	101.0	26.1	0.0	101.0	0.0	100.0
42	22.0	32.1	16.1	31.6	101.0	-10.1	-10.1	91.4	-9.6	98.4
43	25.0	32.1	16.1	31.2	101.0	-7.1	-17.2	85.2	-6.2	97.2
44	22.6	31.9	16.0	30.1	101.0	-9.3	-26.5	77.7	-7.5	94.4
45	24.0	31.7	15.9	29.7	101.0	-7.7	-34.2	72.0	-5.7	93.7
46	18.4	31.7	15.9	27.3	101.0	-13.3	-47.5	63.1	-8.9	86.1
47	11.3	31.7	15.9	22.8	101.0	-20.4	-67.9	51.6	-11.5	71.9
48	1.0	31.6	15.8	14.5	101.0	-30.6	-98.5	38.1	-13.5	45.9
49	7.4	31.2	15.6	15.4	101.0	-23.8	-122.3	30.1	-8.0	49.4
50	0.8	31.2	15.6	8.6	101.0	-30.4	-152.7	22.3	-7.8	27.6
51	1.8	31.2	15.6	7.5	101.0	-29.4	-182.1	16.6	-5.7	24.0
52	0.2	31.2	15.6	4.6	101.0	-31.0	-213.1	12.2	-4.4	14.7

APPENDIX 6

Soil climatic water balance of Murdeshwar

WEEK	Rainfall	PET	1/2 PET	AE	FC	PPE	APWL	ST	DS	MI
1	10.0	23.9	12.0	3.3	101.0	-31.6	-245.0	8.9	-3.3	10.4
2	0.5	23.9	12.0	2.7	101.0	-31.2	-276.2	6.6	-2.3	8.5
3	0.3	23.9	12.0	1.8	101.0	-31.6	-307.8	4.8	-1.8	5.7
4	0.0	23.9	12.0	1.3	101.0	-31.6	-339.4	3.5	-1.3	4.1
5	0.0	26.0	13.0	1.6	101.0	-31.0	-370.4	2.6	-0.9	5.0
6	0.0	27.5	13.8	0.7	101.0	-31.8	-402.2	1.9	-0.7	2.2
7	0.0	27.5	13.8	0.5	101.0	-31.8	-434.0	1.4	-0.5	1.6
8	0.0	27.5	13.8	0.4	101.0	-31.8	-465.8	1.0	-0.4	1.3
9	0.0	30.4	15.2	0.3	101.0	-33.2	-499.0	0.7	-0.3	0.9
10	0.0	32.5	16.3	0.2	101.0	-34.3	-533.3	0.5	-0.2	0.6
11	0.0	32.5	16.3	0.1	101.0	-34.3	-567.6	0.4	-0.1	0.3
12	0.0	32.5	16.3	0.7	101.0	-33.7	-601.3	0.3	-0.1	2.0
13	0.2	32.6	16.3	0.8	101.0	-34.1	-635.4	0.2	-0.1	2.3
14	0.6	32.9	16.5	3.3	101.0	-34.1	-669.5	0.1	-0.1	8.8
15	2.6	32.9	16.5	7.4	101.0	-29.9	-699.4	0.1	0.0	19.8
16	4.3	32.9	16.5	1.5	101.0	-35.8	-735.2	0.1	0.0	4.0
17	1.1	32.9	16.5	3.1	101.0	-34.3	-769.5	0.0	-0.1	8.3
18	29.5	29.5	14.8	13.7	101.0	-24.1	-793.6	0.0	0.0	36.2
19	2.5	28.9	14.5	16.7	101.0	-21.2	-814.8	0.0	0.0	44.1
20	3.5	28.9	14.5	33.2	101.0	-4.7	-819.5	0.0	0.0	87.6
21	26.9	28.9	14.5	37.9	101.0	10.5	-228.6	10.5	10.5	100.0
22	45.9	25.6	12.8	36.5	101.0	31.3	-89.1	41.8	31.3	100.0
23	49.7	21.2	10.6	34.5	101.0	192.7	0.0	101.0	59.2	100.0
24	229.9	21.2	10.6	34.5	101.0	262.2	0.0	101.0	0.0	100.0
25	284.6	21.2	10.6	34.5	101.0	196.0	0.0	101.0	0.0	100.0
26	217.4	20.9	10.5	33.8	101.0	236.7	0.0	101.0	0.0	100.0
27	237.3	18.7	9.4	29.6	101.0	196.5	0.0	101.0	0.0	100.0
28	193.1	18.7	9.4	29.6	101.0	256.6	0.0	101.0	0.0	100.0
29	216.0	18.7	9.4	29.6	101.0	239.0	0.0	101.0	0.0	100.0
30	228.6	18.7	9.4	29.6	101.0	260.9	0.0	101.0	0.0	100.0

