CHARACTERIZATION OF BLACK SOILS UNDER RAMTHAL MICRO IRRIGATION PROJECT FOR SALINITY PARAMETERS

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By

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CERTIFICATE

This is to certify that, the thesis entitled "**CHARACTERIZATION OF BLACK SOILS UNDER RAMTHAL MICRO IRRIGATION PROJECT FOR SALINITY PARAMETERS**" submitted by **Ms. LAKSHMI P. D. ID.NO. UHS16PGM786** for the award of the degree of **MASTER OF SCIENCE (HORTICULTURE) in SOIL SCIENCE AND AGRICULTURAL CHEMISTRY** of the University of Horticultural Sciences, Bagalkot, is a record of research work carried out by her during the period of her study in this university under my guidance and supervision. The data of this thesis has not previously formed the basis for the award of any degree, diploma, associateship, fellowship or other similar titles.

June, 2018
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Affectionately Dedicated to

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1. INTRODUCTION

Geology, climate, topography and human activities are some of the important factors responsible for accumulation of salts in soil. Geological formations consisting of salt rich sediments and primary minerals which are the ultimate source of most of the salts in soil, primarily originate as a result of weathering. At the same time climatic factors such as high temperature, low precipitation and high evaporation can increase the concentration of salts in soils, surface and ground water and contribute to salinity problems.

The area Bagalkot district is categorized under arid and semi-arid agro-ecological region. The geology of the district possess lime stone in North-Western parts while, sandstone dominates in the South Eastern parts. The soils derived from easily weatherable lime based parent material associated with aridity are likely to possess more salts (Doddamani, 1994). The groundwaters in deep layers, accumulated over years due to excess usage and they are saline and restrict its utilization for irrigation. Thus, both soils and groundwater exhibit salinity in Bagalkot district. The salts present in soil are likely to get redistributed with irrigation as the salts move from one region to other region.

Black soils comprise mainly of vertisols and their geographically associated soils (vertic intergrades of inceptisols, entisols and alfisols). These are widely distributed across the globe and occupy about 335 M ha (FAO, 1991) of land area of the world (Blokhuis, 1981). They lie between 45° N and 45° S and are abundant in India, Sudan, Australia, Argentina, Kenya and South western USA and Canada. Indian black soils are commonly known as black cotton soils or “Regur” and classified to vertisols and vertic intergrades of other orders. These soils swell on wetting and shrink on drying and become extremely difficult to work and manage. Traditionally, these soils were believed to be confined to the Peninsular region, but research by NBSS and LUP, Nagpur have reported their presence in other parts of the country as well. Shrink-swell soils in India were reported to cover 70.3 M ha. The present revision from available datasets resulted in an increase in area to about 117 M ha. Found to exist outside the basaltic Peninsular region including states like Bihar, West Bengal, Punjab, Assam, Jammu and Kashmir and Kerala.

Latest estimate of the extent of vertisols and their intergrades indicate that area under these soils is 51.3 M ha of which area under vertisols is 26.62 M ha and area under vertic intergrades of entisols (vertic) is 0.20 M ha, inceptisols (vertic) is 23.76 M ha and alfisols (Vertic) is 0.72 M ha (Mandal *et al.,* 2012). These soils are deep to shallow, dark coloured dominated by specific clay mineralogy with unique profile structure. Among the black soils, the deep black soils (vertisols) are generally calcareous, dark in colour with low chroma, high in clay content, low in organic carbon, high CEC and high in shrink-swell potentials due to the presence of large amount of smectitic clay in the fine earth. In general, vertisols occupy lower topographic positions (toe slopes) and sometimes they also occur on comparatively higher positions with stable slopes in association with shallow black soils. The climatic setting of these soils ranges from arid to semi-arid to sub-humid to humid, characterized by hot and dry summer and mild winter intervened by short period of summer monsoonal rainfall.

The results of the frontline demonstrations of the All India Coordinated Project of ICAR showed a large gap in crop yield does exist between the farmer's yield and the achievable yield. This indicates that despite the fact vertisols make up a relatively homogenous major soil group in India, this gap can be due to different pedogenetic processes occurring in vertisols under different climatic environments (Pal *et al.* 2011). Under rain-fed conditions, yield of deep rooted crops in cracking clay soils (vertisols) mostly depend on the amount of rain water that enter the soil profile and the extent to which this water is released during the crop growth. However, the release of soil water during the crop growth is a function not only of the nature and content of clay minerals but also of the nature of exchangeable cations.

In toposequences, the entisols occur in upper topography, structurally they are weak sub-angular blocky and inceptisols in mid topography with moderate to strong sub-angular blocky structure with shiny pressure faces in deeper horizons. The vertisols occupying lower element of topography have normally very thick horizons with strong structure, slickensides close enough to intersect, wedge shaped aggregates (25 cm or more thick within 100 cm) and associated with 30 or more than 30 per cent clay and cracks close and open (0.5 cm) periodically up to 30 cm deep.

Soils are derived from chemical and physical weathering of rocks and other geological and organic materials. Thus, they always contain some soluble inorganic and organic compounds. Rain can also lead to the accumulation of salt over time, although it contains only small amounts of salt. Application of soluble fertilisers and soil amendments, poor quality irrigation water and capillary rise of shallow saline groundwater can all contribute to the salinisation of the soil layers. The particular processes contributing salt, combined with the influence of other climatic and landscape features and the effects of human activities, determine where the salt accumulates in the landscape. Plants also determine where salts accumulate in the vertical horizon of the soil profile. Even though the general assumption is that salt affected soils occur primarily in arid and semiarid climates, these soils are actually found in every climatic zone in every continent except Antartica. All soil types with diverse morphological, physical, chemical and biological properties may be affected by salinity (Rengasamy, 2010).

Crop growth responds to salinity in two phases: a continuous osmotic phase that inhibits the water uptake by plants due to osmotic pressure of saline soil solution lowering its potential energy (water always moving from a higher to lower potential energy levels); and a slower ionic phase when the accumulation of specific ions in the plant over a period of time leads to ion toxicity or ion imbalance. However, the interactions between root-zone environments and plant responses to increased osmotic pressure or specific ion concentrations in the field are complicated by many soil processes such as soil water dynamics, soil structural stability, solubility of compounds in relation to pH and pE (electron concentration related to redox potential) and nutrient and water movement in soil.

The topography influences the movement of salts from higher elevation to lower elevation only when there is enough water to carry the salts from higher topographical region to lower topographical region through surface and also surface flow of water. However, in few conditions when there is no surface flow of water and due to capillary rise the salts are deposited and salts are likely to be higher in case of higher elevation when compared to lower elevation. This is in contrast to the actual situation.

The subsurface drainage, reuse and disposal of drainage waters are relatively new areas of management. The quality of drainage waters largely varies from one region to other regions and locally from one site to other site. In addition, drainage waters from irrigated lands vary in quality with time. The exact composition would, however, depend upon the nature and amount of salts present in the soil profile, and the quality of shallow ground water.

Therefore in order to understand the influence of topography, a study was carried out in a small area to characterize the black soils of Ramthal Micro Irrigation Project area with following objectives

Objectives:

1. Characterization of surface soils for salinity parameters
2. Characterization of soil profiles at different topographic positions for salinity parameters
3. Identification of suitability of soils for different horticultural crops

2. REVIEW OF LITERATURE

Soils are considered as integral part of the landscape and their characteristics is governed by the landforms on which they are formed. Topography, an important soil forming factor, was first identified by Jenny (1941) based on its important role in the gains and losses of matter and energy. Majority of the salt affected soils occur in lower valleys as the salts are transported from ridge areas along with flowing water. Topography influences local and regional microclimates by changing the pattern of precipitation, temperature, solar radiation and relative humidity which in turn determines the salinity. Thus, the type and amounts of salts, its cations/anions, plays an important role in determining the soil chemical and physical properties (Lal and Steward, 1990; Ghassemi *et al.,* 1995). The literature available on the formation, classification, causes, features, management etc are reviewed under different subheadings and presented in this section.

2.1 Salt affected soils

Over 10 per cent of world's land is salt affected. Salt affected soils usually distinguish themselves in having higher concentration of exchangeable sodium and /or higher concentration of electrolytes and poor fertility status, resulting in restricted availability and uptake of nutrients to plants (Szabolcs, 1989). The buildup of salt content might influence the crop production in several ways through changes in the proportion of exchangeable and water soluble cations, soil reaction, physical properties of soil and osmotic and specific ion toxicity effects (Abrol and Fireman, 1977; Seghal, 1981). These changes has an effect on plant roots and soil microbes. Classification of salt affected soil is generally based on pH, electrical conductivity (EC) and exchangeable sodium percentage (ESP).

Salt affected soils are characterized by excessively high levels of water-soluble salts, comprising of chlorides, sulphates, carbonates of calcium, magnesium, sodium, potassium etc (Tanji, 2002).

Salt affected soils are spread in many arid and semi-arid regions of the world and increasingly threatening agricultural expansion and productivity. In 2000, FAO published a report about 831 m ha of land in the world is under soil salinity and alkalinity of which 397 m ha is under alkalinity geology, climate, topography and human activities are some of the important factors responsible for accumulation of salts. Climatic factors like high temperature, low rainfall and high evaporation can increase the concentration of salts (Martinez-Beltran 2005). Geology, climate, topography and human activities also contribute for accumulation of salts and exhibit salinity problems (Abrol *et al.,* 1980)

2.2 Origin and distribution

The secondary salinization refers to the salinization resulting from human activity, (Lal and Steward, 1990) viz. land development and agriculture (Ghassemi *et al.,* 1995). In this type of salinization there is gradual buildup of salt in soil, occurs in irrigated areas, as salt is introduced into the soil with every irrigation. In command areas due to over use of water along with poor water management practices enhances the problem, particularly when there is no sufficient drainage. As the water table rises, salts stored within the profile are carried towards the surface through capillary pores, resulting in salinization.

Soils of arid regions are naturally saline by salt accumulation from weathering of parent materials, deposition from marine salts carried by rain and wind. Sedimentary deposits like sandstone, shale, glacial, gypsum, limestone are the sources of salts (Michael and Paul, 2002).

Secondary salinization has been intensified by change in land use, means changes from agriculture to non-agriculture, dryland crops to irrigated crops etc leads to water table rise Overgrazing or intensive cropping, excessive use of fertilizers, deforestation, impeded natural drainage by construction of roads, canals, embarkments *etc.*, water logging, through seepage, water pollution by industrial effluents are the other salinity causes (Selliah and Pathmarajah, 2003)

Saline soils occur in association with the normal soils of arid and semi-arid regions (Sharma *et al.*, 2004). The salt affected soils are formed by both primary-natural; secondary human activities (Michael and Paul, 2002).

Nearly one billion hectares of agricultural land is affected by salinity and sodicity (Daggar, 2009). According to FAO, over 6 percent of the world land area is affected by either salinity or sodicity. In India Salt affected soils occupy about 10 m ha of land (Bhargava, 1989), which is spread over semi-arid and semi- humid gangetic plains, coastal deltaic and arid regions of the country. In Indo-Gangetic plains, alkali soils are generally confined to areas with mean annual rainfall between 550 and 1000 mm. (Bhargava *et al*., 1976).

2.3 Classification of salt affected soils

Salt-affected soils were first classified as saline, sodic and saline-sodic on the basis of ECe, SAR and pH (Brady and Weil, 2002; Richards, 1954). Saline soils have an ECe (saturated extract) > 4 dS m^{-1} (SAR< 13) and contain Na^{+}, Mg^{2+}, and Ca^{2+} as dominant cations and Cl^{-} and SO_4^{2-} are the dominant anions. In sodic soils, Na^{+} is a major cation on the exchange sites of the soil particles. These soils are characterized by SAR > 13 and EC < 4 dS m^{-1}. Soils with ECe > 4 dS m^{-1} and SAR > 13 are classified as saline-sodic (Richards, 1954; Gupta and Gupta, 1987).

Bhargava (1989) and Chhabra (1996) have grouped salt affected soils occurring in India into following two categories:

1. **Alkali soils:** Soils with pHs more than 8.5, ESP of 15 or more and preponderance of carbonates and bicarbonates of sodium. The ECe is limitless if originating from salts of alkali hydrolysis, otherwise less than 4 dS m^{-1}at 25^{o}C. While, Abrol *et al*. (1980) suggested that pHs of 8.2 is more realistic diagnostic criterion for distinguishing sodic from non-sodic soils.

2. **Saline soils:** Soils having pH is less than 8.5, ESP less than 15 and preponderance of chlorides and sulphates of sodium, calcium and magnesium. The ECe is more than 4 dS m^{-1} at 25 ^{o}C. Composition of salts is dependent on the rainfall of an area. With rainfall around 750 mm, carbonates and bicarbonates are the dominant anions followed by chlorides and sulphates, isohyets of 500-550 mm contained anionic composition of sulphates, chlorides and carbonates + bicarbonates. Below 300 mm isohyets chlorides and sulphates dominate with only traces of carbonates.

2.4 Primary salinization and Secondary salinization

The quality of irrigation water is assessed based on the salt and salt inducing contents, the presence and abundance of micro and macro nutrients, alkalinity, acidity, hardness, trace elements and the amount of suspended solids (Richards, 1954).

Shaha *et al.* (1958) reported that the ESP values exceeded in the saline soils of Rann of Kutch. Although these soils are not submerged by tides, the soils are generally saline with dominance of chlorides and sulfates of sodium, magnesium and calcium.

Mehta *et al.* (1969) studied periodical observation on changes in depth and fluctuation of water table and quality of water was made in Chambal command area of Rajasthan. They observed that water table was raised significantly in large number of wells during the period of monsoon indicating a potential danger of water logging. The quality of well water was also deteriorated in most of the cases.

The use of irrigation water containing predominantly divalent cations caused higher accumulation of salts in sub-surface layers was observed by Gupta and Abichandani (1970). Salt concentration in the soil solutions increased with increasing concentration of leaching solution.

The canal waters in Karnal District caused the salt problem was observed by Kanwar and Seghal (1972) due to higher water table that brought up the salts to the surface which were formerly distributed throughout the profile.

In another study in deltic regions of West Bengal, Bhargava (1989) observed distribution of salts in the entire soil profile due to introduction of sea water. Similar observations with high sodium salts in the Kutch region of Gujarat could be attributed to sea water intrusion into the low lying topographical area.

The effect of seepage on the development of saline and sodic soils in Bhadra project area of Karnataka was studied by Bhadrapur and Rao (1979). They observed that all low land soils were saline-sodic due to seepage from uplands.

Patil *et al*. (1982) reported the canal water seepage on water table fluctuation and salinity development in Mula command. The hydrological parameters were studied along with the piezometric water table fluctuation near the canal. The water table near the canal (50 m) increased by about 20 per cent after three years. EC of the ground water near the canal increased from <1.0 to 2.06 m mhos/cm, indicating the salt accumulation at surface.

Dubey and Sharma (1987) found that occurrence of salt affected soil on coastal and inland areas of Gujarat is due to intrusion of sea water, aridity of the climate, relief, saline ground water and salt bearing sub soil strata.

Bharambe *et al*. (1990) studied the periodical observation on ground water table and quality of waters were made in Jayakwadi command, wherein they reported that water table rose considerably in the command area indicating possibility of water logging in the area. The ground water in the command area was rated as low saline water.

Weathering of rocks and soil forming processes are source of all kinds of soluble salts. All soils contain soluble salts and they are important from the point of plant nutrition. At their higher concentrations, however, influence growth, yield and quality of crops (Lal and Steward, 1990). The extent and type of salts accumulations depend on parent material, climate, topography, drainage, external additions, irrigation methods – quality and quantity of water used etc (Gupta *et al*., 1990). Thus, the native and externally added salts and their redistribution play a significant role in soil salt concentrations.

Srinivasa (1999) in the irrigated areas of Vishweshwaraiah canal tract of Cauvery command they characterized six sodic soil profiles. The ionic composition in case of water soluble cations and anions in the profiles were in the order: $Na^{+} > Ca^{2+} > Mg^{2+} > K^{+}$ and anions were $HCO_3^{-} > Cl^{-} > SO_4^{2-} > CO_3^{2-}$.

Alur (2003) characterized the soils of UKP command in Shahapur and Surpur taluks. The salinity was found even before the introduction of irrigation. The magnitude of salinity was found higher in the low lying valley region compared to high elevated ridges. Natural salinity in the dry tracts were attributed to the aridity (PET > RF), easily weatherable parent material and topography.

The soils of Rajasthan were characterised for physical and chemical properties by Sharma *et al.* (2004). They observed that salt accumulated mostly by weathering of lime and gypsum based parent material. In low lying areas more salts were seen due to movement of salts from upslope areas.

Salt balance of soils can be significantly affected through improper soil and water management, mainly improper management of irrigation schemes, including insufficient water application, insufficient drainage, irrigation at low efficiency or over-irrigation contribute to a high water table, increasing drainage requirements and causing waterlogging and salinity build-up in many irrigation projects of the world (FAO, 2005).

Gebrakidan and Mishra (2005) characterized and classified three toposequence of Amensis sub-catchment of Hirna watershed in western Hararghe region, Ethiopia. The soils in steep were shallow whereas they became deep in topographic lows. They concluded that soils on mountainous landscape were gravelly and eroded particularly on steep slope.

Latif and Ahmed (2009) carried out a survey in the canal irrigated areas of Pakistan. Both soil and ground water samples were collected along the six secondary canals of the main canal. The study showed that groundwater salinity increased from head to lower along the irrigation canals. Similarly, the soil salinity also increased along the canal from head to tail regions. Higher salinity in the soils and groundwater in the tail regions of the command were largely attributed to movement of salts in the subsurface layer by seepage water.

Karche and Pharande (2010) assessed the soil quality degradation due to salinity and sodicity in Mula command area Ahmednagar. Physical and chemical properties of soil varied greatly. The area was affected due to salinity and sodicity in command area. They concluded that soil quality in Mula command was severely degraded in tail region as compared to head and mid region due salinity and sodicity.

Sharma *et al.* (2011) reported that the excess of canal water irrigation and water stagnation was made to accumulate salts due to higher water table and presence of abundant $CO_3^{=}$ and HCO_3^{-} influenced the ionic mobility that enhanced the soil alkalization reported that soils in the central area of irrigation district 110 “Rio verde”, Oaxaco, Mexico are affected by hydrochloric salinity induced by irrigation with well water of moderate salt concentration whose values of EC and SAR identify it as water with slight restriction for irrigation.

The study was conducted to know the relationship between water table and soil degradation in Sharda Sahayak canal command in Barabanki district of U.P. by Verma *et al*. (2012). They noticed that areas which were close to canal were permanently waterlogged. The water table data was correlated with soil data it showed that soil samples near to canal had high pH, SAR and ESP. They found that the problem of sodicity was due to inherent chemical nature of water but developed by capillary action of water in the soil.

In two sub regions in the Malwa region, the water table has been rising, which is creating problems of waterlogging. In the 4 blocks of Abohar to Talwandi Sabo subregion, the water table has gone up from more than 25 meters bgl in 1970s to 5-6 meters bgl in 2003. Just above these blocks, in the 5 blocks from Khuyian Sarwar to Maur, water table rose from 17 meters bgl in 1970s to 5 meters bgl in 2003. The water is saline and unfit for irrigation (Shah *et al.*, 2013).

Jena and Natarajan (2013) assessed the sodicity problem in the part of Cauvery command area of Karnataka. Soil studies indicated waterlogging and presence of numerous white spots in the vicinity of the lowland canal areas. They concluded from this study that surface and sub-surface of lowland condition were sodic, whereas in case of midland and upland condition were non- saline and non-sodic.

Kadu *et al.* (2013) conducted the experiment to characterize and classify the salt affected soils Purna valley in Vidarbha region Maharastra. They characterized eight profiles and observed that because of low hydraulic conductivity, soils were affected severely with drainage problems. They also observed that the soils in lower topographic region possessed low hydraulic conductivity and proned to degradation due to sub soil sodicity resulting in deterioration of soil structure and drainage impairment.

Rasool *et al.* (2014) studied about relationship between soil properties and slope segments of Sallarwullaraha ma watershed in Lidar catchment of Jammu and Kashmir. Physico- chemical properties were analysed for 34 samples. The samples collected from upper slope is mountain summit and two lower category of slope was considered as mid and footslope. They concluded that slope factor is involved in transport and accumulation of solutes resulted in higher pH in depositional area of footslope.

Datta *et al.* (2016) studied the salt affected soils of Rewari district Haryana they collected 77 soil samples from four depths 0-15, 15-30, 30-60, 60-90cm of Rewari district in Haryana state. Physico-chemical analysis indicated that alkalinity and salinity increased with depth. Among cations and anions Na^+ and Cl^- were dominant ions.

The reclamation of saline soils through subsurface drainage technology in Haryana was studied by Raju *et al.* (2016). They identified a techonology with strategy to sustain and enhance the agricultural productivity in waterlogged saline soils. The study concluded that 44.24% reduction in soil salinity, 49.5% reduction in drain water salinity and remarkable reduction of water table depth 35.8%. The study also recorded increase in cropping intensity and significant increase in crop yield.

Veerabhadrappa and Gundlur (2016) studied the effect of long term irrigation on physic-chemical properties of vertisols under Ghataprabha command. Profile samples were collected from irrigated fields (10-15, 15-20, 20-30 and >30) years and from adjacent unirrigated one. The results showed that, the pH, SAR, ESP, EC were highest for field irrigated for >30 yrs. They concluded that continuous irrigation in Ghataprabha command lead to development of salinity.

2.5 Physical properties of soil:

In sodic soils, the high concentration of sodium on the exchange sites of the soil particles in combination with low salt concentrations in the soil solution leads to dispersion and degrades the soil structure. After wetting, there is swelling and dispersion of clay particles are the major reasons for the deterioration of the soil structure (Rengasamy *et al.*, 1984).

The cations which are accompanying sodium on soil exchange sites also have an impact on the dispersion of sodic soils. Magnesium has been implicated in soil structural deterioration, enhancing dispersion when compared with Ca but contributing less to dispersion than Na (Gupta and Gupta, 1987; Minhas and Sharma, 2003).

Soils with high salts or sodium content are sticky when wet and hard when it is dried. The physical characters of salt- affected soils are due to changes in the proportions of few cations and anions which are present in soil solution and on exchangeable sites (Chhabra, 1996).

Sodic and saline-sodic soils generally exhibit structural problems such as slaking, swelling, dispersion of clay and surface crusting. Such problems might restrict the water and air movement and decreases the plant-available water, reduce nutrient availability, root penetration and seedling emergence and increase runoff and erosion potential (Suarez, 2001).

High concentration of salts in soil solution promotes flocculation by preventing soil particles from dispersing. Hence, vegetation in saline soils is not limited by aeration but due to presence of high salt concentrations it effects plant growth (Rengasamy, 2002; Gupta and Abrol 1990).

2.6 Chemical properties of soil

The increase in pH with depth in Malaprabha and Ghataprabha valley salt affected soils was studied by Kotur (1985). The pH was higher in subsurface horizons may be because of the soluble carbonates in titrable quantities. The pH of soils from Malaprabha valley were lower compared to Ghataprabha valley. The salt concentration in former group of soils were higher thus lower pH values were observed whereas in case of latter group soils the salt content was low and amount of free alkaline carbonates were higher which might have attributed for higher pH in these soils.

Many saline-sodic soils contain appreciable quantities of soluble carbonates in addition to neutral salts, which manifest the alkaline soil properties. Hence, it is imperative that the former type of saline-sodic soils be grouped and managed like saline soils in the beginning and the later as alkaline soils (Gupta and Abrol, 1990).

In salt affected soils, sodium, magnesium and calcium are dominant cations and chloride, sulphate, carbonate and bicarbonate are dominant anions. Excess concentration of these cations and anions in plant can lead to ion imbalance. Rengasamy (2010) reported that ion effect dominates only at low salinity and osmotic effect becomes more important at higher salinity.

Soil Reaction (pH)

Nakayama (1970) reported that the high pH values under field condition is due to sodium bicarbonate and carbonate minerals present in alkali soils, which precipitates Ca and Mg carbonate during evaporation. (Cruz-Romero and Coleman, 1975) noted that higher concentration of sodium carbonate in alkali soils is the cause for higher pH.

Mediratta *et al*. (1985) noted decreased pH down the profile, indicating the start of sodification process from the upper layer and exhibited a defined trend. Contrastingly, More *et al*. (1988) reported irregular trend of sodification in the soils of Purna command area of Maharashtra.

The pH of salt affected soils in Cauvery command area was in the range of 8.1-10.1 (Srinivasa, 1999), in Vanivilasa command area in Karnataka ranged from 8.5-11 (Mruthunjaya and Gowda, 1993).In Keliveli of Purna valley Maharashtra, it ranged from 7.5-9.7 (Kadwe *et al*., 2005) and the pH of soils of Purna command ranged from 8.1 to 10.7 (More *et al*., 1988)

The characterization and delineation of waterlogged and salt affected soils in Gandak command area of Bihar by Sharma *et al*. (2011) showed accumulation of CO_3^{2-} and HCO_3^- ions due to presence of calcite and dolomite in soils. The presence of high sodium ions resulted in high pH.