31	229.3	19.4	9.7	29.4	101.0	175.2	0.0	101.0	0.0	100.0
32	205.4	19.6	9.8	29.4	101.0	202.0	0.0	101.0	0.0	100.0
33	178.1	19.6	9.8	29.4	101.0	224.2	0.0	101.0	0.0	100.0
34	186.0	19.6	9.8	29.4	101.0	169.2	0.0	101.0	0.0	100.0
35	120.0	20.4	10.2	30.4	101.0	100.8	0.0	101.0	0.0	100.0
36	102.9	22.2	11.1	33.1	101.0	56.8	0.0	101.0	0.0	100.0
37	68.2	22.2	11.1	33.1	101.0	28.3	0.0	101.0	0.0	100.0
38	54.3	22.2	11.1	33.1	101.0	25.5	0.0	101.0	0.0	100.0
39	47.5	22.2	11.1	33.1	101.0	38.6	0.0	101.0	0.0	100.0
40	49.0	22.6	11.3	32.1	101.0	48.5	0.0	101.0	0.0	100.0
41	58.0	22.6	11.3	32.1	101.0	1.0	0.0	101.0	0.0	100.0
42	46.6	22.6	11.3	31.1	101.0	-14.2	-14.2	87.8	-13.2	96.9
43	25.0	22.6	11.3	31.1	101.0	-6.6	-20.8	82.2	-5.6	96.9
44	26.9	23.7	11.9	29.8	101.0	-9.4	-30.2	74.9	-7.3	93.4
45	16.4	24.5	12.3	28.8	101.0	-10.0	-40.2	67.8	-7.1	90.9
46	11.4	24.5	12.3	28.9	101.0	-7.9	-48.1	62.7	-5.1	91.2
47	8.1	24.5	12.3	19.9	101.0	-26.0	-74.1	48.5	-14.2	62.8
48	2.5	24.1	12.1	13.4	101.0	-31.0	-105.1	35.7	-12.8	42.4
49	0.8	23.3	11.7	15.3	101.0	-23.3	-128.4	28.3	-7.4	49.0
50	6.0	23.3	11.7	9.9	101.0	-28.2	-156.6	21.4	-6.9	31.7
51	2.4	23.3	11.7	7.8	101.0	-28.7	-185.3	16.1	-5.3	25.0
52	1.2	23.3	11.7	7.0	101.0	-28.1	-213.4	12.2	-3.9	22.4

APPENDIX 7

Soil climatic water balance of Ullal

WEEK	Rainfall	PET	1/2 PET	AE	FC	PPE	APWL	ST	DS	MI
1	0.1	30.7	15.4	7.6	119.0	-30.6	-182.7	25.6	-7.5	24.8
2	2.3	30.7	15.4	7.7	119.0	-28.4	-211.1	20.2	-5.4	25.1
3	2.5	30.7	15.4	6.8	119.0	-28.2	-239.3	15.9	-4.3	22.1
4	0.0	30.7	15.4	3.6	119.0	-30.7	-270.0	12.3	-3.6	11.7
5	0.0	32.6	16.3	2.9	119.0	-32.6	-302.6	9.4	-2.9	8.9
6	0.0	34.0	17.0	2.4	119.0	-34.0	-336.6	7.0	-2.4	7.1
7	0.0	34.0	17.0	1.7	119.0	-34.0	-370.6	5.3	-1.7	5.0
8	0.0	34.0	17.0	1.3	119.0	-34.0	-404.6	4.0	-1.3	3.8
9	0.0	35.7	17.9	1.1	119.0	-35.7	-440.3	2.9	-1.1	3.1
10	1.4	37.0	18.5	2.1	119.0	-35.6	-475.9	2.2	-0.7	5.7
11	1.3	37.0	18.5	1.9	119.0	-35.7	-511.6	1.6	-0.6	5.1
12	0.0	37.0	18.5	0.4	119.0	-37.0	-548.6	1.2	-0.4	1.1
13	4.9	36.9	18.5	5.2	119.0	-32.0	-580.6	0.9	-0.3	14.1
14	4.3	35.9	18.0	4.5	119.0	-31.6	-612.2	0.7	-0.2	12.5
15	7.1	35.9	18.0	7.3	119.0	-28.8	-641.0	0.5	-0.2	20.3
16	6.5	35.9	18.0	6.6	119.0	-29.4	-670.4	0.4	-0.1	18.4
17	5.8	35.9	18.0	5.9	119.0	-30.1	-700.5	0.3	-0.1	16.4
18	10.5	32.4	16.2	10.5	119.0	-21.9	-722.4	0.3	0.0	32.4
19	22.7	31.8	15.9	22.7	119.0	-9.1	-731.5	0.3	0.0	71.4
20	28.8	31.8	15.9	28.9	119.0	-3.0	-734.5	0.2	-0.1	90.9
21	57.4	31.8	15.9	31.8	119.0	25.6	-181.9	25.8	25.6	100.0
22	78.0	27.8	13.9	27.8	119.0	50.2	-53.4	76.0	50.2	100.0
23	276.8	22.4	11.2	22.4	119.0	254.4	0.0	119.0	43.0	100.0
24	278.2	22.4	11.2	22.4	119.0	255.8	0.0	119.0	0.0	100.0
25	235.5	22.4	11.2	22.4	119.0	213.1	0.0	119.0	0.0	100.0
26	269.0	22.1	11.1	22.1	119.0	246.9	0.0	119.0	0.0	100.0
27	193.1	20.5	10.3	20.5	119.0	172.6	0.0	119.0	0.0	100.0
28	262.0	20.5	10.3	20.5	119.0	241.5	0.0	119.0	0.0	100.0
29	221.2	20.5	10.3	20.5	119.0	200.7	0.0	119.0	0.0	100.0
30	232.5	20.5	10.3	20.5	119.0	212.0	0.0	119.0	0.0	100.0
31	203.7	21.2	10.6	21.2	119.0	182.5	0.0	119.0	0.0	100.0