Electrical Conductivity (dS/m)

In of Godavari, Krishna and Cauvery deltas, the Ece values were very high throughout the profile and the maximum being just above the water table in saline soils was reported by Bhargava (1989). The Richards (1954) used ECe criteria for the classification of salt affected soils, the saline soils and saline alkali soils have ECe more than 4 dS m^{-1}.

The pH 8.5 of saturation paste was associated with the higher ESP than sodic soils formed under the influence of sodium carbonate was studied by Abrol *et al*. (1980).These observations suggested that pH of 8.2 of saturation paste, will be more appropriate than hitherto used value of 8.5 to diagnose sodic soils.

Costa *et al.* (1991) studied that increase in EC of irrigation water increased in EC of saturation extract but at equal EC of irrigation water, carbonates and divalent ions reduced the EC of saturation extract due to precipitation of calcite and gypsum. They found that irrigation water with high SAR increased the EC of saturation extract, mainly due to high sodium concentration compared to calcium and magnesium.

The salinity problem in soils of Purna Valley in Maharashtra was studied by Tamagade *et al*. (1993). The low electrical conductivity was observed *i.e.*, < 4dS/m in surface and lower solum of <65 cm depth were saline-sodic. The Vanivilas command area had electrical conductivity values ranging from 1.83 to 3.68 dS/m.

The salt affected coastal soils of Astaranga, Orissa were characterized by Sahu and Dash (1993), noticed that in profiles protected by embankment, EC values increased with depth whereas in profile an opposite trend was noticed.

In another study high electrical conductivity in lower depths was mainly due to leaching of salts from the upper layers and accumulation in the lower depths on account of irrigation (Balphande *et al*., 1996).

Walia and Rao (1996) noted the electrical conductivity of black soils ranging from 0.08 to 4 dS/m and there was no specific relationship with the depth indicating the low amount of soluble salts in soil.

Bikash *et al*. (2000) significant variation in the values of EC was detected ranging from 0.184 to 1.624 dSm^{-1} at 25°C. Higher EC values indicated the higher salt concentration that might affect the irrigation water quality in relation to salinity hazard.

Datta and Jong *et al.* (2002) reported adverse effect of waterlogging and soil salinity on crop and land productivity in Northwest region of Haryana. The data was collected on depth of water table and analysed the pH, EC of saturated paste, crop yields and soil samples were also analysed. They concluded that cropping intensity and crop yields decreased with increasing soil salinity.

2.7 Water soluble cations and anions

Agarwal and Rammoorthy (1970) while investigating the morphological and chemical properties of black and red soils from various parts of India observed that in black soil region, the Cl^-SO_4 ratio was higher in surface layers than in normal soil. This observation indicated the accumulation of Cl^- owing to evaporation and protection from further leaching, due to heavy texture of the soil. The process of evaporation when rapid, as in case of arid and semi-arid regions will lead to concentration of $CO_3^{=}$ and HCO_3^- in the soil solution. With the increase in concentration of the latter, Ca^{2+} and Mg^{2+} are precipitated and rendered less soluble. This phenomenon which greatly reduces the activity Ca^{2+} and Mg^{2+} and increases that of Na^+ is responsible for the development of sodic soils. However, between $CO_3^{=}$ and HCO_3^- at same level of salt concentration.

Levy and Feighonbaum (1977) indicated that increased soluble sodium upon dilution was due to its replacement mainly by calcium and magnesium. Bhadrapur and Rao (1979) opined that water soluble cations decreased with depth in the salt affected soils.

Decreased water soluble cations with depth in sodic and saline soils of Tungabhadra left bank canal area was found by Bhadrapur and Rao (1979). The concentration of water soluble cations in the studied pedons followed by Na, Ca, Mg, K. This showed that water soluble Na was present in the highest concentration. This was mainly due to higher solubility of Na compared to other salts.

In the sodic soils of Kanpur region of Uttar Pradesh, carbonate was the dominant anion followed by bicarbonate, chloride and sulphate in all the profiles, but when bicarbonate was dominant the other ions followed the order: Chloride, carbonate and sulphate (Tiwari *et al*., 1983).

In some salt affected soils of Bijapur district, Karnataka, sodium was found to be the dominant cation, followed by calcium and magnesium, while sulphate was the dominant anion in soil water extracts. The tendency of sulphate in surface layers, which is highly soluble compared to sulphates of calcium and magnesium (Ballolli, 1987). Chloride was the dominant anion followed by sulphate whereas bicarbonate content exceeded chloride in sodic profiles of Purna command area of Maharashtra (More *et al*., 1988).

Comparative studies on salt affected soils of Indo Gange tic plains was studied by Sharma and Jha (1989) and they observed that the pH of saturation extract varied from 8.6 to 10.1, increasing with depth in alkali profile, indicating the dispersion and downward movement of sodium clay in the alkali soils. Further, it was noticed that in salt affected soils, the sequence of soluble cations was Na^{+}> Ca^{++} + Mg^{++}> K^{+}, while in normal soils the order was Ca^{++} + Mg^{++}> Na^{+}> K^{+}, the higher K content in alkali hydrolysis of soil minerals. Among anions, bicarbonates were the dominant, followed by sulphates in salt affected soils, while a reverse order was evident in normal soils.

In vertisols of semiarid region of Maharashtra plateau, sodium was found to be the dominant cation followed by Ca^{2+}, while $CO_3^{2-}$and HCO_3^{-} was dominant anion with increasing depth (Challa *et al*., 2000). Sahu and Dash (1993) studied on characterization of salt affected costal soils Orissa, observed that Na^{+} and Ca^{++} are dominant cations followed by Mg^{++} while, Cl^{-} was the dominant anion followed by SO_4^{2-}, it indicating the salts to be mostly of chloride and sulphate type of salt affected soils is due to intrusion of sea water.

Patagundi *et al*. (1996) characterized the soils of Tungabhadra left bank command area and observed that among water soluble cations Na^{+} was the dominant ion compared to calcium and magnesium. Among anions Cl^{-} was found dominant followed by SO_4^{2-}, HCO_3^{-} and CO_3^{2-} were found in traces. The development of sodicity in the soils which were rich in water soluble sulphates were noticed by Bhadrapur and Rao (1979).

Characterization of vertisols of Upper Krishna command area Karnataka by Yerriswamy (1996). They found that sodium was dominated in the soil water extract, followed by Ca and Mg. Results revealed that there is possibility of further sodification in these soils.

Six sodic soil profiles of irrigated areas of Vishweshwaraiah canal tract of Cauvery command was studied by Srinivasa (1999). The ionic composition to water soluble ions indicated that sodium was dominant cation in all the soil profiles. The cation sequence of soluble cations in soil profiles were Na^{+}> Ca^{2+}> Mg^{2+} and K^{+}.

Sharma *et al.* (2011) studied Characterization and delineation of waterlogged and salt affected soils in Gandak command area of Bihar the study found that the accumulation of CO_3^{2-} and HCO_3^{-} ions due to the presence of calcite and dolomite in the soils. The presence of high sodium ions resulted in high pH.

2.8 Sodicity indices

Pathak and Patel (1980) noticed the characteristics of salt affected soils of Kaira district of Gujarat state. The values of ESP and pH were comparatively higher in lower layers of salt affected areas. Similarly, calcium carbonates and soluble boron were also noted to be in salt affected areas.

Bajwa *et al.* (1986) noted that with the application of saline water there was rapid increase in sodium than Ca and Mg in soil where as Ca and Mg were found maximum at higher salinity but their higher level resulted in lower amounts of SAR.

Mruthyunjaya and Gowda (1993) observed high SAR values of 12.3 to 29.4 in salt affected soils of Vanivilas command area of Karnataka. Exchangeable sodium was higher than the predicted values from SAR. Cucci *et al.* (2013) reported that high amount of salt concentration and SAR of irrigation water resulted in the increase in ESP and decrease in the exchangeable K, Ca^{++} and Mg^{++}.

Yerriswamy (1996) reported the increase in exchangeable sodium percentage down the soils of Tungabhadra command area in Karnataka and exchangeable sodium percentage was found to increase in the soil depth. A trend of increase in ESP from soil surface downwards has been considered to indicate initiation of sodiumization process in a downward direction (Balphande *et al.*, 1996)

The Indo-Gangetic plains of NW part of India were studied by Pal *et al.* (2003) they studied non-sodic and moderately sodic soils in microhigh and highly sodic soils occur in microlow positions of semiarid climate. They concluded that subsoil sodicity impairs HC of the soils and also ESP increases.

The ESP of the soils in Vanivilasa command area ranged from 39.86 to 54.62 indicates alkali nature of these soils (Mruthunjaya and Gowda, 1993) and Chamarajanagar taluk under Kabini track (Cauvery command area) the soils had pH of 9.06 and ESP of 40.8 per cent (Guruprasad, 2005).

3. MATERIAL AND METHODS

Salt is the integral part of the soil and it is dynamic in nature. The salt concentration at any given point of time depends on its net balance as determined by the regional climate and topography. This study was conducted during 2016-17 in black soil region of Ramthal Micro Irrigation Project area situated between 75.99° - 76.02°E and 16.09° - 16.11°N to assess the spatial distribution of salts in a small area. The details of the study area and the methodologies adopted are presented sequentially in this section.

3.1 General description of study area:

Location: Bagalkot district has a total geographical area of 6.50 lakh ha and it is situated in Northern Karnataka. It comes under semi-arid climatic condition. Ramthal Micro Irrigation Project is one of the lift irrigation projects of UKP where the water is delivered to the field by micro irrigation system instead of open canal system. The Ramthal lift irrigation project, situated in Hunagund taluk is one of the biggest lift irrigation project it covers an area of about 11,700 ha. The location of the study area is depicted in Fig 1. Large part of the project area is under black soils (vertisols) existing on basaltic and granitic parent materials.

Climate: The climate of the area is sub-tropical with dry semi-arid conditions possess distinct summer (March to May), rainy (June to October) and winter (November to February) seasons. The mean annual temperature (last 10 year) of the Hungund taluk varied from 33^0 C to 36 ^{0}C. The average annual precipitation was about 633.45 mm and nearly 90 per cent of it is received during monsoon season.

Land use pattern: In the study area, a large proportion of cultivated land were observed under sunflower, chickpea, chilli, soyabean, maize with assured protective irrigation in irrigated area. However sorghum, onion, millets etc were recorded as rainfed crops in non-irrigated areas.

3.2 Selection of study area

The major objective of the study was to assess the influence of topography on soil salinity parameters and to use the information as base line data for impact assessment with irrigations. Entire Ramthal Micro Irrigation Project area was traversed

Table 1: Rainfall and temperature data of the Hungund taluk during the study period

Month	Rainfall (mm)	Temperature (°C)	
		Max.	Min.
Apr - 2017	69.0	43.80	19.30
May - 2017	71.0	42.20	19.40
June - 2017	58.0	41.30	20.80
July - 2017	29.0	36.70	18.60
Aug - 2017	25.0	39.20	18.40
Sept - 2017	84.0	38.20	19.70
Oct – 2017	88.0	35.20	14.10
Nov - 2017	1.5	36.20	12.50
Dec - 2017	33.5	34.20	9.40
Jan - 2018	0.0	35.40	10.50
Feb - 2018	9.0	38.10	10.60
Mar – 2018	9.5	42.30	14.40

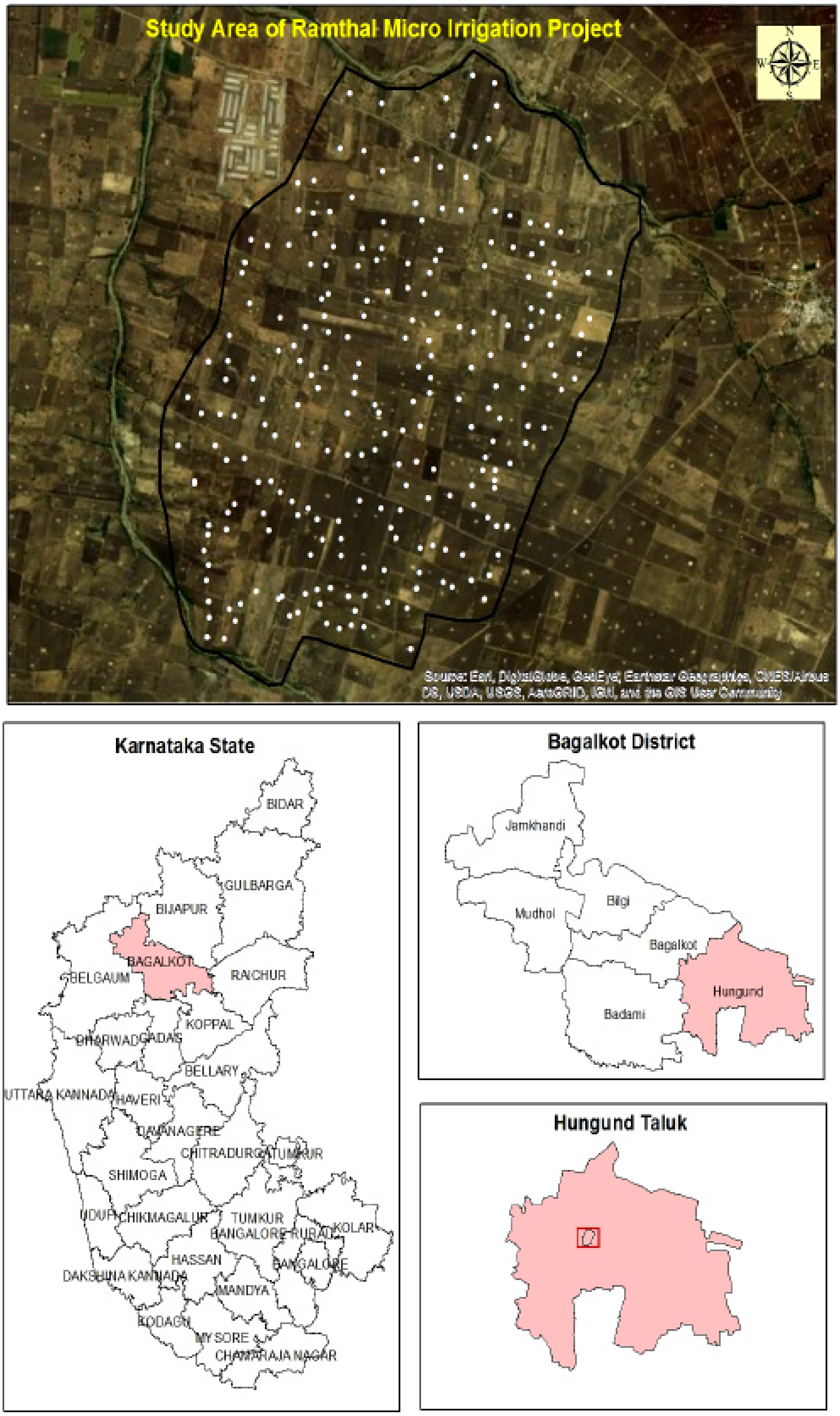

Figure 1: Location map of Ramthal study area

to identify a suitable site for the study. The maps depicting soil and land features generated by NBSS & LUP, Netafim, KSRSAC and Survey of India toposheets were also used to identify the study area. Finally, the zone number 20 of Netafim was chosen for this study.

3.3 Collection of soil samples

Land holding maps of Netafim and the village cadastral maps were used for soil samples collection. The entire zone 20 of Netafim project area and a small area beyond zone 20 towards natural drain was also covered so as to understand the effect of topography on soil salinity parameters. Each land unit of 2-5 ha in study area was considered as a sampling unit. The survey number, name of the farmer and the exact position of the sampling site were recorded using GPS meter. Representative surface soil samples (0-15 cm) for each study unit was collected by pooling soil samples collected from 3 different points in the same area. Representative soil samples were mixed thoroughly, cleaned (stones, roots etc removed) and reduced to its mass to a kilogram of soil. Then, the soil samples were air dried, pounded, sieved and stored in air tight containers. Thus, 236 surface soil samples were collected, processed and stored for further analysis for this study.

3.4 Profile study:

To understand the vertical distribution of salt contents in soils, three sampling sites were identified along the gradient namely, high elevation (L_1), mid elevation (L_2) and low elevation (L_3) for the profile study. The soil samples were collected separately at depths of 0-15 cm, 15-30 cm, 30-45 cm, 45-60 cm, 60-75 cm, 75-90 cm and 90-100cm. These profile samples were processed as above and stored for further analysis.

3.5 Soil analysis:

Processed and stored soil samples were used for analyzing salinity related parameters and the details of standard procedures adopted are given below.

3.5.1 Electrochemical properties

Soil reaction (pH): The soil suspension was prepared in 100 ml of glass beakers by mixing soil and water at 1:2.5 ratio (Jackson, 1973). The suspension was stirred intermittently for 30 min and the potential difference developed at the glass electrode was recorded using pH meter (Model: Systronics 361).

Electrical conductivity ($EC_{2.5}$): The soil water suspensions (1:2.5) were kept overnight and the electrical conductivity was measured for the clear suspension using conductivity meter (Model: Conductivity TDS meter 308) as given by Jackson (1973).

3.5.2 Extraction and determination of water extractable cations and anions

Extraction of cations and anions: Water soluble salts present in soil were extracted with distilled water at 1:2 soil and water ratio. Fifty gram soil was taken in a 250 ml conical flask and 100 ml of distilled water was added. The soil water mixture was kept in vertical shaker for 30 minutes for shaking. The suspension was allowed to settle for 10 minutes and the supernatant was centrifuged for 20 minute at 1500 rpm. Then, the solution stored was filtered using Watman no. 42 filter paper to obtain the clear extract. The extracts were stored in vials and refrigerated for further analysis.

Determination of cations and anions: The refrigerate soil-water extractant were brought to normal temperature and used for determination of cations and anions and the methods are given below

Calcium and Magnesium ions (Ca^{2+} and Mg^{2+}): The amounts of calcium and magnesium ions present in soil-water suspension were determined by complexometric (EDTA) titrations. Calcium and magnesium were determined by titrating it with 0.01N EDTA solution in presence of ammonia buffer to maintain a pH of 10.0 and EBT indicator. The concentration of calcium alone was determined by EDTA titration at a pH of 12 (using 10% NaOH solution) in the presence of Patton and Reader's indicator. The difference between the above two values was used to derive the amount of magnesium present in soil-water extract (Baruah and Barthakur, 1999).

Sodium and Potassium (Na^{+} and K^{+}): The concentrations of potassium and sodium in soil-water extracts were determined by flame photometry (Sharma *et al.*, 1987). The soil water extract was directly fed to the flame photometer (Systronics Model) after standardizing the instrument with suitable standards.

Carbonates and Bicarbonates (CO_3^{2-} & HCO_3^-): The amounts of carbonate sand bicarbonates present in soil-water extract were determined by acid titrations. As majority of the soil-water extracts had carbonate below the detectable limits by titrations, the carbonates and bicarbonates were determined together by titrating with standard sulphuric acid in presence of methyl orange indicator (Richards, 1954).

Chlorides (Cl^-): The chlorides in soil-water extracts were determined by Mohr's method. A known volume of soil-water extract was taken and titrated against standard silver nitrate solution in presence of potassium chromate indicator (Richards, 1954).

Sulphates (SO_4^{2-}): Water soluble sulphates in soil-water extracts were determined by turbidometric method. The turbidity was developed by precipitation of sulphate as barium sulphate using barium chloride crystals. The turbidity was measured using spectrophotometer (spectronic-200; thermofischer scientific) at 420 nm wavelength (Black, 1965).

Total cations and anions: The above individual cations and anions were grouped separately and their total contents were derived by their summation.

3.5.3 Sodicity Indices: The dominance of alkalinity forming ions viz, sodium and carbonates + bicarbonates over calcium and magnesium determines the susceptibility of soils for sodification. Thus, two important values Residual Sodium Carbonate (RSC), Sodium Adsorption Ratio (SAR) are commonly used and the methodologies are given below.

Sodium Adsorption Ratio (SAR): The extent of susceptibility of soils for sodification is determined by their relative proportions of activities of sodium to divalent cations and it is expressed as Sodium Adsorption Ratio. The SAR was derived by using the formula

$$SAR = \frac{Conc. of\ Na\ ion}{\sqrt[2]{\frac{Conc. of\ Ca\ ions + Conc. of\ Mg\ ions}{2}}}$$

Residual Sodium Carbonate (RSC): The presence of carbonates and bicarbonates in soil solutions is likely to alter the balance of divalent cations. Thus, the relative abundance of carbonates and bicarbonates over calcium and magnesium indicate the susceptibility of soils for sodicity over time and it is indicated by Residual Sodium Carbonate values. The RSC of soils were derived by using the formula

$$RSC = (CO_3^{2-} + HCO_3^{-}) – (Ca^{2+}+Mg^{2+})$$

Concentrations of ions and units of expressions of RSC are in meq/l.

3.6 Categorization of land categories:

The Ramthal study area exhibited an additional gradient of about 30m ranging from 508 to 536 MSL. To understand the influence of topography on soil salinity parameters, the entire study area was categorized into 3 groups namely, High Elevation Areas (L_1) - > 526 m; Mid Elevation Areas (L_2) – 516 to 526 m; and Low Elevation Areas (L_3) - < 516 m. The soil sampling points falling under each category were identified and grouped them into L_1, L_2 and L_3 as High Elevation, Mid Elevation and Low Elevation soil representatives respectively. Their respective salinity parameter were pooled and subjected to statistical analysis for further interpretation.

3.7 Statistical analysis

The data obtained were subjected to statistical tests using Anova: single factor and Descriptive Statistical Analysis. Simple correlation studies were made to understand their interaction effects.

3.8 Evaluation of soil suitability for horticultural crops

The information was used to know the suitability of different horticultural crops for salinity, sodicity. The severity of cations and anions were noted. The information on critical limits were used in regrouping soils samples for their suitability to horticultural crops.

4. EXPERIMENTAL RESULTS

Topography is an important parameter on the movement and distribution of salts in a given soil. A study was carried out in black soils of Ramthal Micro Irrigation Project area to assess the influence of topography on soil salinity parameters. The results obtained on pH, EC, distribution of cations and anions etc are presented in this chapter.

4.1 Soil reaction (pH)

The information on soil reactions in black soils belonging to different land categories at Ramthal study area is presented in Table 2. All the soil samples indicated alkalinity in soil reaction and the soil pH ranged from 8.13 to 9.67. Majority of the soil samples were observed in moderate (n=97) to high alkalinity (n=136) ranges with respective pH of 8.5 – 9.0 and > 9.0.

The soils present at different elevations showed significant variations in soil pH. The soils at lower elevations (L_3) areas recorded significantly lower pH (8.80 ± 0.23) while, the land existing at high elevations (L_1) recorded significantly higher pH values (9.15 ± 0.24). The soils existing at mid elevation recorded a pH of 8.98 ± 0.29. Thus, the soil pH as different elevations varied in the order of high > mid > low elevation soils.

4.2 Electrical Conductivity ($EC_{2.5}$)

The data on electrical conductivity of soil water suspension at 1:2.5 ratio for the black soils of Ramthal study area are given in Table 3. The electrical conductivity ranged from 0.10 to 0.36 dS m^{-1}. All the soil samples in the study area were observed under non saline category (normal soils) with $EC_{2.5}$ values of < 0.8 dS m^{-1} (for 1: 2.5 soil water suspensions). For the convenience of comparisons, the $EC_{2.5}$ values were categorized into low, medium and high with respective conductivity values of < 0.15, 0.15- 0.30 and > 0.30 dS m^{-1}. However, the distribution of salts measured in terms of $EC_{2.5}$ varied significantly with elevation of the land.

In terms of salt distributions in Ramthal study area, nearly 64 per cent of soil samples (n=151) recorded $EC_{2.5}$ values in the range of 0.15 to 0.30 dS m^{-1}. Higher amounts of salts were found only to an extent of 8 per cent (n=21) of total samples analysed and most of them were observed at higher elevations. Remaining 27 per cent of soil samples (n=64) recorded lower salinity values (< 0.15 dS m^{-1}).