32	184.2	21.5	10.8	21.5	119.0	162.7	0.0	119.0	0.0	100.0
33	188.1	21.5	10.8	21.5	119.0	166.6	0.0	119.0	0.0	100.0
34	142.7	21.5	10.8	21.5	119.0	121.2	0.0	119.0	0.0	100.0
35	98.4	22.0	11.0	22.0	119.0	76.4	0.0	119.0	0.0	100.0
36	63.0	23.3	11.7	23.3	119.0	39.7	0.0	119.0	0.0	100.0
37	73.2	23.3	11.7	23.3	119.0	49.9	0.0	119.0	0.0	100.0
38	60.1	23.3	11.7	23.3	119.0	36.8	0.0	119.0	0.0	100.0
39	53.5	23.3	11.7	23.3	119.0	30.2	0.0	119.0	0.0	100.0
40	84.9	24.6	12.3	24.6	119.0	60.3	0.0	119.0	0.0	100.0
41	53.7	24.6	12.3	24.6	119.0	29.1	0.0	119.0	0.0	100.0
42	36.3	24.6	12.3	24.6	119.0	11.7	0.0	119.0	0.0	100.0
43	45.1	24.6	12.3	24.6	119.0	20.5	0.0	119.0	0.0	100.0
44	23.2	26.0	13.0	26.0	119.0	-2.8	-2.8	116.2	-2.8	100.0
45	30.9	27.1	13.6	27.1	119.0	3.8	0.0	119.0	2.8	100.0
46	31.4	27.1	13.6	27.1	119.0	4.3	0.0	119.0	0.0	100.0
47	8.4	27.1	13.6	25.7	119.0	-18.7	-18.7	101.7	-17.3	94.8
48	0.7	27.6	13.8	21.3	119.0	-26.9	-45.6	81.1	-20.6	77.2
49	1.4	28.9	14.5	18.1	119.0	-27.5	-73.1	64.4	-16.7	62.6
50	6.1	28.9	14.5	17.3	119.0	-22.8	-95.9	53.2	-11.2	59.9
51	0.2	28.9	14.5	11.6	119.0	-28.7	-124.6	41.8	-11.4	40.1
52	1.4	28.9	14.5	10.1	119.0	-27.5	-152.1	33.1	-8.7	34.9

APPENDIX-8

List of abbreviations

Abbreviation	Meaning
1. ha	Hectare
2. kg	Kilogram
3. mm	Millimeter
4. º	Degree (latitude and longitude)
5. ºS, ºN, ºE	Degree latitude (ºS,ºN) Degrees of longitude (ºE)
6. ′	Minutes
7. ″	Seconds
8. %	Per cent
9. *M*	Molar
10. cmol(+) kg^{-1}	Centimoles per kilogram
11. CEC	Cation exchange capacity
12. O.C	Organic carbon
13. pH	Soil reaction (negative logarithm of hydrogen ion concentration)
14. EC	Electrical conductivity
15. ECEC	Effective cation exchange capacity
16. PET	Potential evapotranspiration
17. AET	Actual evapotranspiration
18. ½ PET	Half of potential evapotranspiration
19. BS	Base saturation

20. Al	Aluminium
21. MSL	Mean sea level
22. TGA	Total geographical area
23. USDA	United state Department Agriculture
24. FAO	Food and Agricultural Organization
25. IMD	Indian Meterology Department
26. *et al*	And Co-Worker
27. Vol. %	Volume per cent
28. cm	Centimeter
29. M. ha	Million hectare
30. KF	Potassium fluride