Table 2: Influence of topography on soil reaction (pH) in Ramthal study area

Land Category	**Number of samples with pH values**				
	Low (8.0 - 8.5)	**Medium (8.5-9.0)**	**High (> 9.0)**	**pH range**	**Mean ± SD**
L_1- High Elevation (n = 97)	-	23 (9.7)	74 (31.3)	8.20 to 9.67	9.15 ± 0.24[a]
L_2- Mid Elevation (n = 121)	3 (1.2)	61 (25.8)	57 (24.1)	8.13 to 9.60	8.98 ± 0.29[b]
L_3- Low Elevation (n = 18)	-	13 (5.5)	5 (2.1)	8.51 to 9.24	8.80 ± 0.23[c]
Total (n = 236)	**3 (1.2)**	**97 (41.1)**	**136 (61.3)**	**8.13 to 9.67**	**9.03 ± 0.29**
Statistical Analysis	**$CD_{1,2}$ = 0.074**		**$CD_{1,3}$ = 0.140**		**$CD_{2,3}$ = 0.138**

(Note: 1. Values in the parenthesis depict per cent of samples in that category;
2. Different letters in the mean column imply significant difference at $P_{0.05}$.)

Table 3: Influence of topography on electrical conductivity ($EC_{2.5}$) in Ramthal study area

Land Category	Number of samples with $EC_{2.5}$ values (dS m^{-1})				
	Low (<0.15)	**Medium (0.15–0.30)**	**High (> 0.30)**	**Range**	**Mean ± SD**
L_1- High Elevation (n = 97)	13 (5.5)	68 (28.8)	16 (6.7)	0.11 to 0.35	0.22 ± 0.07^{b}
L_2- Mid Elevation (n = 121)	42 (17.7)	74 (31.3)	5 (2.1)	0.10 to 0.36	0.18 ± 0.06^{a}
L_3- Low Elevation (n = 18)	9 (3.81)	9 (3.8)	-	0.12 to 0.28	0.16 ± 0.04^{a}
Total (n = 236)	**64 (27.1)**	**151 (63.9)**	**21 (8.8)**	**0.10 to 0.36**	**0.20 ± 0.08**
Statistical Analysis	**$CD_{1,2}$ = 0.017**		**$CD_{1,3}$ = 0.032**		**$CD_{2,3}$ = 0.032**

(Note: 1. Values in the parenthesis depict per cent of samples in that category;
2. Different letters in the mean column imply significant difference at $P_{0.05}$.)

The soils existing at low elevation areas (L_3) recorded significantly lower EC values (0.16 ± 0.04 dS m^{-1}). Contrastingly, the soils at higher elevations (L_1) recorded significantly higher conductivity with $EC_{2.5}$ values of 0.22 ± 0.07 dS m^{-1}. However, the soils of mid elevated region (L_2) recorded lesser EC values compared to high elevated areas and it was found on par with L_3 land category.

4.3 Water extractable cations

The water extractable cations namely, calcium, magnesium, sodium and potassium were determined for the soil extractants obtained at 1:2 ratios. The extent of water soluble cations are presented in this section.

Water extractable-Ca: The amounts of calcium present in soil water extractant are presented in Table 4. The water extractable-Ca ranged from 0.46 meq/l at higher elevation soils (L_1) to 2.52 meq/l in mid elevation soils (L_2). The water extractable- Ca were grouped into 3 ranges namely low (< 0.6 meq/l), medium (0.6-1.2 meq/l) and high (> 1.2 meq/l). Among 236 soil sample analysed, nearly 70 per cent of soil samples (n=167) were observed in medium range (0.6-1.2 meq/l) while, 24 per cent of soil samples (n=57) were found in higher range (>1.2 meq/l).

Among different land categories, the soils existing on lands at mid elevations (L_2) recorded significantly higher calcium contents (1.09 ± 0.37 meq/l). Significantly lower calcium contents were observed in high elevation areas. However, the soil present at low elevations did not differ significantly from high and mid elevation areas.

Water extractable-Mg: The concentrations of water extractable Mg in black soils of Ramthal study area are given in Table 5. The water extractable- Mg content ranged from 0.26 to 2.62 meq/l in soils of lower elevation areas (L_3). The magnesium contents were categorized into low, medium and high ranges based on similar values used for calcium. In terms of its distributions, more than 2/3rd of the samples recorded medium range of magnesium (0.6 to 1.2 meq/l). Higher amounts of magnesium (>1.2 meq/l) were observed in 25 per cent of the samples analysed (n=58).

Among land areas existing at different elevations, the mean values of water extractable-Mg contents were found significantly higher (1.10 ± 0.37 meq/l) in soils at mid elevations

Table 4: Influence of topography on water extractable calcium in Ramthal study area

Land Category	Number of samples with calcium values (meq /l)				
	Low (<0.60)	Medium (0.60 – 1.20)	High (>1.20)	Range	Mean ± SD
L_1- High Elevation (n = 97)	6 (2.5)	78 (33.0)	13 (5.5)	0.46 to 1.70	0.89 ± 0.29^{a}
L_2- Mid Elevation (n = 121)	4 (1.6)	76 (32.2)	41 (17.3)	0.56 to 2.52	1.09 ± 0.37^{b}
L_3- Low Elevation (n = 18)	2 (0.8)	13 (5.5)	3 (1.2)	0.56 to 1.56	0.97 ± 0.28^{ab}
Total (n = 236)	**12 (5.0)**	**167 (70.7)**	**57 (24.1)**	**0.46 to 2.52**	**1.01 ± 0.35**
Statistical Analysis	**$CD_{1,2}$ = 0.092**		**$CD_{1,3}$ = 0.174**		**$CD_{2,3}$ = 0.171**

(Note: 1. Values in the parenthesis depict per cent of samples in that category;
2. Different letters in the mean column imply significant difference at $P_{0.05}$.)

Table 5: Influence of topography on water extractable magnesium in Ramthal study area

Land Category	Number of samples with magnesium values (meq /l)				
	Low (<0.60)	**Medium (0.60–1.20)**	**High (> 1.20)**	**Range**	**Mean ± SD**
L_1- High Elevation (n = 97)	11 (4.6)	75 (31.7)	11 (4.6)	0.42 to 2.12	0.93 ± 0.27^{a}
L_2- Mid Elevation (n = 121)	4 (1.6)	74 (31.3)	43 (18.2)	0.40 to 2.18	1.10 ± 0.37^{b}
L_3- Low Elevation (n = 18)	4 (1.6)	10 (4.2)	4 (1.6)	0.26 to 2.62	0.99 ± 0.61^{ab}
Total (n = 236)	**19 (8.0)**	**159 (67.3)**	**58 (24.5)**	**0.26 to 2.62**	**1.02 ± 0.37**
Statistical Analysis	**$CD_{1,2}$ = 0.100**		**$CD_{1,3}$ = 0.188**		**$CD_{2,3}$ = 0.185**

(Note: 1. Values in the parenthesis depict per cent of samples in that category;
2. Different letters in the mean column imply significant difference at $P_{0.05}$.)

(L_2) and it was found on par with soils at low elevation areas (0.99 ± 0.61 meq/l). The soils in high elevation areas (L_1) recorded significantly lower water extractable-Mg values (0.93 ± 0.27 meq/l).

Water extractable-K: The data on water extractable– K in soils existing on lands at different elevations are presented in Table 6 and its concentration ranged from 0.05 to 0.31 meq/l. Water extractable-K contents were grouped into < 0.1, 0.1 - 0.2 and > 0.2 meq/l as low, medium and high ranges respectively. Nearly 2/3rd of the soil samples (n=159; 67.4%) recorded medium range of potassium with 0.1 to 0.2 meq/l and majority of the samples were represented by L_1 and L_2 land categories. Water extractable-K was low (<0.10 meq/l) in 18.6 per cent of the samples (n = 44) and high (>0.2 meq/l) in 14 per cent (n = 33) of the samples analysed.

All the three land categories recorded significantly different amounts of water extractable-K. The soils existing in low elevation areas recorded significantly higher amounts of potassium while, the soils of higher elevations (L_1) had the least amounts (0.13 ± 0.05 meq/l). Thus, the water extractable-K varied significantly in the order of low (L_3) > mid (L_2) > high (L_1) elevations.

Water extractable- Na: The concentrations of water extractable-Na among soils of different land categories are presented in Table 7. Among different water extractable cations, the amounts of sodium were substantially higher compared to all other cations and its concentration ranged from 3.37 to 17.54 meq/l. The concentrations of water extractable- Na were grouped into low (<6 meq/l), medium (6-12 meq/l) and high (>12 meq/l) ranges for the comparisons. In terms of its concentration, nearly 3/4th of soil samples recorded medium range values (6-12 meq/l) while, only 6 per cent of the sample (n = 14) were in low range category (<6 meq/l). Twenty per cent of soil samples remained in high–Na range (>12 meq/l). At Ramthal study area, the soils existing at high elevations recorded significantly higher values (10.90 ± 2.03 meq/l). However, soils occurring at medium and low elevations recorded significantly lower values and both the values were found on par with each other.

4.4 Water extractable anions

The same soil water extractant obtained for cations at 1:2 soil-water ratio, were used for the determination of anions namely, carbonates + bicarbonates, chlorides and

Table 6: Influence of topography on water extractable potassium in Ramthal study area

Land Category	Number of samples with potassium values (meq /l)				
	Low (<0.10)	**Medium (0.10 – 0.20)**	**High (>0.20)**	**Range**	**Mean ± SD**
L_1- High Elevation (n = 97)	23 (9.7)	67 (28.3)	7 (2.9)	0.05 to 0.31	0.13 ± 0.05^a
L_2- Mid Elevation (n = 121)	20 (8.4)	80 (33.8)	21 (8.8)	0.05 to 0.31	0.15 ± 0.06^b
L_3- Low Elevation (n = 18)	1 (0.4)	12 (5.0)	5 (2.1)	0.07 to 0.27	0.18 ± 0.05^c
Total (n = 236)	**44 (18.6)**	**159 (67.3)**	**33 (13.9)**	**0.05 to 0.31**	**0.14 ± 0.06**
Statistical Analysis	**$CD_{1,2}$ = 0.015**		**$CD_{1,3}$ = 0.028**		**$CD_{2,3}$ = 0.028**

(Note: 1. Values in the parenthesis depict per cent of samples in that category;
2. Different letters in the mean column imply significant difference at $P_{0.05}$.)

Table 7: Influence of topography on water extractable sodium in Ramthal study area

Land Category	Number of samples with sodium values (meq /l)				
	Low (<6.0)	**Medium (6.0 – 12.0)**	**High (>12.0)**	**Range**	**Mean ± SD**
L_1- High Elevation (n = 97)	-	78 (33.0)	19 (8.0)	7.03 to 16.50	10.90 ± 2.03^{b}
L_2- Mid Elevation (n = 121)	14 (5.9)	78 (33.0)	29 (12.2)	3.37 to 17.54	9.61 ± 3.01^{a}
L_3- Low Elevation (n = 18)	-	17 (7.2)	1 (0.4)	6.27 to 12.50	9.32 ± 1.47^{a}
Total (n = 236)	**14 (5.9)**	**173 (73.3)**	**49 (20.7)**	**3.37 to 17.54**	**10.12 to 2.63**
Statistical Analysis	**$CD_{1,2}$ = 0.710**		**$CD_{1,3}$ = 1.338**		**$CD_{2,3}$ = 1.317**

(Note: 1. Values in the parenthesis depict per cent of samples in that category;
2. Different letters in the mean column imply significant difference at $P_{0.05}$.)

sulphates. The data on individual and total anions are presented in this section under different sub headings.

Carbonates and bicarbonates: Majority of the soil samples indicated the presence of carbonates. However, they were not in detectable limits by titrometric methods. Hence, the carbonates and bicarbonates were measured together and presented in Table 8. For the convenience of comparison across elevations, the total carbonates and bicarbonates were grouped as low (<1.5 meq/l), medium (1.5 – 3meq/l) and high (>3meq/l) ranges. All most all the soil samples indicated medium to higher range of carbonates and bicarbonates. Among 236 soil samples analysed, 43.69 per cent belonged to medium range and 52.1 per cent belonged to higher range.

In terms of total carbonates and bicarbonates, soils existing on lands at high and mid elevations (L_1 and L_2) recorded significantly higher amounts with respective values of 2.89 ± 0.84 and 2.91 ± 0.80 meq/l. The soils at lower elevations (L_3) had least total carbonates and bicarbonates (2.45 ± 0.84 meq/l).

Chloride: Occurrence of chlorides in soils is very common and it's concentrations in soils of different land categories were measured and tabulated (Table 9). The chloride concentration in soils ranged from 1.80 to 14.40 meq/l. Based on chloride concentration range in soil-water extracts, three ranges namely, low (<5 meq/l), medium (5-10 meq/l) and high (>10 meq/l) groups were maded and used for comparisons. More than 3/4th of soil samples (n = 177; 75%) were observed in medium range (5 -10 meq/l). Its concentration was found higher (> 10 meq/l) in 20.3 per cent of the samples (n = 48).

The elevations of the land had significant influence on chloride contents. The soils of low and mid elevations (L_3 and L_2) recorded least chlorides with respective values of 7.73 ± 1.93 and 7.80 ± 2.41 meq/l. The soils at high elevations (L_1) recorded maximum chloride concentrations of 8.69 ± 1.81 meq/l).

Sulphate: The amounts of water extractable sulphates present in different land categories are presented in Table 10. The SO_4^{2-} ion concentration in water extract ranged from 0.48 to 1.80 meq/l. Of the 236 soil samples analysed, nearly half of them (n=107; 45.3%) belonged to medium range (0.6 to 1.2 meq/l) while, the other half (n=111; 47%) exhibited higher range of sulphate (>1.2 meq/l).

Table 8: Influence of topography on water extractable carbonate + bicarbonate in Ramthal study area

Land Category	Number of samples with carbonate + bicarbonate values (meq /l)				
	Low (<1.5)	Medium (1.5-3.0)	High (>3.0)	Range	Mean ± SD
L_1- High Elevation (n = 97)	1 (0.4)	50 (21.1)	46 (19.0)	1.09 to 5.45	2.87 ± 0.84^b
L_2- Mid Elevation (n = 121)	6 (2.5)	45 (19.0)	70 (29.6)	1.09 to 4.81	2.91 ± 0.80^b
L_3- Low Elevation (n = 18)	3 (1.2)	8 (3.3)	7 (2.9)	1.09 to 3.27	2.45 ± 0.84^a
Total (n = 236)	**10 (4.2)**	**103 (43.6)**	**123 (52.1)**	**1.09 to 5.45**	**2.86 ± 0.82**
Statistical Analysis	**$CD_{1,2}$ = 0.227**		**$CD_{1,3}$ = 0.427**		**$CD_{2,3}$ = 0.421**

(Note: 1. Values in the parenthesis depict per cent of samples in that category;
2. Different letters in the mean column imply significant difference at $P_{0.05}$.)

Table 9: Influence of topography on water extractable chloride in Ramthal study area

Land Category	Number of samples with chloride values (meq /l)				
	Low (<5.0)	**Medium (5.0 – 10.0)**	**High (>10.0)**	**Range**	**Mean ± SD**
L_1- High Elevation (n = 97)	-	74 (31.3)	23 (9.7)	5.40 to 14.40	8.69 ± 1.81^b
L_2- Mid Elevation (n = 121)	10 (4.2)	88 (37.2)	23 (9.7)	1.80 to 14.40	7.80 ± 2.41^a
L_3- Low Elevation (n = 18)	1 (0.4)	15 (6.3)	2 (0.8)	3.60 to 10.80	7.73 ± 1.93^a
Total (n = 236)	**11 (4.6)**	**177 (75)**	**48 (20.3)**	**1.80 to 14.40**	**8.16 ± 2.19**
Statistical Analysis	**$CD_{1,2}$ = 0.598**		**$CD_{1,3}$ = 1.126**		**$CD_{2,3}$ = 1.109**

(Note: 1. Values in the parenthesis depict per cent of samples in that category;
2. Different letters in the mean column imply significant difference at $P_{0.05}$.)

Table 10: Influence of topography on water extractable sulphate in Ramthal study area

Land Category	Number of samples with sulphate values (meq /l)				
	Low (<0.60)	**Medium (0.6 – 1.20)**	**High (>1.20)**	**Range**	**Mean ± SD**
L_1- High Elevation (n = 97)	4 (1.6)	38 (16.1)	55 (23.3)	0.54 to 1.75	1.18 ± 0.22[b]
L_2- Mid Elevation (n = 121)	13 (5.5)	60 (25.4)	48 (20.3)	0.48 to 1.80	1.09 ± 0.28[a]
L_3- Low Elevation (n = 18)	1 (0.4)	9 (3.8)	8 (3.3)	0.56 to 1.27	1.10 ± 0.20[a]
Total (n = 236)	**18 (7.6)**	**107 (45.3)**	**111 (47.0)**	**0.48 to 1.80**	**1.13 ± 0.25**
Statistical Analysis	**$CD_{1,2}$ = 0.070**		**$CD_{1,3}$ = 0.132**		**$CD_{2,3}$ = 0.130**

(Note: 1. Values in the parenthesis depict per cent of samples in that category;
2. Different letters in the mean column imply significant difference at $P_{0.05}$).

In terms of the mean values of water extractable SO_4^{2-}, the lands existing at mid (L_2) and low (L_3) elevations recorded significantly lower sulfate values of 1.09 ± 0.28 and 1.10 ± 0.20 meq/l respectively. Contrastingly, the soils belonging to high elevations (L_1) recorded significantly higher water extractable- SO_4^{2-} (1.18 ± 0.22 meq/l).

4.5 Water extractable total cations and anions:

The total water extractable cations in soils of different land categories were derived by the summation of all the individual water extractable cations. Similarly, the water extractable anions were determined by summation of all the anions. The data on total water extractable cations and anions are presented in Tables 11 and 12.

Water extractable total cations: The total cations in soil water extract ranged from 5.70 to 19.61 meq/l and both the values were found in soils at mid elevations (L_2). In terms of its distribution, nearly half of the soil samples analyzed (n = 119) were found with higher range (>12 meq/l) while, the other half of the samples (n = 116) were observed in medium range (6-12 meq/l) of total cations.

Comparisons of different land categories indicated that higher elevations (L_1) recorded significantly higher values (12.84 ± 1.98 meq/l). Contrastingly, the soils existing at low elevations (L_3) had significantly lower amounts (11.45 ± 1.56 meq/l). However, the soils existing at mid elevations (L_2) showed on par water extractable-Na values with the other two land categories (L_1 and L_3).

Water extractable total anions: The total anions concentrations in the soil water extracts were estimated by adding the quantities of CO_3+HCO_3, Cl^- and SO_4^{2-} and the data is presented in Table 12. Similar to other parameters, three concentration ranges were made with values of <6 meq/l as low, 6-12 meq/l as medium and >12 meq/l as high ranges. The total anion concentration ranged from 5.74 to 19.45 meq/l. Similar to total cations, most of the soil samples recorded medium and higher range values of total anions.

In terms of the mean values of soils of different land categories, the soils existing at high elevations (L_1) recorded significantly higher values (12.74 ± 2.29 meq/l) while, soils belonging to lower elevations (L_3) and mid elevations (L_2) recorded significantly lower amounts (11.79 ± 2.81 meq/l in L_2 and 11.28 ± 2.05 meq/l in L_3).

Table 11: Influence of topography on water extractable total cations in Ramthal study area

Land Category	Number of samples with total cations values (meq /l)				
	Low (<6.0)	**Medium (6.0 – 12.0)**	**High (>12.0)**	**Range**	**Mean ± SD**
L_1- High Elevation (n = 97)	-	34 (14.4)	63 (26.6)	9.39 to 18.18	12.84 ± 1.98^{a}
L_2- Mid Elevation (n = 121)	1 (0.4)	69 (29.2)	51 (21.6)	5.70 to 19.61	11.97 ± 2.78^{ab}
L_3- Low Elevation (n = 18)	-	13 (5.5)	5 (2.1)	8.20 to 14.79	11.45 ± 1.56^{b}
Total (n = 236)	**1 (0.4)**	**116 (49.1)**	**119 (50.4)**	**5.70 to 19.61**	**12.29 ± 2.44**
Statistical Analysis	**$CD_{1,2}$ = 0.668**		**$CD_{1,3}$ = 1.259**		**$CD_{2,3}$ = 1.239**

(Note: 1. Values in the parenthesis depict per cent of samples in that category;
2. Different letters in the mean column imply significant difference at $P_{0.05}$.)

Table 12: Influence of topography on water extractable total anion in Ramthal study area

Land Category	Number of samples with total anion values (meq /l)				
	Low (<6.0)	**Medium (6.0 – 12.0)**	**High (>12.0)**	**Range**	**Mean ± SD**
L_1- High Elevation (n = 97)	-	42 (17.7)	55 (23.3)	8.23 to 19.45	12.74 ± 2.29[a]
L_2- Mid Elevation (n = 121)	2 (0.8)	63 (26.6)	56 (23.7)	5.74 to 18.50	11.79 ± 2.81[b]
L_3- Low Elevation (n = 18)	-	11 (4.6)	7 (2.9)	7.48 to 14.13	11.28 ± 2.05[b]
Total (n = 236)	**2 (0.8)**	**116 (49.1)**	**118 (50.0)**	**5.74 to 19.45**	**12.14 ± 2.60**
Statistical Analysis	**$CD_{1,2}$ = 0.711**		**$CD_{1,3}$ = 1.339**		**$CD_{2,3}$ = 1.318**

(Note: 1. Values in the parenthesis depict per cent of samples in that category;
2. Different letters in the mean column imply significant difference at $P_{0.05.}$)

4.6 Soil sodicity indices

The soils of arid and semi-arid regions are prone for salt induced salinity and sodicity problems. The susceptibility of soils for sodicity and the extent of sodicity are evaluated using residual sodium carbonates (RSC) and sodium adsorption ratio (SAR) values. The results obtained on these indices are discussed below.

Residual sodium carbonate (RSC): The alkalinity behavior of carbonates and bicarbonates in soils solution is counteracted by the presence of calcium and magnesium in soil solution. The excess of carbonates and bicarbonates over quantities of calcium and magnesium in the soils is assessed as RSC values and the soil values were arranged into three ranges namely low (<0 meq/l), medium (0-2.0 meq/l) and high (>2.0 meq/l) by RSC values. The information on RSC values of soils belonging to different land categories and the extent of its distribution are presented in Table 13.

In general, the RSC values were found in safer limits though the carbonates and bicarbonates were more than calcium and magnesium contents in soil solution. The RSC values ranged from -1.98 to 3.51 meq/l. Nearly 70 per cent of the soil samples (n = 166) were found in medium RSC ranges (0 to 2 meq/l). Only 10 per cent of the soil samples (n=24) indicated higher RSC values (> 2 meq/l) and they were observed only in soils existing at mid and high elevations.

In terms of susceptibility of soils for sodicity, the soils existing at higher elevation (L_1) recorded significantly higher RSC values of 1.05 ± 0.93 meq/l. Contrastingly, the soils belonging to low elevation areas (L_3) recorded least RSC values (0.50 ± 1.11 meq/l). The soils of mid elevation areas (L_2) was on par with low elevation areas with RSC of 0.70 ± 1.10 meq/l.

Sodium adsorption ratio (SAR): Occurrence and formation of sodicity is also measured by the ratios of activities of sodium to calcium and magnesium. The risks of sodicity are also expressed in terms of SAR values. The information on SAR values of soils under different land category are presented in Table 14. The SAR values ranged from 2.90 to 20.65 $(meq/l)^{1/2}$. In the study area, > 70 per cent of soil samples were found safe in terms of sodification with SAR values of <10 $(meq/l)^{1/2}$. However, 30 per cent of the soil samples indicated moderate sodicity risks with >10 $(meq/l)^{1/2}$ of SAR

Table 13: Influence of topography on Residual Sodium Carbonate (RSC) in Ramthal study area

Land Category	Number of samples with RSC values (meq /l)				
	Low (<0)	**Medium (0 – 2)**	**High (>2)**	**Range**	**Mean ± SD**
L_1- High Elevation (n = 97)	11 (4.6)	74 (31.5)	12 (5.0)	-0.88 to 3.51	1.05 ± 0.93^{ab}
L_2- Mid Elevation (n = 121)	31 (13.1)	78 (33.0)	12 (5.0)	-1.98 to 3.04	0.70 ± 1.10^{b}
L_3- Low Elevation (n = 18)	4 (1.6)	14 (5.9)	-	-1.71 to 1.75	0.50 ± 1.11^{a}
Total (n = 236)	**46 (19.4)**	**166 (70.3)**	**24 (10.1)**	**-1.98 to 3.51**	**0.83 ± 1.04**
Statistical Analysis	**$CD_{1,2}$ = 0.287**		**$CD_{1,3}$ = 0.541**		**$CD_{2,3}$ = 0.532**

(Note: 1. Values in the parenthesis depict per cent of samples in that category;
2. Different letters in the mean column imply significant difference at $P_{0.05}$).

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Table 14: Influence of topography on Sodium Adsorption Ratio (SAR) in Ramthal study area

Land Category	Number of samples with SAR values (vmeq /l)				
	Low (<6)	**Medium 6 – 12)**	**High (>12)**	**Range**	**Mean ± SD**
L_1- High Elevation (n = 97)	2 (0.8)	60 (25.4)	35 (14.8)	5.73 to 20.65	11.75 ± 2.87^{ab}
L_2- Mid Elevation (n = 121)	23 (9.7)	66 (27.9)	32 (13.5)	2.90 to 20.18	9.60 ± 3.80^{a}
L_3- Low Elevation (n = 18)	-	14 (5.9)	4 (1.6)	6.23 to 13.99	9.87 ± 2.37^{b}
Total (n = 236)	**25 (10.5)**	**140 (59.3)**	**71 (30.0)**	**2.90 to 20.65**	**10.50 ± 3.50**
Statistical Analysis	**$CD_{1,2}$ = 0.933**		**$CD_{1,3}$ = 1.756**		**$CD_{2,3}$ = 1.729**

(Note: 1. Values in the parenthesis depict per cent of samples in that category;
2. Different letters in the mean column imply significant difference at $P_{0.05}$.)

It was observed that the soils existing in high elevated areas (L_1) were susceptible for sodification compared to low (L_3) and mid (L_2) elevated areas. The soils of high elevated areas exhibited significantly higher mean SAR values of 11.75 ± 2.87 $(meq/l)^{½}$. Significantly low SAR values were observed in soils of both mid elevation (L_2) and low elevation (L_3) areas with respective SAR values of 9.60 ± 3.80 $(meq/l)^{½}$ and 9.87 ± 2.37 $(meq/l)^{½}$.

4.7 Correlation studies

The electrochemical properties of soils (pH and EC), the amounts and type of cations and anions present in soil-water extracts (as free salts) and their influence on soil salinization and alkalization were analysed using correlation matrix. The correlation coefficient values of different parameters are presented in Table 15 and their corresponding 'r' values are presented in the parenthesis along with their significance.

The correlation coefficient values for different soil salinity parameters indicated the $EC_{2.5}$ values were strongly correlated with water extractable sodium (0.26**), chloride (0.22**), carbonates + bicarbonates (0.16*) and sulphate (0.55**). The positive significant values clearly indicated that the soils are having both alkaline and neutral salts. The pH of the soil water suspension was found positively and significantly correlated with sodium (0.37**) and carbonates and bicarbonates (0.53**) while, it was found negatively correlated with calcium (-0.21**) and magnesium (-0.38**). Interestingly, there was very strong relationship existed between chlorides and sodium with (0.68**) compared to sodium and carbonates (0.43**).

In terms of susceptibility of soils for sodicity or alkalinity the water extractable –Na was found highly significant with RSC (0.58**), SAR (0.92**) and SSP (0.80**). Similarly the alkaline bases (carbonates and bicarbonates) also showed significantly higher influence on RSC (0.82**), SAR (0.37**) and SSP (0.25**) values.

4.8 Soil profile studies

The study area had a topographical gradient of about 30 meters and the area was grouped into 3 categories namely, high elevated (L_1), mid elevated (L_2) and low elevated (L_3) areas with respective elevations of > 526 m, 516 - 526 m and < 516 m. Three representative soil profiles were excavated for the above three categories to understand

Table 15: Correlation matrix for different soil salinity parameters in Ramthal study area

	pH	*EC*	*Ca^{2+}*	*Mg^{2+}*	*K^{+}*	*Na^{+}*	*Carbonat es*	*Cl^{-1}*	*SO_4^{-2}*	*RSC*
$EC_{2.5}$	*0.45*									
Ca^{2+}	-0.03	-0.21**								
Mg^{2+}	-0.08	-0.38**	0.38**							
K^{+1}	-0.01	-0.10	0.05	0.20**						
Na^{+1}	0.26**	0.37**	-0.35**	-0.34**	-0.04					
Carbonates	0.20**	0.16*	0.01	-0.11	-0.02	0.43**				
Cl^{-1}	0.22**	0.20**	-0.14*	-0.05	0.00	0.68**	0.27**			
SO_4^{-2}	0.55**	0.40**	-0.12	-0.18**	0.01	0.22**	0.07	0.22**		
RSC	0.22**	0.33**	-0.46**	-0.57**	-0.10	0.58**	0.82**	0.27**	0.16**	
SAR	0.25**	0.41**	-0.57**	-0.58**	-0.08	0.93**	0.37**	0.56**	0.25**	0.68**

the effects of topography on the whole soil. A profile depth of 1 m was dug in high and mid elevation areas while, the depth of the soil profile was only 45 cm at low elevation due to the presence of a hard rock at the base. The information on soil salinity parameters of the profiles are tabulated and presented in Tables 16 to 20.

Soil reaction (pH) and electrical conductivity ($EC_{2.5}$): The pH and electrical conductivity of three soil profiles is presented in Table 16. The pH of soils of profile-1 belonging to L_1 category was higher compared to soil pH of profile-2 and 3. The pH was in highly alkaline in profiles-1 and 2 while, the profile-3 recorded moderate alkalinity. In terms of soil salinity, the $EC_{2.5}$ values were higher in profile-1 and it decreased in profile-2 and 3 at all the depths. With respect to depth, the salt content increased with depth in all the three soil profiles.

Water extractable cations: The data on water extractable cations of 3 different profiles are presented in Table 17. Among different soil water extractable cations, the amounts of sodium was substantially higher than other cations while, water extractable-K was found least in all the three profiles. In general, the soils of profile-1 recorded higher amounts of cations compared to profile-2 and profile-3. However, the amounts of sodium in the top four layers of profile - 1 were higher than subsurface soils. Contrastingly, the profile-2 recorded higher amounts of Na^+ in subsurface soils also.

Water extractable anions: The amounts of water extractable anions among soils of three profiles excavated at high, mid and low elevation areas are presented in Table 18. Among water extractable anions, the chloride was substantially higher in all the profile samples while, SO_4^{-2} was least. In terms of topography, the profile samples at high elevation (L_1) had higher amounts of all anions compared to mid (L_2) and low (L_3) elevations. In general, the subsurface profile soils recorded higher amounts of total carbonates and sulfates compared to surface samples. However, water extractable- Cl was found higher in surface soils compared to subsurface soils.

Water extractable total cations and total anions: The total amounts of cations and anions were derived by summation method and the data are presented in Table 19. It was found interesting to observe that both total cations and total anions were found higher in profile-1 and they declined gradually along the falling gradient. The amounts of total cations were found almost equal to the total anions in all the profile soil samples.

Table 16: pH and electrical conductivity (dS m^{-1}) of soil profiles in Ramthal study area

Soil Depth (cm)	Profile-1:High Elevation		Profile-2:Mid Elevation		Profile-3: Low Elevation	
	pH	EC (dS /m)	pH	EC (dS /m)	pH	EC (dS /m)
0-15	9.12	0.27	8.86	0.13	8.68	0.10
15-30	9.17	0.24	9.01	0.19	8.53	0.11
30-45	9.29	0.35	9.08	0.24	8.40	0.11
45-60	9.32	0.33	9.25	0.22		
60-75	9.34	0.39	9.39	0.23		
75-90	9.31	0.43	9.37	0.20		
90-100	9.46	0.18	9.36	0.19		

Table 17: Distribution of water extractable cations (meq/l) in soil profiles of Ramthal study area

Soil Depth (cm)	Profile-1: High Elevation				Profile-2: Mid Elevation				Profile-3: Low Elevation			
	Cations (meq/l)				Cations (meq/l)				Cations (meq/l)			
	Na^+	Ca^{+2}	Mg^{+2}	K^+	Na^+	Ca^{+2}	Mg^{+2}	K^+	Na^+	Ca^{+2}	Mg^{+2}	K^+
0-15	10.78	0.91	1.20	0.14	9.66	0.96	1.04	0.17	8.65	0.90	0.95	0.14
15-30	10.87	1.42	1.36	0.18	10.48	1.14	1.26	0.19	7.48	0.90	1.02	0.13
30-45	10.52	1.74	1.02	0.15	10.96	1.72	1.24	0.12	8.45	1.42	1.06	0.14
45-60	10.02	1.56	1.28	0.18	9.66	0.94	1.06	0.14				
60-75	9.91	1.52	1.68	0.14	11.44	1.02	1.18	0.18				
75-90	8.35	1.16	2.04	0.13	10.96	0.86	1.26	0.18				
90-100	9.33	2.04	1.02	0.14	10.59	0.90	1.26	0.20				

Table 18: Distribution of water extractable anions (meq/l) in soil profiles of Ramthal study area

Soil Depth (cm)	Profile 1: High Elevation (meq/l)			Profile 2: Mid Elevation (meq/l)			Profile 3: Low Elevation (meq/l)		
	Cl^{-1}	CO_3^{-2} + HCO_3^{-1}	SO_4^{-2}	Cl^{-1}	CO_3^{-2} + HCO_3^{-1}	SO_4^{-2}	Cl^{-1}	CO_3^{-2} + HCO_3^{-1}	SO_4^{-2}
0-15	8.42	2.92	1.27	7.48	2.64	1.18	4.42	2.54	2.29
15-30	7.86	3.00	2.23	7.16	3.20	2.66	4.40	2.78	3.02
30-45	8.12	2.94	2.90	8.40	3.18	2.51	5.40	3.24	1.91
45-60	7.42	3.25	2.84	5.60	2.84	2.84			
60-75	7.12	3.62	3.14	7.64	2.74	3.04			
75-90	5.80	3.54	2.92	7.40	3.24	2.99			
90-100	6.82	3.78	1.89	7.24	3.20	2.85			

Table 19: Distribution of water extractable total cations and total anions (meq/l) in soil profiles of Ramthal study area

Soil Depth (cm)	Profile 1: High Elevation (meq/l)		Profile 2: Mid Elevation (meq/l)		Profile 3: Low Elevation (meq/l)	
	total cations	total anions	total cations	total anions	total cations	total anions
0-15	13.03	12.61	11.83	11.30	10.64	9.25
15-30	13.83	13.09	13.06	13.02	9.53	10.20
30-45	13.43	13.96	14.04	14.09	11.07	10.55
45-60	13.04	13.51	11.80	11.28		
60-75	13.26	13.88	13.83	13.42		
75-90	11.68	12.26	13.26	13.63		
90-100	12.53	12.49	12.95	13.29		

In terms of their distribution with depth, the soil profile-1 of high elevation (L_1) recorded higher amounts of cations and anions at all depths except at 75-90 and 90-100 cm soil layers recording slightly lower value. Contrastingly, the soil profiles of mid elevation (L_2) and low elevation (L_3) recorded higher amounts at all depths except the surface soil layer.

Soil sodicity indices: The cations and anions data were subjected to soil sodicity indices tests namely, RSC and SAR to assess the susceptibility of soils for sodification (Table 20). In terms of RSC values, all the soil profile samples were found safe from sodification. The relative dominance of carbonates and bicarbonate over calcium and magnesium was slightly higher in surface soils of profile-1 while, it declined in subsurface layers. Contrastingly, the subsurface soils of profile-2 indicated slightly higher values. However, no specific trend was observed with respect to RSC values.

The SAR index indicated that the profile-1 recorded highest SAR values in the surface soil and it gradually declined with depth. Contrastingly, the profile-2 recorded higher SAR values in subsurface soils (60-75 to 90-100 cm) than surface soils (0-15 to 45-60 cm depths). However, the SAR values of profile-3 were much lesser. Thus, the sodicity problems are likely exist in the entire area and even to subsurface soils.

4.9 Suitability of soils for different horticultural crops

Crops suitable for soil salinity tolerance levels for different horticultural crops are given in Table 21. It indicated that the yield potential of bean, onion, carrot, radish and grape are likely to get reduced to the extent of 25 per cent even at moderate levels of salinity (ECe of 2.00 to 4.00 dSm^{-1}). Similarly yield reduction are anticipated in perennial crops such as grape. These crops are sensitive for salinity. However, no major impacts on the yield potential of beetroot, tomato, pomegranate, cabbage and cucumber (90% yields with 0-10% reductions) at same salinity levels.

Tolerance yield potentials (90-100%) crops of different soil-water chloride content are given in Table 22. It is evident that most of the horticultural crops such as beans, carrot, onion, radish etc can attain the yield upto 90-100 per cent at low chloride content. Whereas, potato, cabbage, grapes are grouped under moderately tolerance with no major loss upto 15 meq/l. However, cucumber, tomato produce upto 90-100 per cent yield potential with 25 meq/l and these crops are said to be tolerant crops.

Table 20: RSC and SAR values in soil profiles of Ramthal study area

Soil Depth (cm)	Profile-1:High Elevation		Profile-2:Mid Elevation		Profile-3: Low Elevation	
	RSC (meq/l)	SAR $(meq/l)^{1/2}$	RSC (meq/l)	SAR $(meq/l)^{1/2}$	RSC (meq/l)	SAR $(meq/l)^{1/2}$
0-15	0.81	10.50	0.64	9.66	0.69	9.00
15-30	0.22	9.22	0.80	9.57	0.86	7.63
30-45	0.18	8.96	0.22	9.01	0.76	7.59
45-60	0.41	8.41	0.84	9.66		
60-75	0.42	7.84	0.54	10.91		
75-90	0.34	6.60	1.12	10.65		
90-100	0.72	7.54	1.04	10.19		

Table 21: Yield potential of important horticultural crops with soil salinity (ECe in dS m^{-1}) level

Crops	Yield potential			
	100%	**90%**	**75%**	**50%**
Bean	1.0	1.5	2.3	3.6
Carrot	1.0	1.7	2.8	4.6
Onion	1.2	1.8	2.8	4.3
Radish	1.2	2.0	3.1	5.0
Grape	1.5	2.5	4.1	6.7
Cabbage	1.8	2.8	4.4	7.0
Cucumber	2.5	3.3	4.4	6.3
Tomato	2.5	3.5	5.0	7.6
Pomegranate	2.7	3.8	5.5	8.4
Beetroot	4.0	5.1	6.8	9.6

Source: Ayers and Westcost, 1976

Table 22: Yield potential (90-100%) of important horticultural crops with Chloride concentration

Crops	**Cl^- ion conc. (meq/l)**
Bean	10
Carrot	10
Onion	10
Radish	10
Potato	15
Grape	15
Cabbage	15
Spinach	20
Cucumber	25
Tomato	25
Broccoli	25

Source: Ayers and Westcost, 1976

The result obtained for the soils of Ramthal study area on salinity parameters indicated that the soils as such are not exhibiting any ill effects in terms of pH, Electrical conductivity, sodium, carbonates, chlorides on horticultural crop. The critical values indicated in the present literature as much above the present soil salinity parameters.

5. DISCUSSION

A study was conducted to assess the influence of topography on the distribution of salts in black soils of Ramthal Micro Irrigation Project area. The results obtained from the study area are discussed in this chapter.

5.1 Soil reaction (pH) and electrical conductivity ($EC_{2.5}$)

The results on soil reactions and electrical conductivity of black soils under different land categories of Ramthal study area is depicted in Figure 2 and the spatial distribution of soil pH and electrical conductivity is depicted in Figure 3. Majority of the soil samples showed moderate to high alkalinity and the soil pH ranged from 8.13 to 9.67. The topography of the study area had influenced the soil reaction significantly at all the three elevations. The soils at low elevation (L_3) areas recorded significantly lower pH (8.80 ± 0.23) while, the soils existing on high elevations recorded higher pH values (9.15 ± 0.24).

The electrical conductivity ($EC_{2.5}$ – 1:2.5 soil water suspension) ranged from 0.10 to 0.36 dS m^{-1}. All the soil samples in the study area were observed under non saline category with $EC_{2.5}$ values of < 0.8 dS m^{-1}. The distribution of salts measured in terms of $EC_{2.5}$ varied significantly with the topography of the land. In Ramthal study area, nearly 64 per cent of soil samples (n=151) recorded medium conductivity in the range of 0.15 to 0.30 dS m^{-1} while, 27 per cent of the soil samples (n = 64) recorded conductivity of < 0.15 dS m^{-1}. The soils of low elevations areas (L_3) recorded significantly lower $EC_{2.5}$ values (0.16 ± 0.04 dS m^{-1}) while, the soils at higher elevations (L_1) recorded significantly higher $EC_{2.5}$ values (0.22 ± 0.07 dS m^{-1}). However, the $EC_{2.5}$ values of mid elevated region were on par with low elevation areas.

The soil reaction is largely determined by the type of water soluble salts and associated ions present in the soil (Bohn *et al.*, 2001; Tan, 2013). Presence of basic cations viz., calcium, magnesium and sodium in soil is known to induce soil alkalinity (Agarwal *et al.*, 1982; Rengasamy, 2010). These basic cations appear to be contributed by weathering of basaltic, lime and gneiss based parent materials (Gupta *et al.*, 1990; Chhabra, 1996). The presence of sodium along with CO_3^{-2} + HCO_3^{-1} in soil might

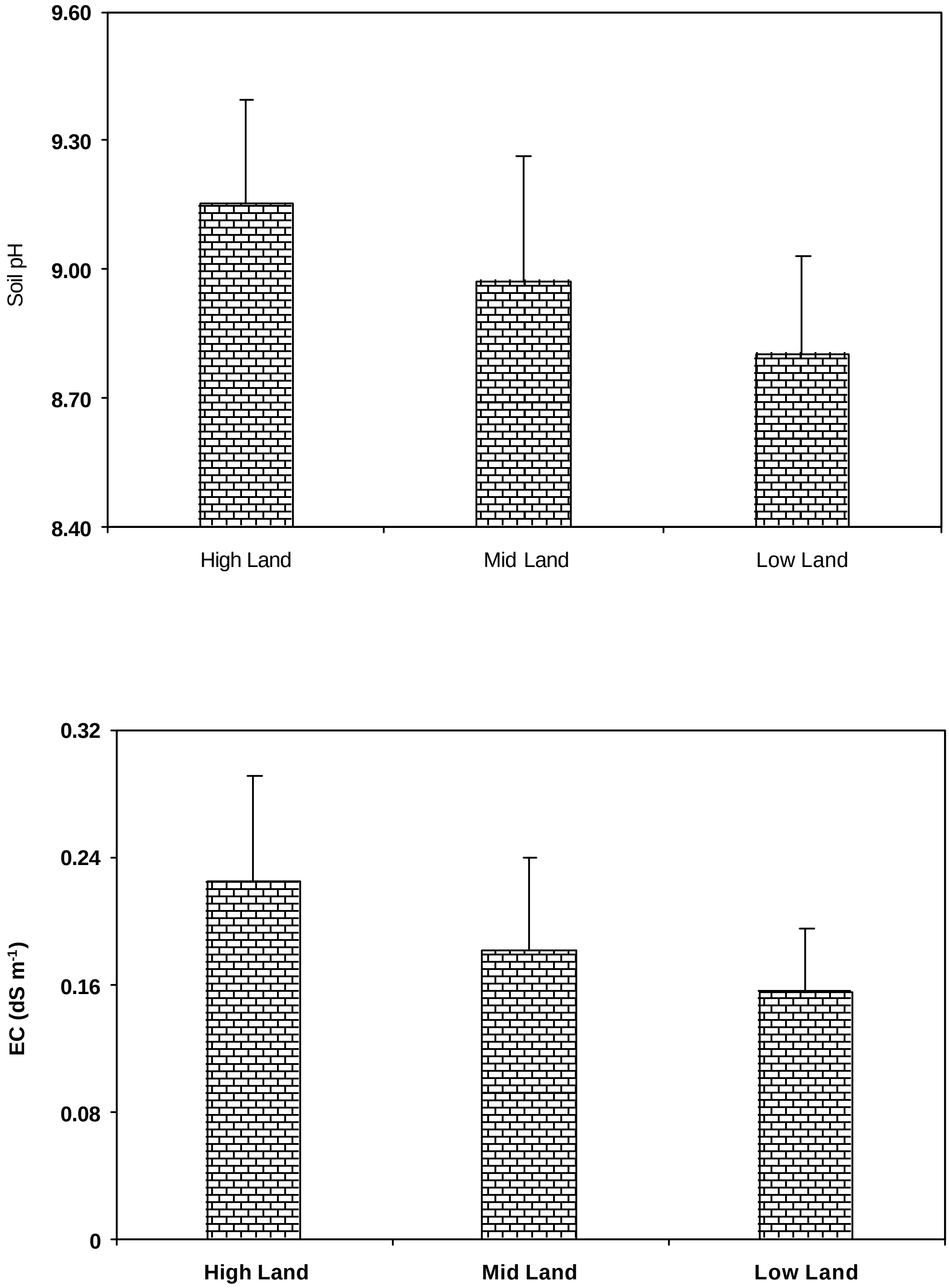


Figure 2: Influence of topography on soil reaction (pH) and electrical conductivity (EC dS m^{-1}) in Ramthal study area

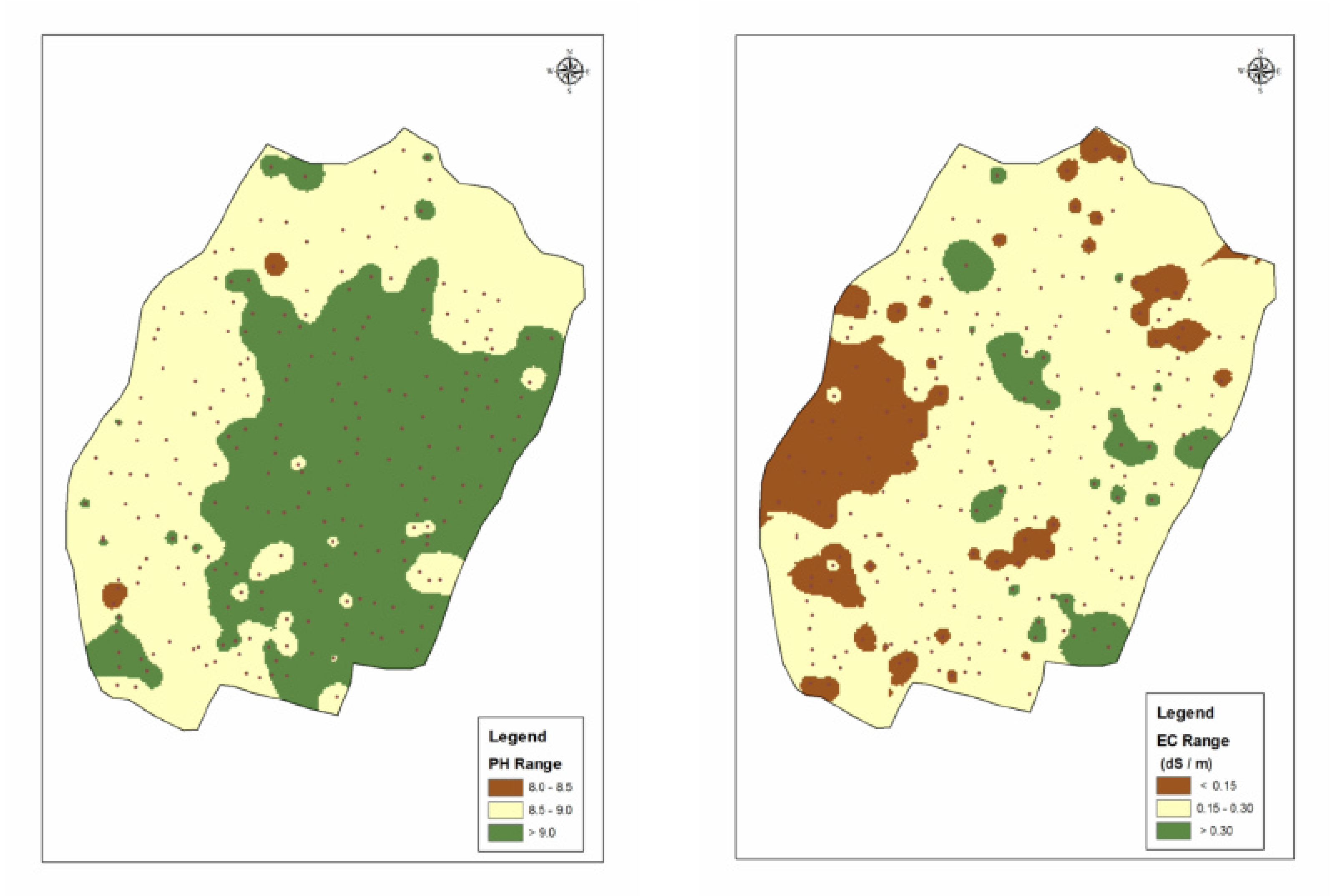


Figure 3: Spatial distribution of soil reaction (pH) and electrical conductivity (EC) in Ramthal study area

have enhanced soil pH further (Tiwari *et al.,* 1983; Sharma *et al.,* 2011). Higher pH in high elevation areas was evidenced by the presence of higher amounts of sodium, carbonates and bicarbonates (r=0.20**). Less accumulation of above alkali ions in soils might have caused lower pH in mid (L_2) and low (L_3) elevated areas. Similar values of higher pH in black soils of this region are also reported by Kuligod *et al* (2006), Kirankumar *et al.,* (2016) and Patil *et al.,* (2016).

The conductivity of soils reflects the amounts of water soluble salts in any given soil. Low rainfall and high evapo-transpiration in this region is likely to cause both reduced leaching losses and encourage salt accumulation (Chabbra, 1996). Moreover, capillary movement of water is very common in clayey soils and the magnitude of water movement depends on amounts of clay, thickness of the soil layer, evapo-transpiration losses from the soil surface (Kijne *et al.,* 1998; Rajanna *et al.,* 2018). Thus, these processes might have resulted in salt accumulation in clayey soils existing at higher elevations compared to soils of mid and low elevated areas (Pluym, 1978; Ghassemi *et al.,* 1995; Rajanna *et al., 2018*). These results were in contrast to the general observations of accumulation of salts in lower elevation areas due to transport of salts from higher region to lower region by flowing water (Alur, 2003; Jena and Natarajan, 2013; Ashwin, 2014; Patil *et al.,* 2016; Kirankumar *et al.,* 2016; Veerabhadrappa and Gundlur, 2016; Lingappa and Kuligod, 2017).

Interestingly, the $EC_{2.5}$ values of Ramthal study area were relatively lesser compared to soils of neighboring talukas (except Ilakal). This could be attributed firstly to the leaching of salts from surface soils to subsurface soils as during rainy season by percolating water (Rasool *et al.,* 2014). It was observed in the soil profile study (discussed later), where subsurface soils recorded higher $EC_{2.5}$ values. Secondary salinization due to excess irrigations and faulty water usage may be the reason in other areas (Bhadrapur and Rao, 1976). Moreover, soils derived from lime based parent material are known to possess higher salt contents especially in arid regions (Doddamani, 1994; Sharma *et al.,* 2004) and such lime materials were not found in Ramthal study area. The salinity has increased in all irrigated areas due to secondary salinization and its magnitude is determined by the source of irrigation water and the quantity of water used (Kharche and Pharande, 2010; Kadu *et al.,* 2013 and Ashwin, 2014).

5.2 Water exractable cations

The results obtained on the amounts of calcium, magnesium, sodium and potassium in soil water extract at 1:2 ratio are given in this section.

Water extractable-Ca and Mg: The amounts of calcium and magnesium present in soils of different land categories are diagrammatically given in Figure 4 and their spatial distribution in Ramthal study area is presented in Figure 5. The water extractable-Ca ranged from 0.46 to 2.52 meq/l while, the respective magnesium content ranged from 0.26 to 2.62 meq/l. These water extractable calcium and magnesium values were much lesser than the values reported for soils of Mudhol, Bilagi and Bagalkot (Ashwin, 2014 and Kirankumar, 2014). Among 236 soil sample analysed, nearly 70 percent of the samples recorded medium range (0.6-1.2 meq/l) of both calcium and magnesium. Higher amounts of calcium and magnesium (>1.2 meq/l) were observed in 25 % of the soil samples and majority of them were observed in mid elevation areas. Among different land categories, the soils existing at mid elevation areas recorded significantly higher amounts of both calcium (1.09 ± 0.37 meq/l) and magnesium (1.10 ± 0.37 meq/l). It was observed that both calcium and magnesium were found significantly least in high and low elevation areas.

Lower values in the soils of the study area may be due to the fact that these soils are mostly basaltic in origin. Geologically, there is no lime parent material in this area compared to Mudhol, Bilagi and Bagalkot talukas (Doddamani, 1994). In addition, the entire Ramthal study area was rainfed without borewell or canal irrigations and thus, there were no additions of calcium and magnesium to these soils. This may be the reason for observing contrasting results in irrigated areas (Bhadrapur and Rao, 1979; Kirankumar *et al.*, 2016; Patil *et al.*, 2016).

Lower amounts of water extractable-Ca and Mg on flat lands at higher elevations may be attributed to its movement to subsurface layers by infiltrating water (Patil *et al.*, 2016). The soil profile data also indicated higher amounts of calcium and magnesium in subsurface soils. The precipitation of calcium as carbonates at high pH also might have reduced calcium contents (Bohn *et al.*, 2001; Chhabra, 1996). The soils of lower elevations is almost on the banks of a small river let which might have caused their removal and thus, resulting in lesser values.

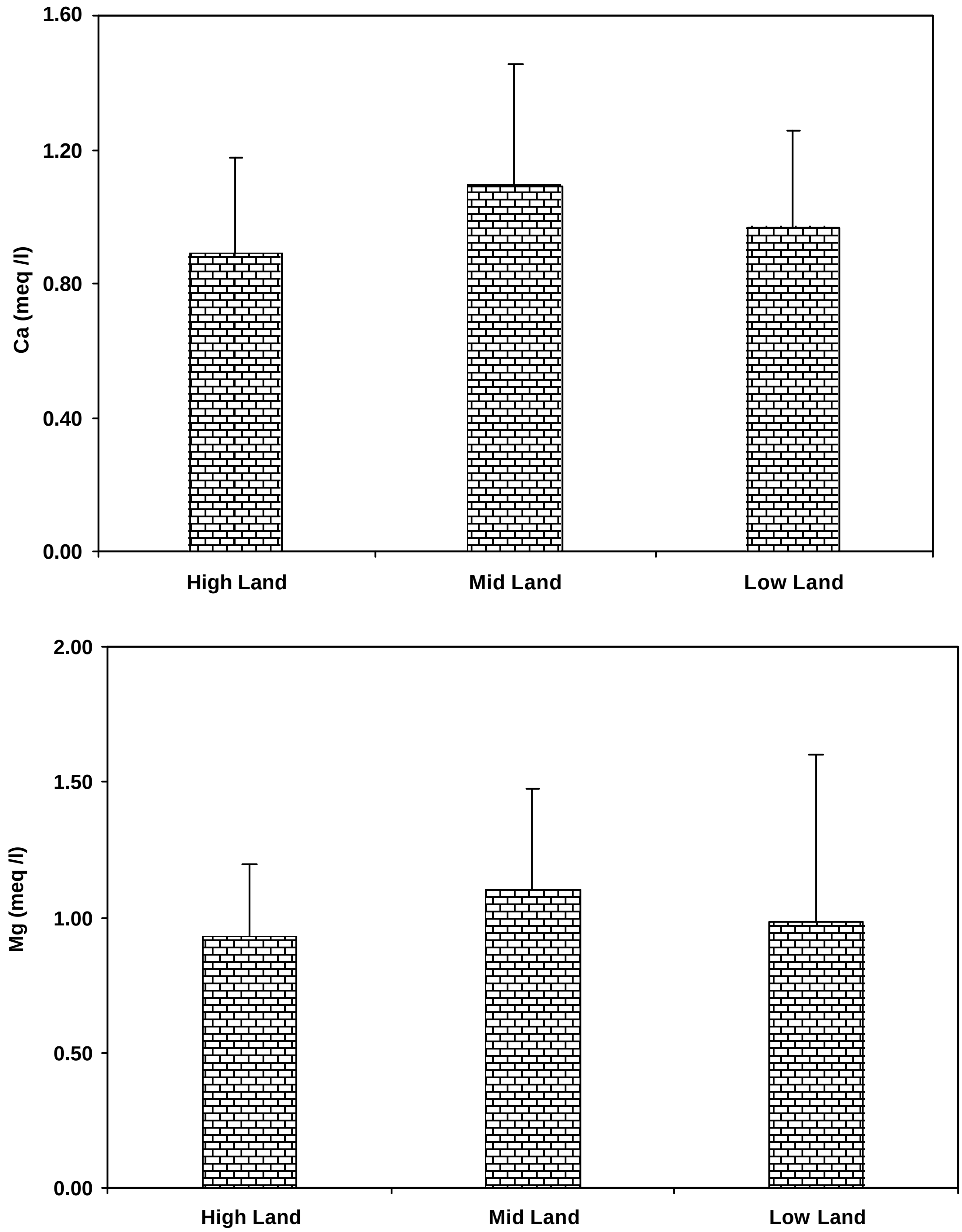


Figure 4: Influence of topography on water extractable calcium and magnesium in Ramthal study area

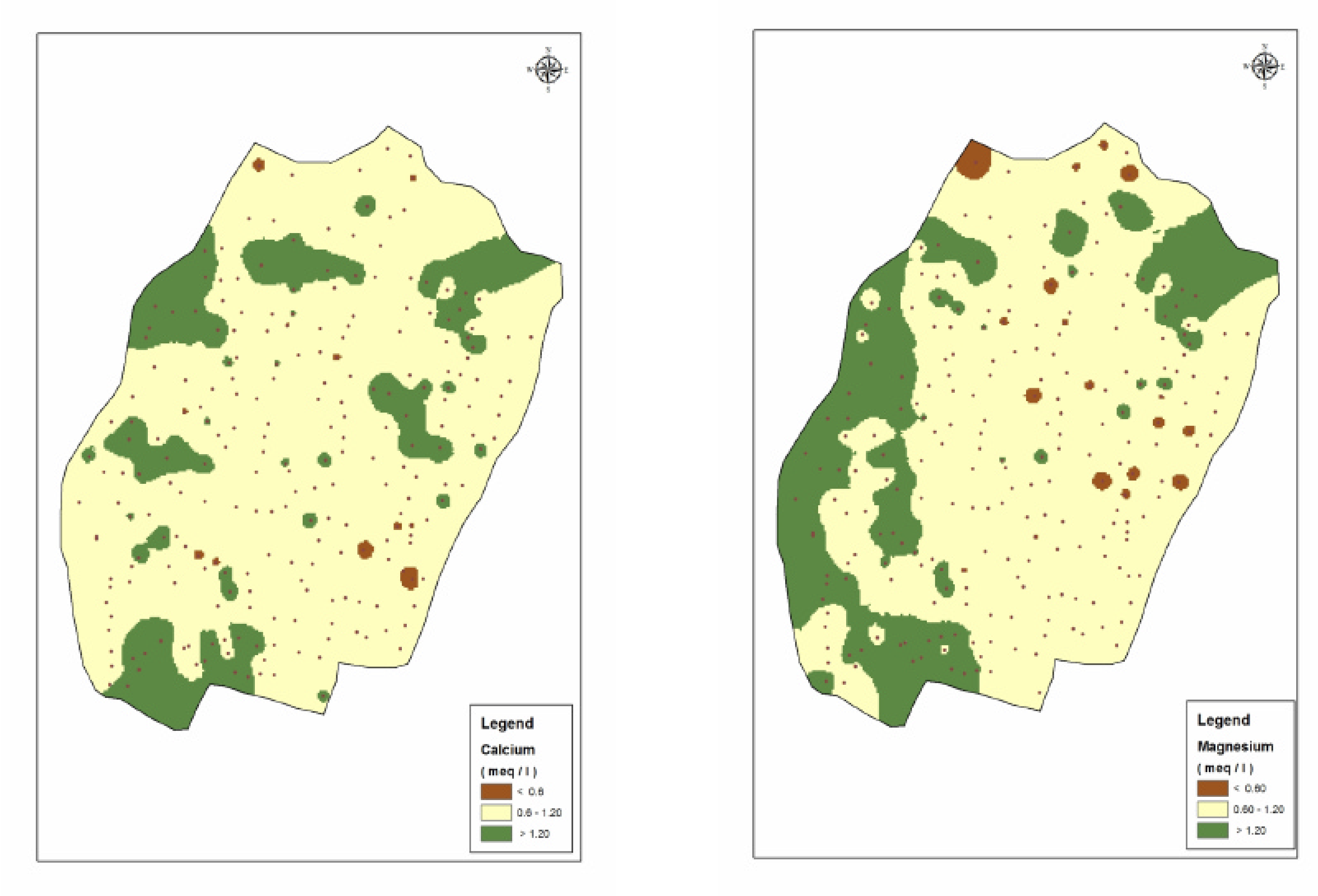


Figure 5: Spatial distribution of water extractable calcium (Ca^{+2}) and magnesium (Mg^{+2}) in Ramthal study area

Water extractable-K and Na: The information on water extractable– K in soils existing on lands at different elevations are depicted in Figure 6 and the spatial distribution of these ions are presented in Figure 7. Among water extractable cations, the concentration of sodium was substantially higher than other cations viz. Ca, Mg and K. The concentration of potassium in soil-water extractants ranged from 0.05 to 0.31 meq/l while, sodium was in the range 3.37 to 17.5 meq/l. Similar to calcium and magnesium, the water extractable –Na was in lower range compared to other regions of the district (Katti and Rao, 1979). In terms of water extractable-K, soils of high elevated areas recorded significantly lower amounts (0.13 ± 0.05 meq/l) compared to soils existing at low elevations (0.18 ± 0.05 meq/l). The potassium in soil water extract varied significantly in the order of low > mid > high elevations. Contrastingly, the water extractable-Na was significantly higher in high elevated areas (10.90 ± 2.03 meq/l) compared to mid and low elevation areas.

The entire Ramthal Micro-Irrigation Project area, as indicated earlier, is under rainfed conditions and application of K-fertilizer is very much limited as majority of the farmers do not use K-fertilizes for dryland crops *viz.*, jowar, bajra, chickpea, *etc.* Moreover, the K^+ ions exhibits adsorption behavior and thus, much of the potassium in soil exists as exchangeable-K than in the soil solution (Bohn *et al.,* 2001). Lesser amounts of water extractable-K compared to other regions may be attributed to the above reasons. The movement of K^+ in clayey soils also gets restricted as it interacts with soil colloids (Rengasamy, 2010; Tan, 2013). The variations with respect to potassium among different land categories could also be attributed to differential amounts of K-removal by the crops.

The productivity of a crop in clayey soils under rainfed conditions largely depends on the thickness of the soil profile. Capillary movement of water during summer enhances the moisture availability and thus, higher productivity is generally observed in deep clayey soils compared to medium and shallow deep clayey soils. High productivity also means more crop uptake and more K-removal from soils. Similar reports of K-depletions are reported by Rekha *et al.* (2018) in areas where K-removal is not compensated.

Higher amounts of water extractable-Na in high elevation areas may be due to movement of sodium salts from subsurface layers to surface soils by capillary water

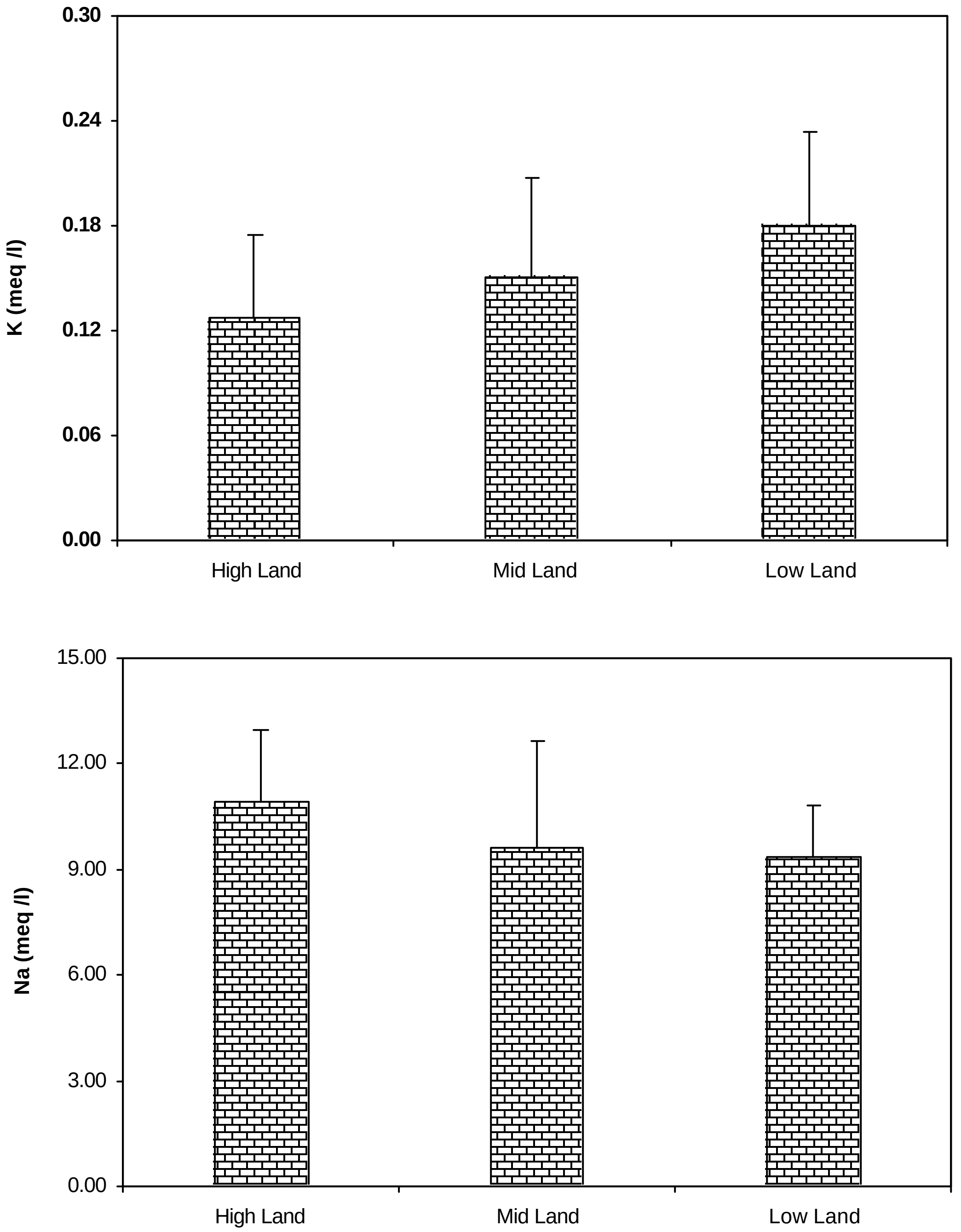


Figure 6: Influence of topography on water extractable potassium and sodium in Ramthal study area

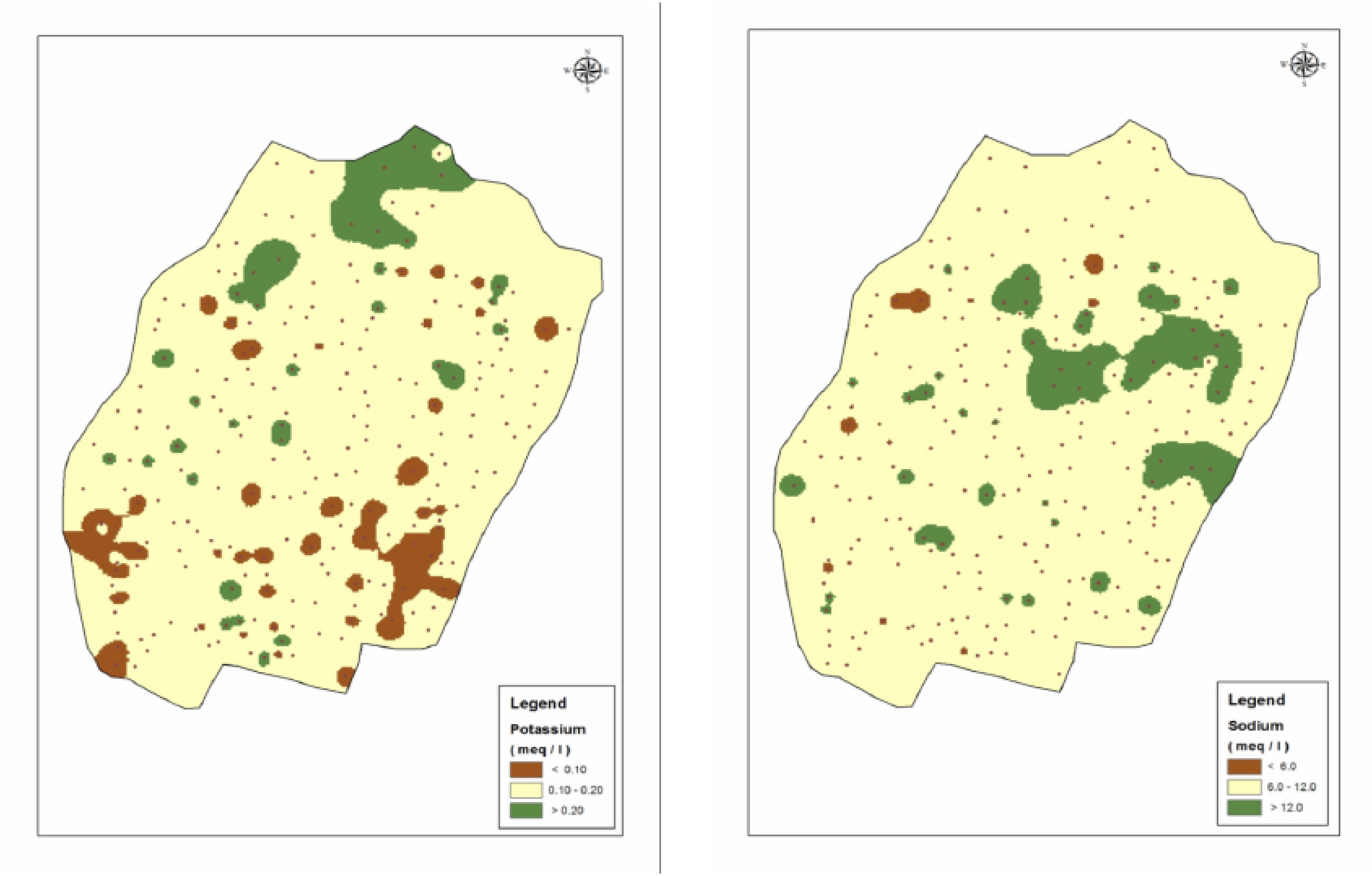


Figure 7: Spatial distribution of water extractable potassium (K^+) and sodium (Na^+) in Ramthal study area

(Agarwal and Ramamurthy, 1970). Moreover, sodium ions are excluded during plant uptake and thus, results in its accumulation. Lateral movement of salts along with percolating water during high rains also might have altered sodium balance. These results were in contrast to the general observations of movement of ions (salts) from ridge to valley through water reported by many authors (Alur, 2003; Kharche and Pharande, 2010; Kirankumar, 2014; Lingappa, 2017 and Kuligod, 2006).

5.3 Water extractable anions

Total carbonates and bicarbonates: The amounts of carbonate and bicarbonates were determined together and their concentrations among different land categories and their spatial distribution are depicted in Figures 8 and 9 respectively. Most of soil samples exhibited medium (n=103; 42.8 %) to higher (n=123; 52.1 %) ranges of total carbonates and bicarbonates. Among different land categories, soils existing at high and mid elevations recorded higher amounts of total carbonates and bicarbonates with respective values of 2.89 ± 0.84 meq/l (in L_1) and 2.91 ± 0.80 meq/l in (L_2). Contrastingly, the soils at lower elevations (L_3) recorded least amounts (2.45 ± 0.84 meq/l). However, these values in Ramthal area were considerably lower than the values reported for soils of other regions especially, Bijapur and Bagalkot (Yogeeshappa, 2007; Ashwin, 2014; Kirankumar *et al.*, 2016).

Generally, the carbonates and bicarbonates are produced by dissolution of CO_2 in soil water. During alternate wetting and drying cycles, more CO_2 gets dissolved in soil water and thus, they enter into the soil system (Chhabra, 1996; Sharma *et al.*, 2011; CSSRI, 2014). The dissolved carbonates interact with other cations and forms respective carbonatious salts. These carbonateous salts mostly of Na^+, are highly soluble and get transported along with water (Rengasamy, 2002). Thus, the movement of capillary water during summer from subsurface soils to surface leads to their accumulations (Chhabra, 1996). This may be the reason for observing significantly higher amounts of carbonates and bicarbonates in high and mid elevation areas. However, lesser soil volume (in terms of soil thickness) in low elevation areas might have caused less capillary movements and hence, lesser carbonates and bicarbonates in these soils. The soil profile studies also showed lesser carbonates and bicarbonates in subsurface soils of low elevation areas (L_3) indicating lesser movement of the above anions to the surface soils compared to mid (L_2) and high (L_1) elevation.

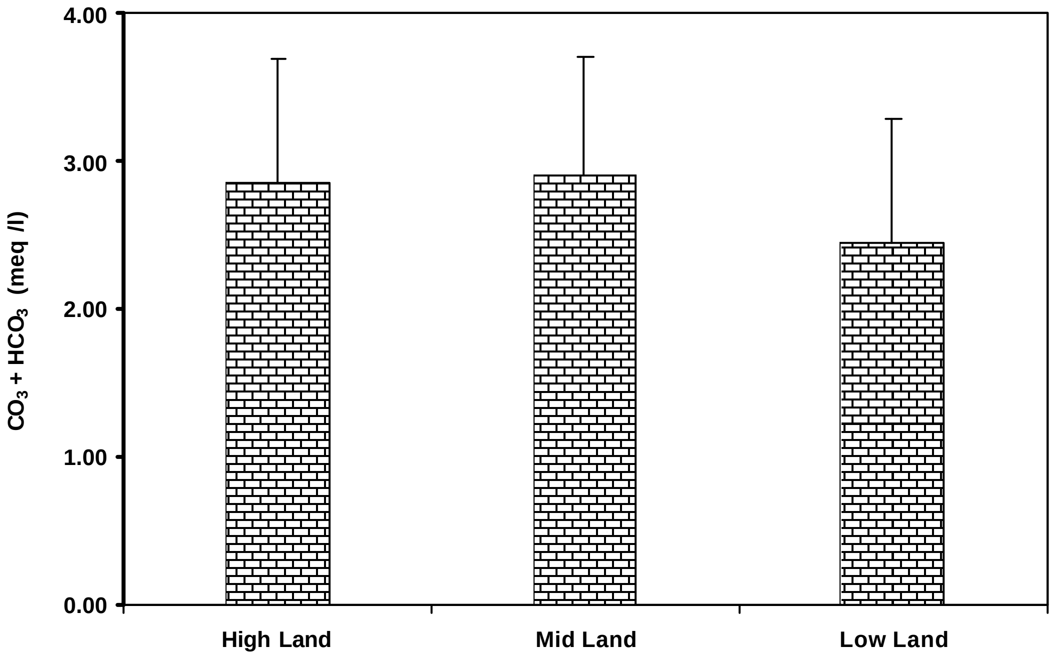


Figure 8: Influence of topography on water extractable carbonate + bicarbonate in Ramthal study area

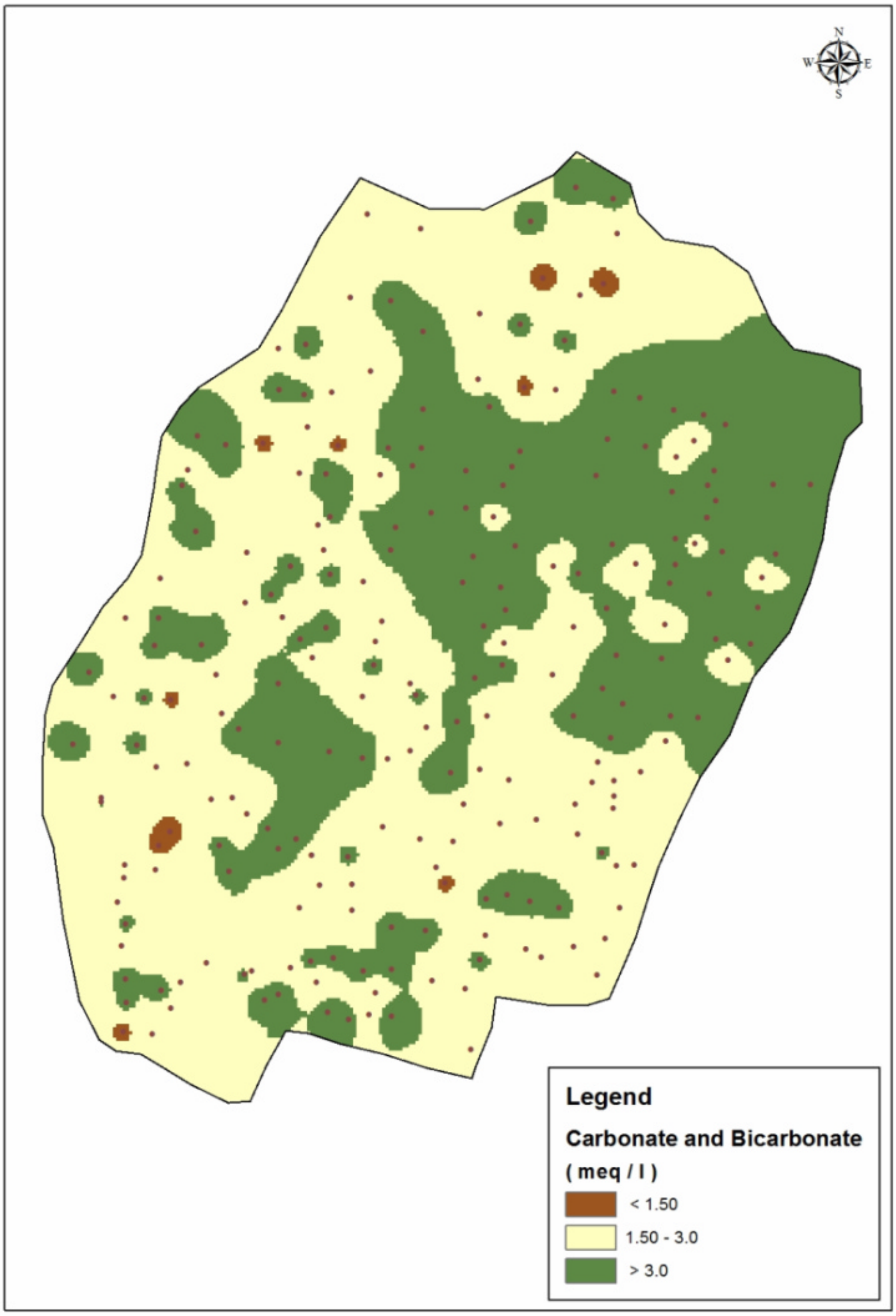


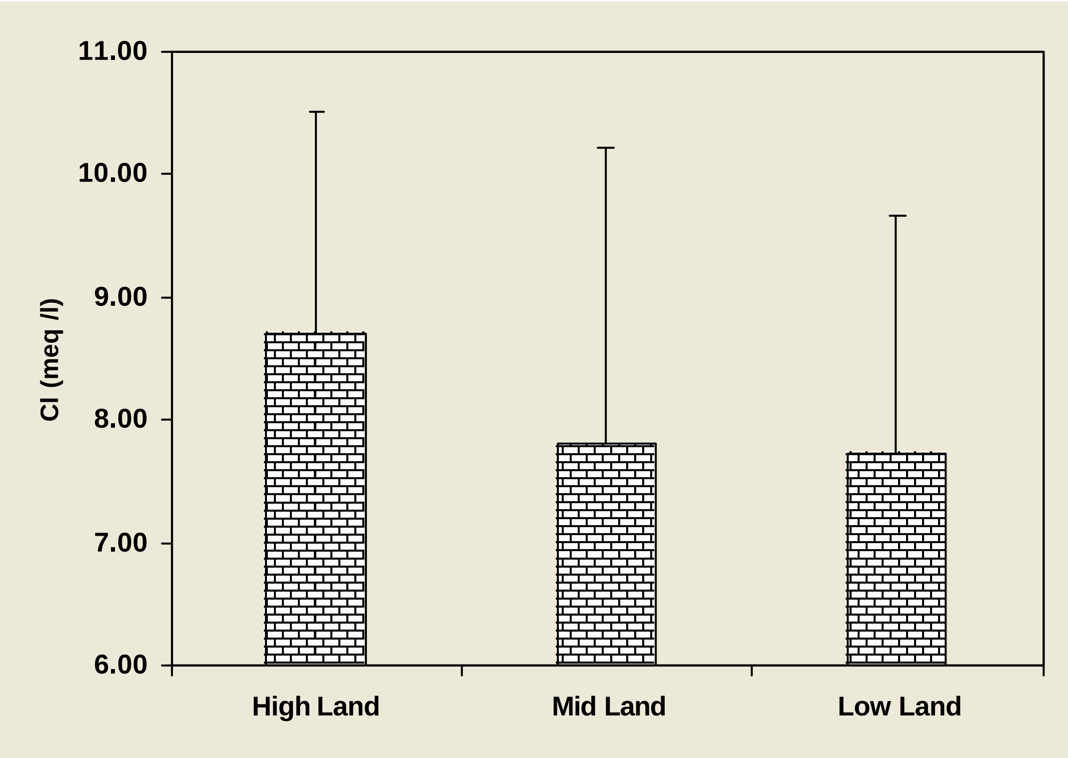
Figure 9: Spatial distribution of water extractable total carbonates (CO_3^{2-} + HCO_3^-) in Ramthal study area

These values were much lower compared to soils of other areas especially, with irrigated areas. This could be due to the fact that the soils of earlier mentioned areas namely, Mudhol, Bijapur, Bagalkot, Bilagi etc are lying on lime based geological material. Thus, large amounts of carbonates and bicarbonates get added with weathe ring process (Agarwal *et al.*, 1982). In irrigated areas, the use of borewell water or any other water with high carbonates and bicarbonates result in its build up over time (Minhas and Sharma, 2003; Sharma *et al.*, 2011; Kirankumar *et al.*, 2016; Rekha *et al.*, 2018).

Chlorides and Sulphates: Occurrence of chlorides along with sulphates in soils is very common. The concentrations of chlorides and sulphates in soils of different land categories are diagrammatically depicted in Figure 10 and their spatial distribution in Ramthal study area are depicted separately in Figure 11. The concentration of chloride in soils ranged from 1.80 to 14.40 meq/l while, the sulpahte varied from 0.48 to 1.80 meq/l. More than 3/4th of soil samples (n = 177; 75%) were observed in medium chloride range (5- 10 meq/l) while, only 20.3 per cent of the samples (n = 48) were found with higher chloride contents (>10 meq/l).

With respect to sulphate, nearly half of the soil samples (n = 107) were observed with medium amounts of sulphates (0.60 – 1.20 meq/l) while, the other half belonged to higher range (> 1.20 meq/l). In general, both water extractable chlorides and sulphates were found higher on high elevation areas and gradually reduced with decrease in elevation. Similar to other cations and anions discussed earlier, the values of chlorides and sulphates were also lesser compared to other areas with irrigation practices and soils derived from gypsic parent material (Ballolli, 1987; Ashwin, 2014; Kirankumar, 2014).

Among anions, the chlorides and sulphate salts are highly soluble in nature. High solubility nature of these salts makes them highly mobile within and across soil profile depending on the magnitude of water movement (Balphande *et al.*, 1996). During rainy seasons, the rain water appears to have carried these salts to deeper layers as observed in the profile studies. However, the capillary movement of water during summer carries the same chlorides and sulphates to surface depending on evapo-transpirational losses from surface soils (Singh *et al.*, 2014). This suggests that the soils exhibiting higher capillary movement are likely to accumulate chloride and



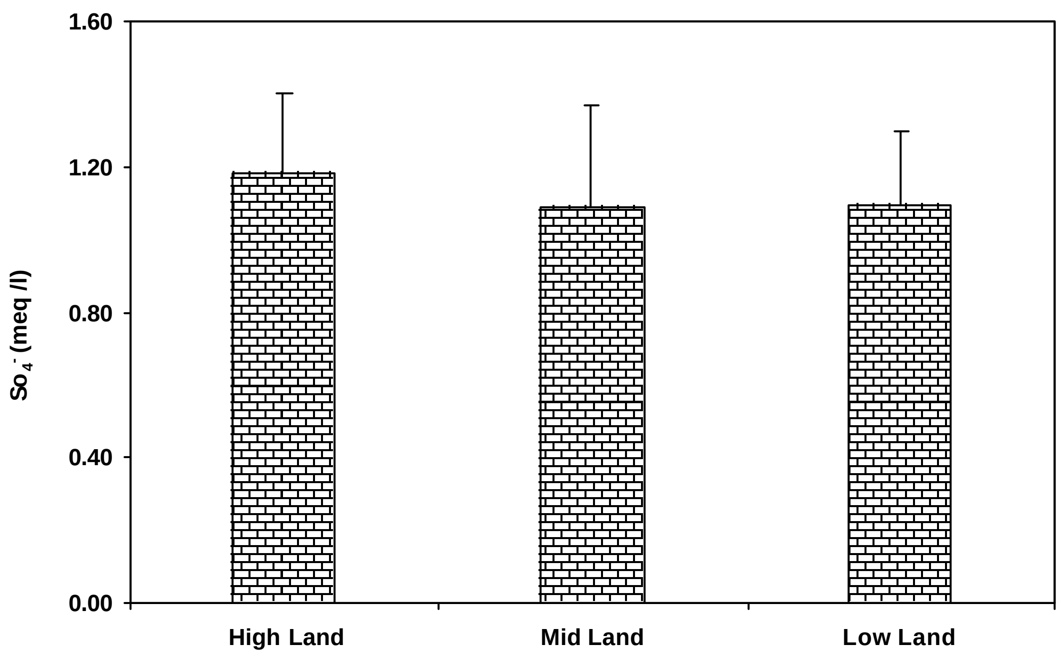


Figure 10: Influence of topography on water extractable chloride and sulphate in Ramthal study area

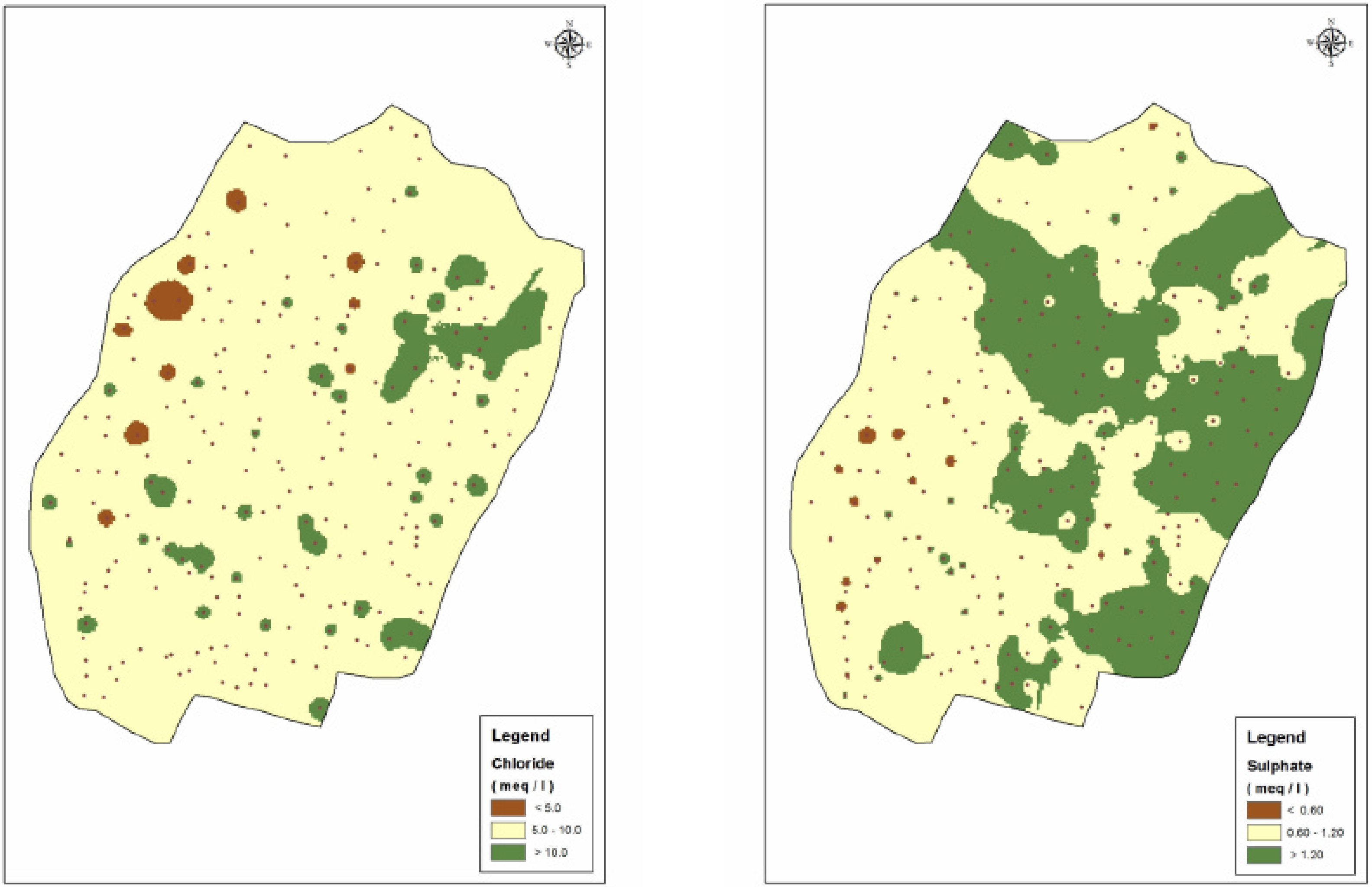


Figure 11: Spatial distribution of water extractable chloride (Cl^-) and sulphate (SO_4^{2-}) in Ramthal study area

sulphates to higher levels (Challa *et al.,* 2000). This could be the major reason for observing significantly higher amounts of both the anions in high elevated areas compared to mid and low elevated regions. Contrastingly, higher amounts of chlorides were observed along the low lying areas compared to higher elevation areas (Bharambe *et al.,* 1990; Challa *et al.,* 2000; Kirankumar *et al.,* 2016).

Moreover, the uptake of chlorides and sulphates by plants are much lesser compared to the amounts added by capillary transport and thus, they get accumulated in surface soils during summer (Datta *et al.,* 2016). In irrigated areas, the irrigation water itself is a source of chlorides and sulfates and thus, their enrichment in soils is anticipated with irrigations. Hence, the irrigated soils are more likely to possess higher chloride and sulphate values compared to dryland areas (Ashwin, 2014; Kirankumar *et al.,* 2016).

5.4 Water extractable total cations and anions

The concentration of total cations and anions in the soils were estimated by adding respective cations (Ca^{2+}, Mg^{2+}, Na^{+} and K^{+}) and anions (CO_3^{2-} , HCO_3^{-}, Cl^{-} and SO_4^{2-}) in soil water extracts. The total amounts of cations and anions in soils among different land categories are depicted diagrammatically in Figure 12 and their spatial distribution in Ramthal study area in Figure 13. The total cations concentration ranged from 5.70 to 19.61 meq/l while, the total anion concentration ranged from 5.74 to 18.50 meq/l. Similar to the values of $EC_{2.5}$ and individual ions, the amounts of water extractable cations and anions were substantially lower than black soils existing in this region of Bijapur and Bagalkot. With respect to total cations and anions, all most all the soil samples were observed with medium to higher range values. Interestingly, majority of these samples were observed in mid and high elevation areas.

In terms of their mean values among different land categories, the soils existing at high elevations (L_1) recorded significantly higher values of both cations (12.84 ± 1.98 meq/l) and anions (12.74 ± 2.29 meq/l). Contrastingly, soils belonging to mid elevation (L_2) and low elevations (L_3) recorded significantly lesser amounts. The values of total cations in soil water extract were almost equal to their respective total anions present in each land category.

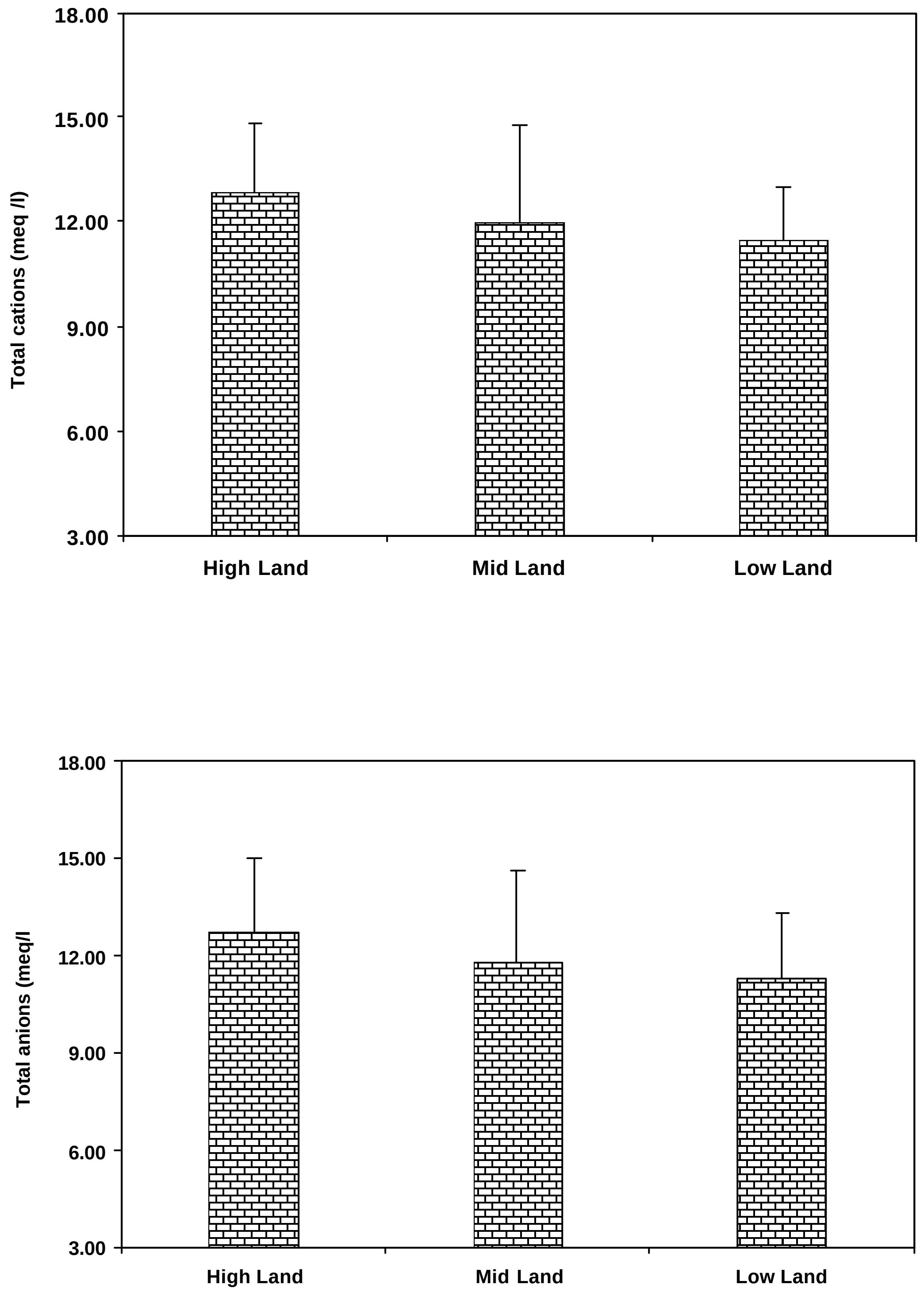


Figure 12: Influence of topography on water extractable total cations and total anions in Ramthal study area

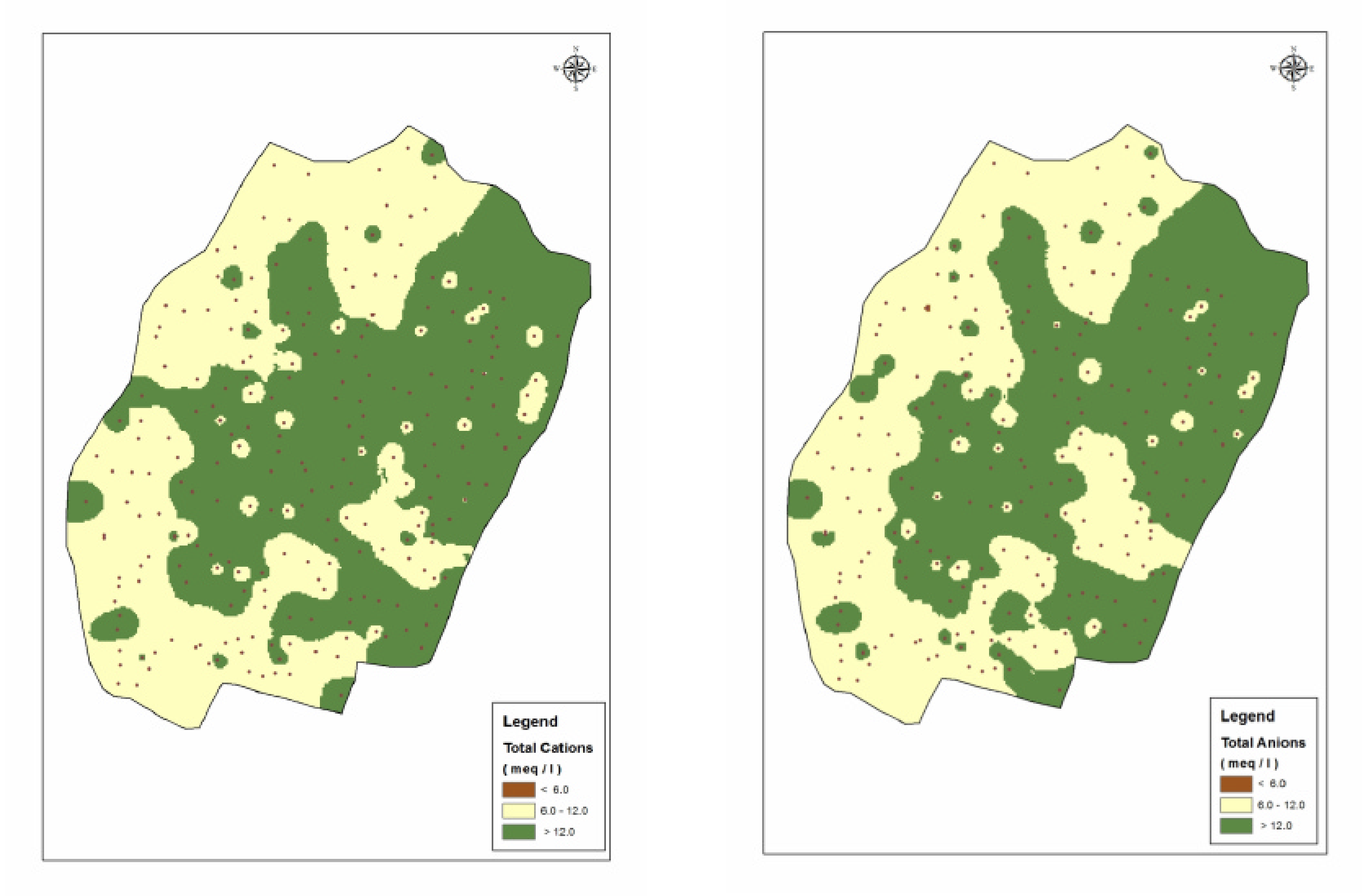


Figure 13: Spatial distribution of water extractable total cations and total anions in Ramthal study area

The amount of total cations and anions present in soil water extract basically represent the amounts of water soluble salts in a given soil (Chhabra, 1996). The amounts of cations and anions in soils of high elevation areas (L_1) were significantly higher than mid (L_2) and low (L_3) elevation areas. This could be attributed to the movement of salts from subsurface horizons to the surface soils along with water to balance the evapo-transpirational losses occurring during summer (Gupta and Abrol, 1990; Rajanna *et al.,* 2018). The magnitude of salt accumulation depends on the thickness of the clayey soil, the amounts of salts present in the subsurface soils and the extent of evapo-transpirational losses occurring on the surface soils (Kharche and Pharande, 2010; Kadu *et al.,* 2013). Deep clayey soils existing in high elevated areas might have undergone higher magnitude of upward movement of water and thus, resulting in accumulation of salts and their respective cations and anions in surface soils compared to soils of mid and low elevation areas (Singh *et al.,* 2014; Rajanna *et al.,* 2018). The chlorides and sulfates in soil also exhibited good correlation with soil salinity values.

The total amounts of cations and anions observed in soil water extracts of these soils were substantially lower than similar black soils existing in Mudhol, Bagalkot, Bilagi and Bijapur (Ballolli, 1987; Yogeeshappa, 2007; Kirankumar, 2014). It could be due to the fact that the Ramthal Project area was under rainfed agriculture for many years and there was no secondary salinization (addition of salts through irrigation water) as it is observed in soils of above talukas. Influence of irrigation, in terms of volume and quality of irrigating water, on salt accumulation is well established (Costa *et al.,* 1991) and many alternate packages have been developed to reduce the ill effects of irrigations (Minhas and Sharma, 2003; CSSRI, 2014).

5.5 Soil sodicity indices

The soils of arid and semi-arid regions are prone for salt induced salinity and sodicity problems. The susceptibility of soils for sodicity and the extent of sodicity are evaluated using residual sodium carbonates (RSC) and sodium adsorption ratio (SAR). The results obtained on these indices are discussed below.

Residual sodium carbonate (RSC) and sodium adsorption ratio (SAR):

The RSC and SAR values are used to assess the susceptibility of a soil for sodification/alkalization. Extent of variations in RSC and SAR values among different land categories and their spatial spread in the study area are depicted in Figures 14 and 15 respectively.

In general, the RSC values were found in safer limits though the carbonates and bicarbonates were more than calcium and magnesium contents in soil solution. The RSC values ranged from -1.98 to 3.51 meq/l. Nearly 70 per cent of the soil samples (n = 166) were found with medium RSC range values with 0.0 to 2.0 meq/l. Only 10% of the soil samples indicated higher RSC values (>2 meq/l). The soils existing at higher elevation (L_1) recorded significantly higher RSC values of 1.05 ± 0.93 meq/l. Contrastingly, the soils of area at low elevations (L_3) recorded least RSC values (0.50 ± 1.11 meq/l) and it was found on par with mid elevation (L_2: 0.70 ± 1.10 meq/l) land category (Figure 14 and 15).

Higher RSC contents in high elevation areas could be attributed to accumulation of higher amounts of carbonates and bicarbonates over calcium and magnesium contents. In terms of relative mobility, the carbonates and bicarbonates are highly mobile as both anions and soil colloids are negative in nature (Lal and Steward, 1990; Rengasamy, 2002; Tan, 2013; Edgar *et al.,* 2012). Contrastingly, the calcium and magnesium are cationic in nature while, the soil colloids possess negative surface. Thus, the cations present in soil water are retained/ obstructed by soil colloids during capillary movement of water (Bohn *et al.*, 2001; Tan, 2013). Thus, the process would lead to dominance of alkaline carbonates resulting in higher RSC values in high elevation areas. As discussed earlier, the magnitude of capillary movement of water is likely to be more in high elevated areas and thus, the dominance of alkaline carbonates over calcium and magnesium are likely to be more in high elevated areas compared to other areas (Sharma *et al.*, 2011). Thus, the soils existing in high elevation areas are more susceptible for sodification than mid elevation and low elevation soils.

In terms of SAR, the values ranged from 2.90 to 20.65 $(meq/l)^{½}$. In the study area, > 70% of soil samples were found safe in terms of sodification with SAR values

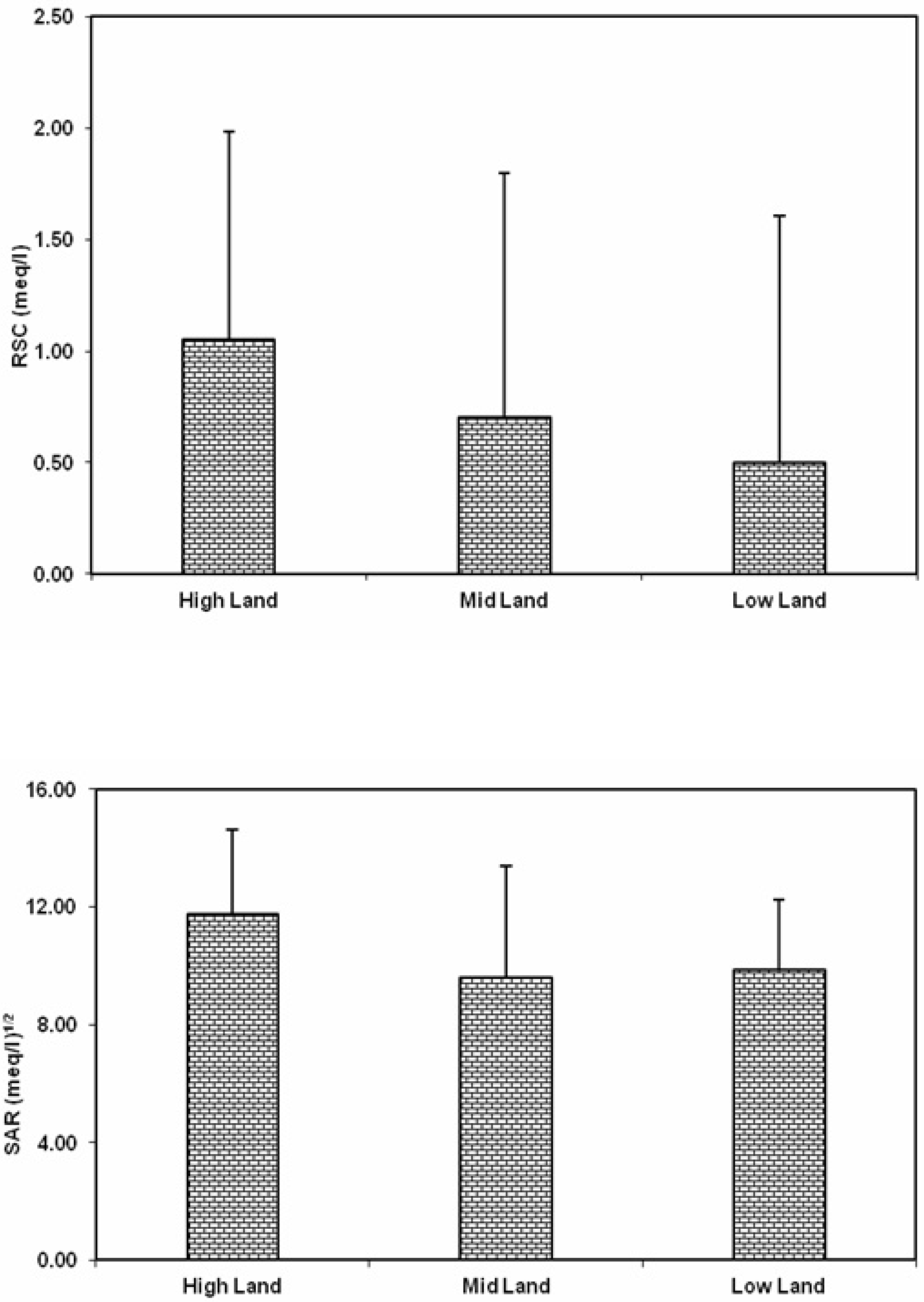
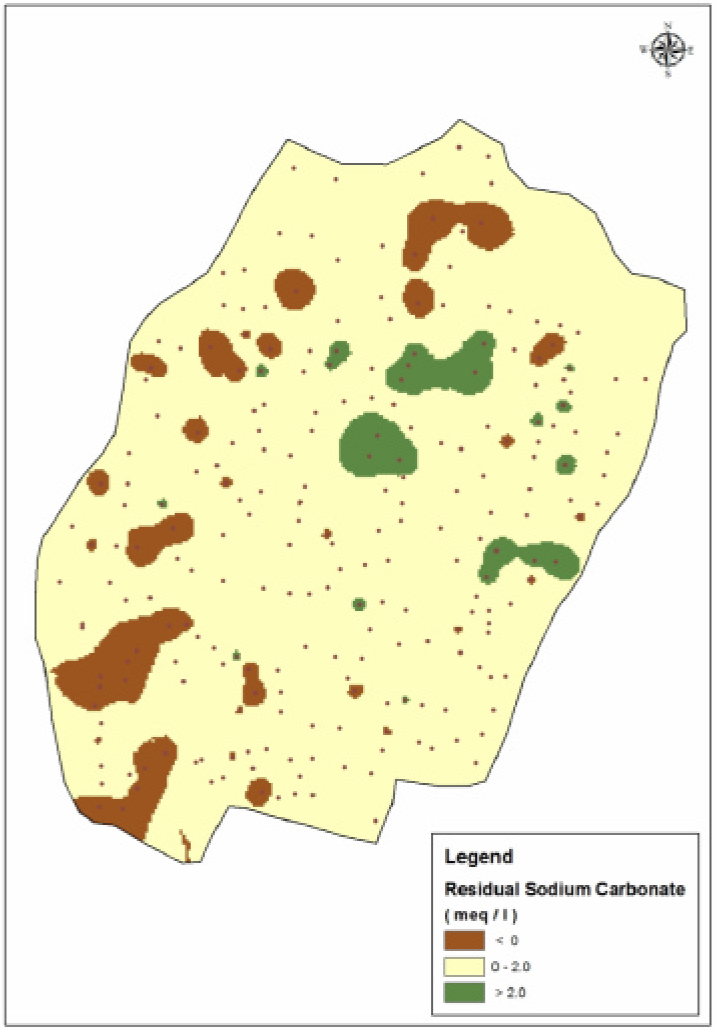


Figure 14: Influence of topography on RSC and SAR values in Ramthal study area



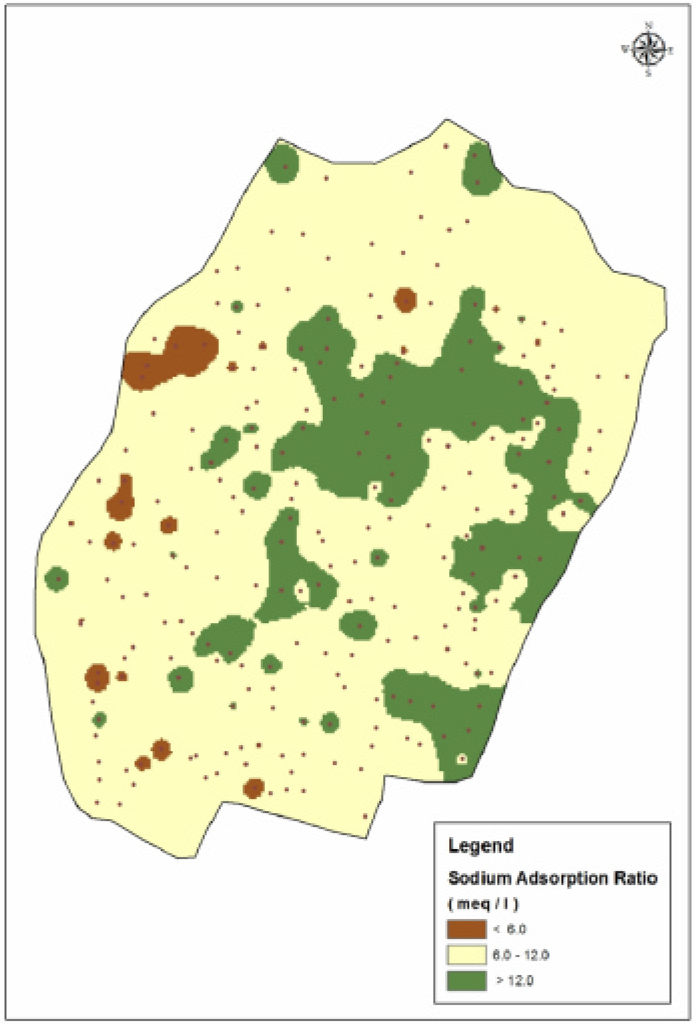


Figure 15: Spatial distribution of RSC and SAR values in Ramthal study area

of < 10 $(meq/l)^{½}$. However, 30 percent of the soil samples indicated moderate sodicity risks with higher SAR values of >10 $(meq/l)^{½}$. It was observed that the soils existing in high elevated areas (L_1) were relatively more susceptible for sodification compared to low (L_3) and mid (L_2) elevated areas. The soils existing on high elevated areas (L_1) exhibited significantly higher SAR values of 11.75 ± 2.87 $(meq/l)^{½}$. The SAR values of soils existing at mid elevation (L_2) and low elevation (L_3) areas were found significantly lesser (Figures 14 and 15).

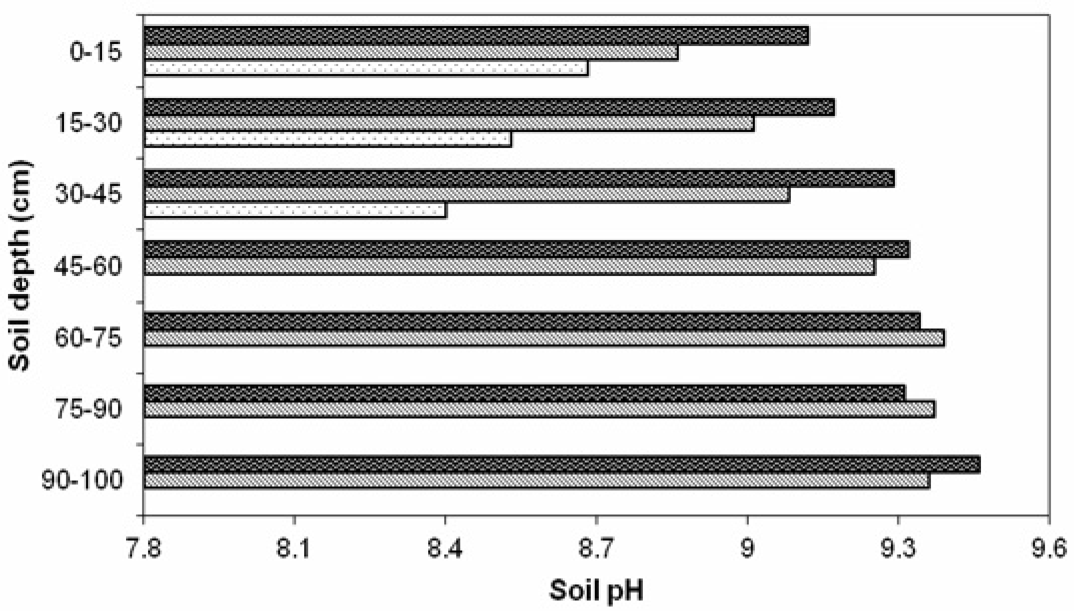
During the capillary movement of water, movement of sodium is likely to happen though the ion is positively charged cation. It is due to the fact that the Na^+ ions possess least affinity for adsorption compared to other polyvalent cations (Bohn, 2001; Tan, 2013). The lyotropic sequence of cations adsorption on soil colloids is of the order: $H^+ = Si^{4+} > Al^{3+} > Ca^{2+} > Mg^{2+} = K^+ > Na^+$. In other words, there is more mobility of Na^+ than divalent cations (Ca^{2+} and Mg^{2+}). This could be the reason for observing significantly higher SAR values in high elevation areas (L_1) than mid (L_2) and low (L_3) elevation areas. Thus, the soils of high elevation areas were found more susceptible for sodification.

5.6 Soil profile studies

The entire study with a topographical gradient of about 30 meters was grouped into high elevated (L_1), mid elevated (L_2) and low elevated (L_3) areas with respective elevations of > 526 m, 516 - 526 m and < 516 m. Three representative soil profiles were excavated for the above three categories to understand the effects of topography on soil salinity parameters and the results obtained are discussed below.

Soil reaction (pH) and electrical conductivity ($EC_{2.5}$): The pH and electrical conductivity of three soil profiles are depicted in Figures 16. In all the three soil profiles, the pH was more than 8.5 and showed moderate to high alkalinity. Higher soil pH could be attributed to the presence of total carbonates along with sodium in higher amounts (Chhabra, 1996; Rengasamy, 2010; Sharma *et al.*, 2011). As these salts are highly soluble in nature, they exhibit high mobility and move along with water. Thus, occurrence of carbonates and sodium in the entire profile may be the reason for observing higher pH in all the three soil profiles at all depths (Minhas and Sharma, 2003; Sharma *et al.*, 2011). The movement of other easily soluble salts such

Soil Reaction (pH)



Electrical Conductivity

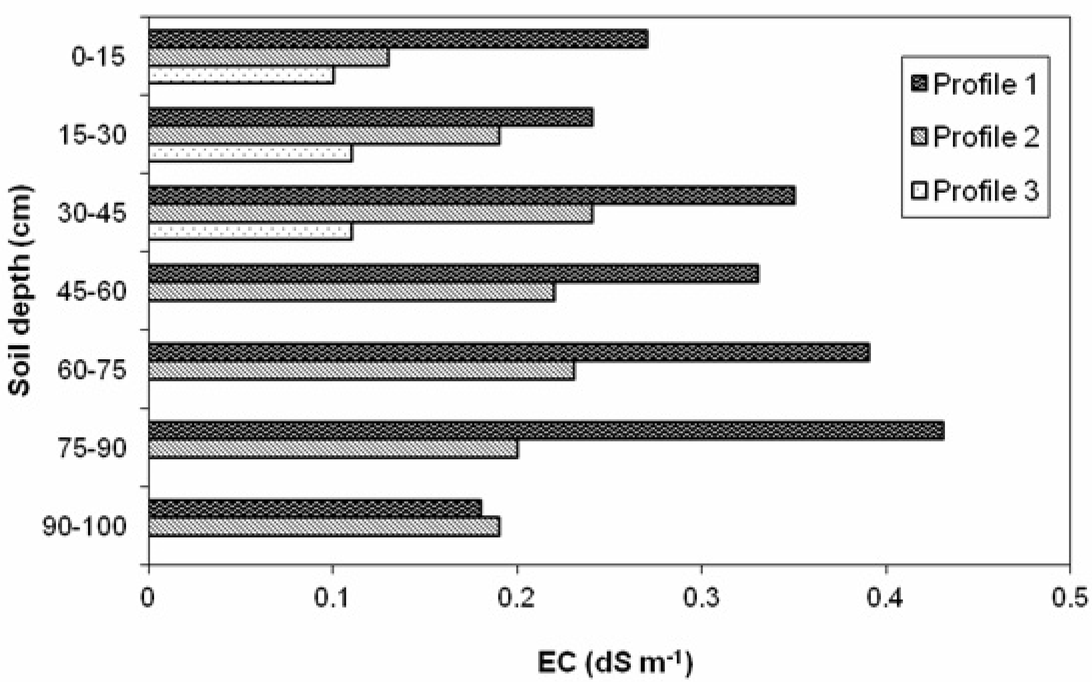


Figure 16: Vertical variation of pH and Electrical conductivity of soil profiles in Ramthal study area

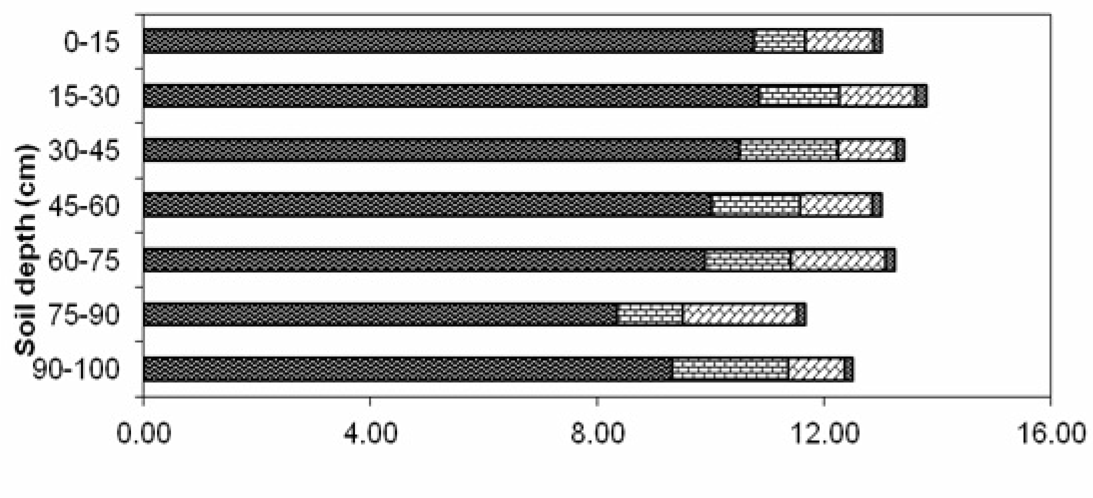
as chlorides and sulfates of sodium and magnesium etc might be the reason for observing higher $EC_{2.5}$ values at lower depths (Kadu *et al.,* 2013; Marami *et al.,* 2017). It clearly demonstrates the movement of salts to deeper layers by the percolating water.

Water extractable cations and anions: The amounts of water extractable total cations and anions across 3 different soil profiles are depicted in Figures 17, 18. Among different soil water extractable cations, the amounts of sodium was substantially higher than other cations while, water extractable-K was found least in all the three profiles. In general, the soils of Profile-1 recorded higher amounts of cations and cations compared to soil profiles of mid and low elevations (Profile-2 and Profile-3). In terms of anions, the chloride was substantially higher in all the profile samples while, SO_4^{-2} was least.

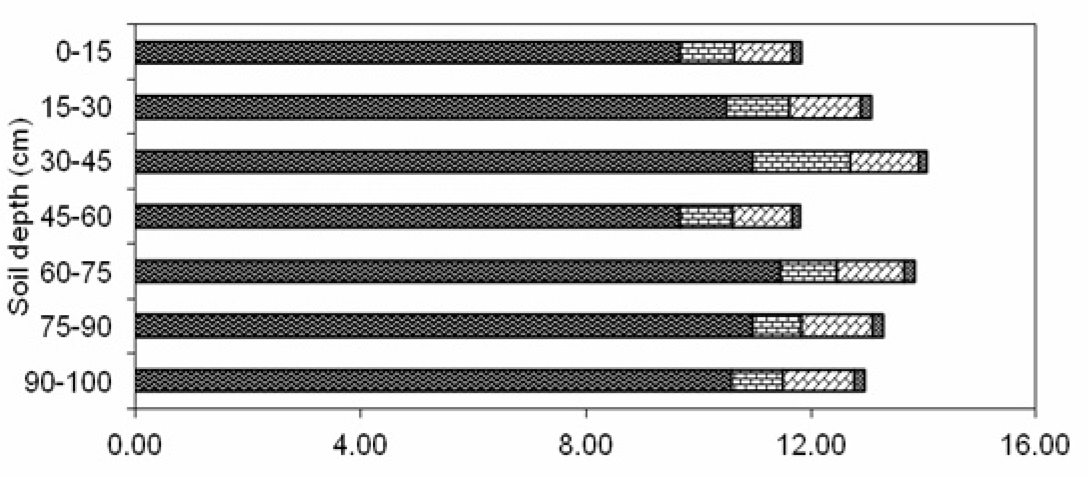
In terms of the effect of topography on salt distributions, the profile samples at high elevation (L_1) had higher amounts of both cations and anions compared to mid (L_2) and low (L_3) elevations. In clayey soils, the water movement is observed in both the directions. During rainy season, the salts get transported to deeper layers along with the percolating water. In contrast, the same salts move upward along with capillary water during summer period. This appears to be the major reason for observing higher values of salinity and associated cations and anions during summer. Contrastingly, the same soils posses lower salinity and lesser amounts of cations and anions during rainy season probably due to leaching of salts (Balaphande *et al.,* 1996; Alur, 2003).

Soil sodicity indices: In terms of susceptibility of soils for sodification, all the profile soil samples indicated higher SAR and RSC values (Figures 19). This could be due to production of higher amounts of carbonates and bicarbonates in arid region due to frequent alternate wetting and drying cycles (Sharma *et al.,* 2011). These carbonates and bicarbonates are highly mobile and get carried along with water. Similarly, the sodium ion is least preferred for adsorption on soil colloids compared to other cations. Movement of above ions along with water across soil layers is very common. They alter the ionic balance in the soil system in terms RSCs and SARs and thus, induce sodicity in the soil. This could be the reason for exhibiting higher susceptibility of the entire soil profile for soil sodicity.

Profile-1 at High Elevation



Profile-2 at Mid Elevation



Profile-3 at Low Elevation

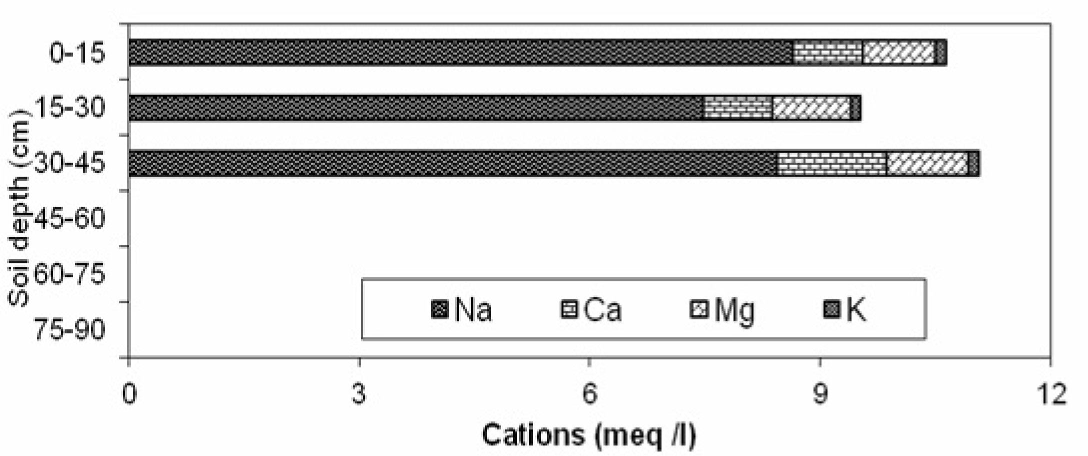
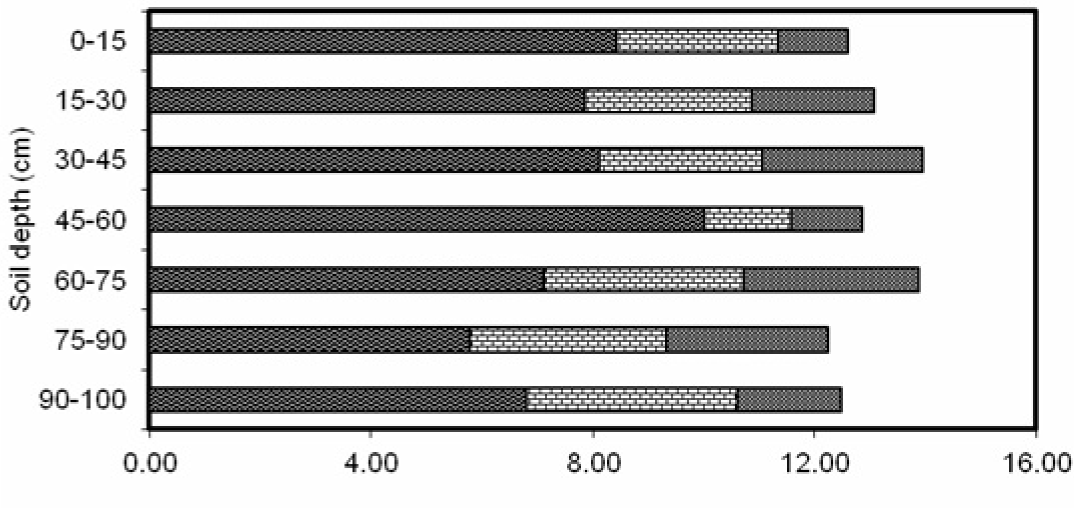
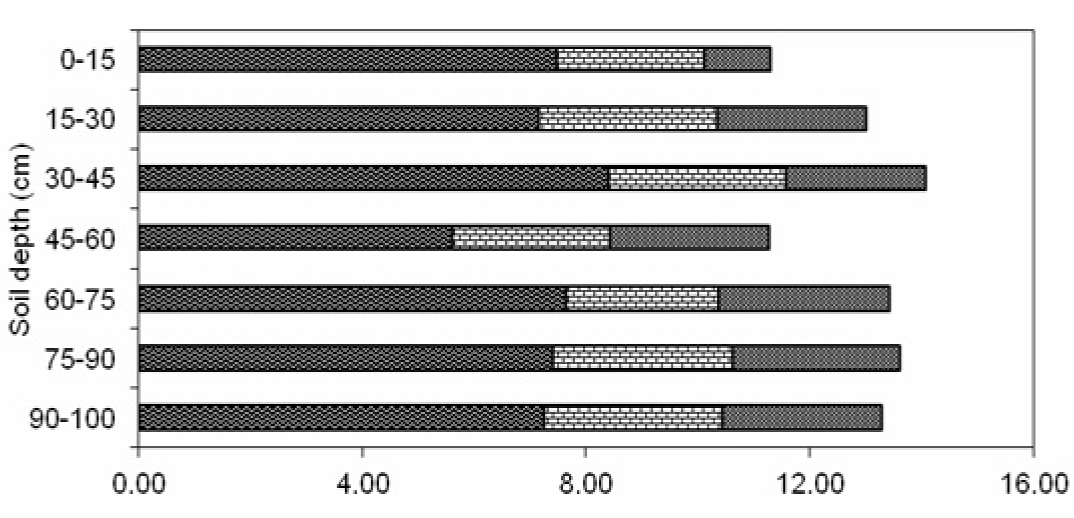


Figure 17: Vertical distribution of cations in soil profiles in Ramthal study area

Profile-1 at High Elevation



Profile-2 at Mid Elevation



Profile-3 at Low Elevation

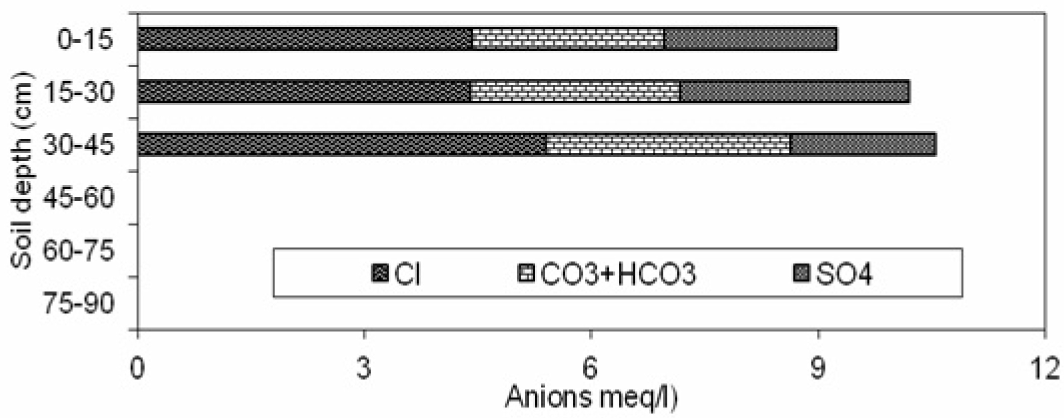
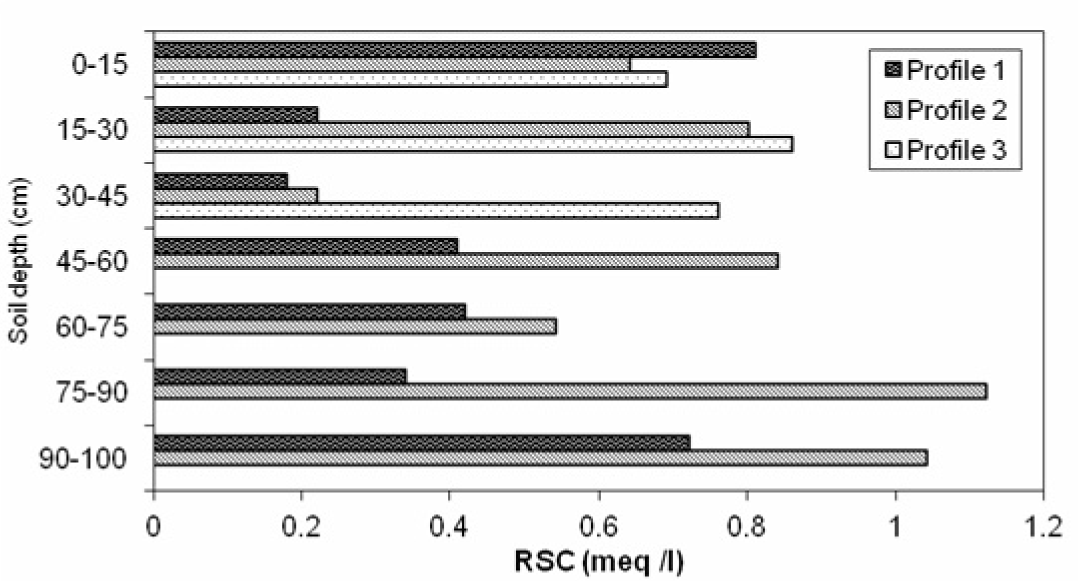


Figure 18: Vertical distribution of anions in the soil profiles in Ramthal study area

Residual Sodium Carbonates (RSC)



Sodium Adsorption Ration (SAR)

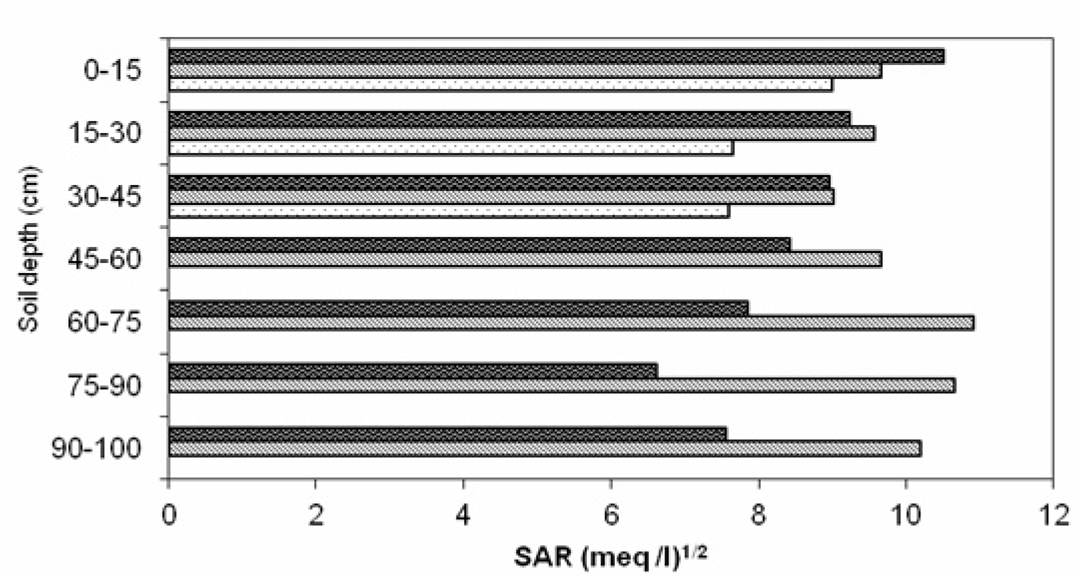


Figure 19: RSC and SAR values of soil profiles of Ramthal study area

5.7 Suitability of soils for different horticultural crops

Several studies have been conducted to evaluate the suitability of different crops for soil salinity. The suitability of different crops for various soil salinity parameters have been developed in the form of critical limits (Minhas and Sharma, 2003; CSSRI, 2004). The extent of yield reduction for different crops is also developed and they are presented in Tables 21 and 22. The soil analysis results of Ramthal study area indicated that the soil pH was the only limiting factor as it was found moderate to high alkalinity. The other important salinity parameters such as electrical conductivity, total carbonates and bicarbonates, chlorides, magnesium and sulfates were much below the critical limits. The soils possessed risks of sodification with moderate values of RSC and high SAR values. Moisture appears to be the most limiting factor. Thus, the soils appear to be suitable for most of the horticultural crops. Protective/ assured irrigation facilities created under Ramthal Lift Irrigation Project should be able to provide an opportunity for the farmers to cultivate most of the horticultural crops.

6. SUMMARY AND CONCLUSIONS

Topography, one of the important soil forming factors, has a great influence on the movement of water and material along with it. Thus, the topography of a landscape determines the movement and distribution of salts in a given soil. Considering its importance, a study was carried out in a portion of black soils of Ramthal Micro Irrigation Project Area to assess the influence of topography on soil salinity parameters. Summary of the results obtained are briefed in this chapter.

The soils present at different elevations showed significant variations in soil pH and all the soils were observed in moderate to high alkaline in reaction. The soils at lower elevations (L_3) areas recorded significantly lower pH (8.80 ± 0.23) while, the land existing at high elevations (L_1) recorded significantly higher pH values (9.15 ± 0.24). The soils existing at mid elevations recorded a pH of 8.98 ± 0.29. The soil pH as different elevations varied in the order of high > mid > low elevation soils.

The electrical conductivity ranged from 0.10 to 0.36 dS m^{-1}. All the soil samples in the study area were observed under non saline category (normal soils) with $EC_{2.5}$ values of < 0.8 dS m^{-1}. The soils at higher elevations (L_1) recorded significantly higher conductivity with $EC_{2.5}$ values of 0.22 ± 0.07 dS m^{-1}. However, the soils of mid elevated region (L_2) recorded lesser EC values and it was found on par with L_3 land category. Contrastingly, the soils existing at low elevation areas (L_3) recorded significantly lower EC values (0.16 ± 0.04 dS m^{-1}).

Water extractable-Ca ranged from 0.46 meq/l to 2.52 meq/l. Among different land categories, the soils existing on lands at mid elevations (L_2) recorded significantly higher calcium contents (1.09 ± 0.37 meq/l) compared to soils of high elevation areas which recorded least amounts (0.89 ± 0.29 meq/l). However, the soil present at low elevations did not differ significantly from high and mid elevation areas.

Among land areas existing at different elevations, the mean values of water extractable- Mg contents were found significantly higher (1.10 ± 0.37 meq/l) in soils at mid elevations (L_2) and it was found on par with soils at low elevation areas (0.99 ±

0.61 meq/l). The soils in high elevation areas (L_1) recorded significantly lower water extractable- Mg values (0.93 ± 0.27 meq/l).

All the three land categories recorded significantly different amounts of water extractable-K. The soils existing in low elevation areas recorded significantly higher amounts of potassium while, the soils of higher elevations (L_1) had the least amounts (0.13 ± 0.05 meq/l). Thus, the water extractable-K varied significantly in the order of low (L_3) > mid (L_2) > high (L_1) elevations. Among different cations, K^+ was found least in terms of its concentration in soil water extract.

Among different water extractable cations, the amounts of sodium were substantially higher compared to all other cations and its concentration ranged from 3.37 to 17.5 meq/l. At Ramthal study area, the soils existing at high elevations recorded significantly higher values (10.90 ± 2.03 meq/l). However, soils occurring at medium and low elevations recorded significantly lower values and both the values were found on par with each other.

In terms of total carbonates and bicarbonates, soils existing on lands at high and mid elevations (L_1 and L_2) recorded significantly higher amounts with respective values of 2.89 ± 0.84 meq/l and 2.91 ± 0.80 meq/l. The soils at lower elevations (L_3) had least total carbonates and bicarbonates (2.45 ± 0.84 meq/l).

The elevations of the land had significant influence on chloride contents. The soils of low and mid elevations (L_3 and L_2) recorded least chlorides with respective values of 7.73 ± 1.93 and 7.80 ± 2.41 meq/l. The soils at high elevations (L_1) recorded maximum chloride concentrations of 8.69 ± 1.81 meq/l).

In terms of the mean values of water extractable SO_4^{2-}, the lands existing at mid (L_2) and low (L_3) elevations recorded significantly lower sulfate values. Contrastingly, the soils belonging to high elevations (L_1) recorded significantly higher water extractable- SO_4^{2-} (1.18 ± 0.22 meq/l).

The total water extractable cations in soils of different land categories were derived by the summation of all the individual cations namely, sodium, calcium, magnesium and potassium in soil water extract and it ranged from 5.70 to 19.61 meq/l. Comparisons of different land categories indicated that higher elevations (L_1)

recorded significantly higher values (12.84 ± 1.98 meq/l). Contrastingly, the soils existing at low elevations (L_3) had significantly lower amounts (11.45 ± 1.56 meq/l). However, the soils existing at mid elevations (L_2) showed on par water extractable-Na values with the other two land categories (L_1 and L_3).

The total anions contents in the soil water extracts were estimated by adding the amounts of all the individual ions namely, total carbonates, chlorides and sulfates. The total anion concentration ranged from 5.74 to 19.45 meq/l. In terms of the mean values of soils of different land categories, the soils existing at high elevations (L_1) recorded significantly higher values (12.74 ± 2.29 meq/l) while, soils belonging to lower elevations (L_3) and mid elevations (L_2) recorded significantly lower amounts (11.79 ± 2.81 meq/l in L_2 and 11.28 ± 2.05 meq/l in L_3).

In general, the RSC values were found in safer limits though the carbonates and bicarbonates were more than calcium and magnesium contents in majority of the soil samples. The RSC values ranged from -1.98 to 3.51 meq/l. In terms of susceptibility of soils for sodicity, the soils existing at higher elevation (L_1) recorded significantly higher RSC values of 1.05 ± 0.93 meq/l. Contrastingly, the soils belonging to low elevation areas (L_3) recorded least RSC values (0.50 ± 1.11 meq/l). The soils of mid elevation areas (L_2) was on with low elevation areas with RSC of 0.70 ± 1.10 meq/l.

The SAR values ranged from 2.90 to 20.65 $(meq/l)^{½}$. In the study area, > 70 per cent of soil samples were found safe in terms of sodification with SAR values of <10 $(meq/l)^{½}$. However, 30 per cent of the soil samples indicated moderate sodicity risks with >10 $(meq/l)^{½}$ of SAR. It was observed that the soils existing in high elevated areas (L_1) were susceptible for sodification compared to low (L_3) and mid (L_2) elevated areas. The soils of high elevated areas exhibited significantly higher mean SAR values of 11.75 ± 2.87 $(meq/l)^{½}$. Significantly low SAR values were observed in soils of both mid elevation (L_2) and low elevation (L_3) areas with respective SAR values of 9.60 ± 3.80 $(meq/l)^{½}$ and 9.87 ± 2.37 $(meq/l)^{½}$.

The study area had a topographical gradient of about 30 meters and the area was grouped into 3 categories namely, with respective elevations of > 526 m, 516 - 526 m and < 516 m.

Soil profiles representing high elevated (L_1), mid elevated (L_2) and low elevated (L_3) areas indicated that high elevated area had deep clayey soils and the depth of the soil decreased gradually towards lower elevation (<50 cm). The pH was highly alkaline in profiles-1 and 2 while, the profile-3 recorded moderate alkalinity. In terms of soil salinity, the $EC_{2.5}$ values were higher in profile-1 and it decreased in profile-2 and 3 and the salt content increased with depth in all the three soil profiles.

Among different soil water extractable cations, the amounts of sodium was substantially higher than other cations while, water extractable-K was found least in all the three profiles. In general, the soils of profile-1 recorded higher amounts of cations compared to profile-2 and profile-3. However, the amounts of sodium in the top four layers of profile - 1 were higher than subsurface soils. Contrastingly, the profile-2 recorded higher amounts of Na^+ in subsurface soils also.

Among water extractable anions, the chloride was substantially higher in all the profile samples while, SO_4^{-2} was least. In terms of topography, the profile samples at high elevation (L_1) had higher amounts of all anions compared to mid (L_2) and low (L_3) elevations. In general, the subsurface profile soils recorded higher amounts of total carbonates and sulfates compared to surface samples. However, water extractable- Cl was found higher in surface soils compared to subsurface soils.

In terms of their respective total ions, both total cations and total anions were found higher in profile-1 and they declined gradually along the falling gradient. The amounts of total cations were found almost equal to the total anions in all the profile soil samples. In terms of their distribution with depth, the soil profile-1 of high elevation (L_1) recorded higher amounts of cations and anions at all depths except at 75-90 and 90-100 cm soil layers recording slightly lesser value. Contrastingly, the soil profiles of mid elevation (L_2) and low elevation (L_3) recorded higher amounts at all depths except the surface soil layer.

Susceptibility of soils for sodification were evaluated by deriving RSC and SAR values. In terms of RSC values, all the soil profile samples were found safe from sodification. The relative dominance of carbonates and bicarbonate over calcium and magnesium was slightly higher in surface soils of profile-1 while, it declined in subsurface layers.

In terms of SAR index, the profile-1 recorded higher SAR values in the surface soil and it gradually declined with depth. Contrastingly, the profile-2 recorded higher SAR values in subsurface soils (60-75 to 90-100 cm) than surface soils (0-15 to 45-60 cm depths). However, the SAR values of profile-3 were much lesser. Thus, the sodicity problems are likely to exist in the entire area and extended even to the subsurface soils.

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CHARACTERIZATION OF BLACK SOILS UNDER RAMTHAL MICRO IRRIGATION PROJECT FOR SALINITY PARAMETERS

LAKSHMI P. D **2018** **Dr. M. S. NAGARAJA**

Major Advisor

ABSTRACT

Topography is one of the important soil forming factor having great influence on the movement of water and salts along with it. Considering its importance, an extensive soil survey was carried out to assess the soil salinity parameters and distribution of cations and anions along the gradient in a block of Ramthal Micro Irrigation Project, Hungund, representing typical black soils. Representative profile samples at different elevations were also studied. The samples were grouped into three categories namely, high elevation (L_1 : >526 m), mid elevation (L_2 : 516-526 m) and low elevation (L_3: <516 m) areas.

The soil pH ranged from moderate to high alkalinity and it varied significantly with elevations in the order of high > mid >low elevations. The electrical conductivity ranged from 0.10 to 0.36 dSm^{-1}. The soils at higher elevation (L_1) recorded significantly higher EC values compared to mid (L_2) and low (L_3) elevations. In terms of cations, the soils existing at mid elevation (L_2) recorded significantly higher amounts of calcium and magnesium compared to soils of high elevation areas. Contrastingly, potassium contents was found high in low elevation (L_3) areas. However, the sodium was found significantly high in higher elevations (L_1). The concentration of cations varied in the order of $Na^+ > Ca^{2+} > Mg^{2+} > K^+$.

The total carbonates and bicarbonates was significantly lower in low elevation areas (L_3) compared to high and mid elevations (L_1 and L_2) areas. Contrastingly, the chloride was maximum in high elevation (L_1) areas compared to mid and low elevations (L_2 and L_3). However, the sulphate was found significantly higher in high elevation areas. In general the concentration of anions varied in the order of $Cl^- > SO_4^{2-} > CO_3^{2-} + HCO_3^-$.

The soil profiles at three elevations also showed similar trends with respective above salinity parameters. Interestingly, all cations and anions increased with depth. However, the magnitude of increase was less in profile-3 representing lower elevation (L_3). The order of distribution of cations and anions among soil profiles at all soil depths remained almost same. It was interesting to note that majority of the soil samples were found susceptible for sodification with higher SAR and RSC values though EC values are low. The study also indicated that the soils in the study area were found suitable for most of the horticultural crops as there was no of salinity or toxicity of cation/ anion.

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