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Full Length Research Paper

Assessment of spatial variability of soil properties in hot semi-arid northern transition zone of India through remote sensing and geographic information system (GIS)

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Knowledge of spatial variability in soil fertility is important for site specific nutrient management. In the present study, spatial variability in properties that influence soil fertility such as soil organic carbon, available N, available P_2O_5 and available K_2O in 133 surface samples (comprising of 108 soil samples from red soils and 25 soil samples from black soils) from farmers' fields in Singhanhalli-Bogur microwatershed of Dharwad taluk in Dharwad district of Karnataka (India) were quantified. Based on the ratings of soil nutrients, the respective thematic maps (soil fertility maps) were prepared using Arc Map 10.1 with spatial analyst function of Arc GIS software through spline interpolation method. Soils were non-gravelly to gravelly with the red soils showing high gravel content (2.0 to 60.6%) than black soils (2.6 to 15.3%). The pH of the study area was slightly acidic to alkaline with normal electrical conductivity. The red soils were slightly acidic to alkaline with pH of 5.2 to 8.3 while the black soils were neutral to alkaline with pH of 6.4 to 8.6. The available N, P, K and S varied from low to medium, with majority of samples showing low values. The available Mn status of soils was sufficient (2.8 to 36.1 ppm for black soils and 0.2 to 88.7 ppm for red soils). The available iron was deficient to excess (0.5 to 7.1 ppm and 0.5 to 3.0 ppm for red and black soils, respectively), with majority of the samples deficient to sufficient in iron. Only 16.5 per cent of the study area was found to contain excess Fe. The available Zn and Cu was deficient to sufficient but major portion of the study area showed deficiency of available zinc and copper. The exchangeable Ca was moderate to high (3.2 to 28.6 cmol (p+) kg^{-1} and 8.6 to 35.8 cmol (p+) kg^{-1} for red and black soils respectively) but major portion of the study area was sufficient in exchangeable Ca while exchangeable Mg ranged from low to medium (1.9 to 16.5 cmol(p+) kg^{-1} and 6.0 to 23.2 cmol(p+) kg^{-1} for red and black soils respectively) . The observed spatial variability in various soil properties that influence soil fertility will help farmers in making crop management decisions that would help to increase crop productivity and improve farmers' livelihood.

Key words: Spatial variability, soil properties, India, remote sensing, geographic information system.

INTRODUCTION

Soil properties change in time and space continuously (Rogerio et al., 2006). According to Du Feng et al. (2008), heterogeneity can occur at large scale (region) or at small scale (community), even in the same type of soil or in the same community. Spatial variability is a term indicating changes in the value of a given property over space (Ettema and Wardle, 2002). It can be assessed using classical descriptive statistics (i.e., mean, range, coefficient of variation) or geostatistics (i.e., semivariogram, autocorrelation, crosssemivariogram, kriged, and co-kriged maps). Therefore, knowledge of the spatial variability of soil properties is essential for site-specific soil management and evaluation of various agricultural land management practices. Spatial variability and distribution of soil properties within agricultural fields can be classified as static (e.g. texture, mineralogy) due to soil formation processes or dynamic (e.g. water content, compaction, electrical conductivity, carbon content) caused by various land management practices (Jabro et al., 2006). Both static and dynamic soil physical and chemical properties vary across agricultural fields, contributing to variable crop yields. Thus characterization of the spatial variability of these soil properties within agricultural fields is essential for site-specific management, also referred to as precision agriculture practices, and can help explain significant effects on the spatial distribution of crop yield and quality. Spatial variability of soil properties is inherent in nature due the influence of geogenetic/pedogenetic processes and management/land use related activities. Pedogenetic (intrinsic) variables interact with each other across spatial and temporal scales and their effects are further modified by erosional and depositional processes which influence landscape evolution (Burrough and McDonnel, 1998).

Despite the temporal and spatial changes of soil characteristics in small and large scales, awareness of how these changes occur for increasing profitability and sustainable agriculture management is necessary (Ayoubia et al., 2007). Determining soil variability is important for ecological modelling, environmental predictions, precise agriculture and management of natural resources (Hangsheng et al., 2005).

Spatial variability and correlation of various soil properties across the landscape has been intensively studied and evaluated during the past two decades using both classical statistics and the theory of regionalized variables as evaluated using geostatistical methods (Cambardella et al., 1994; Fulton et al., 1996; Gaston, et al., 2001; Huang et al., 2001; Iqbal et al., 2005; Mzuku et al., 2005; Guo-Shun et al., 2008). These researchers have shown that various soil properties can vary significantly within a single field. Various studies have shown that spatial variability of soil properties, including nutrient status, can occur across fields owing to tillage, fertilization, cropping history, and other reasons. A study on soil fertility variability within a 50 ha cotton field in Handan County of Hebei Province of China by Jin (2005) showed remarkable variability in available soil nutrient content with available P, K, and B having CVs greater than 30% after 20 years of small-scale operations. A similar study on a 20 ha field within a large-scale, single operational unit of Changyang State Farm in the suburb of Beijing showed a lower extent of spatial variability compared to small-scale operations. Under the small-scale operations, where each farming family operated small plots, the variability of soil nutrients had a close relation with history of fertilization, crop variety, and field management. Fennessy and Mitsch (2001) evaluated spatial distribution of soil properties in 2 year period. They found that the spatial variability of organic matter and total nutrient of soil had decreased in this period. Yong et al. (2006) investigated soil properties and their spatial pattern in a sandy grassland and reported that continuous grazing lead to decrease spatial dependence of soil organic carbon and total nitrogen at sandy hills.

Geostatistics have proved useful for assessing spatial variability of soil properties and have increasingly been utilized by soil scientists and agricultural engineers in recent years (Webster and Oliver, 2001; Iqbal et al., 2005). Furthermore, geostatistical methods have been adopted and used in site-specific management applications, soil sampling strategies and assessment of farm management styles and decisions. Semivariograms and cross-semivariograms have been used to characterize and model spatial variance of data to assess how data points are related with separation distances while kriging uses modelled variance to estimate values between samples (Journel and Huijbregts, 1978). Kriging and co-kriging are common geostatistical procedures that have been used for optimal estimation and spatial interpolation of values at unsampled locations. Co-kriging uses more than one variable in spatial interpolation process. It employs a second variable to estimate values of primary variable of interest that were assumed to be spatially dependent (McBratney and Webster, 1983; Davis, 1986).

Little or no information has been reported on the spatial variability of soil properties in Singhanhalli-Bogur microwatershed. In the present study, it was has realized that an appropriate understanding of the spatial variability in soil properties of the study area is essential in order to gather knowledge and prepare soil maps through spatial interpolation of point based measurements of soil properties which is in conformity with Santra et al. (2008). Keeping this in mind, the present study was conducted to characterize field-scale spatial variability of selected soil properties in the study area.

MATERIALS AND METHODS

Description of the study area

Singhanhalli-Bogur micro-watershed having an area of 760.6 ha, is located between 15°31'30.30" to 15°34'49.45" N latitude and 74°50'47.46" to 74°53'35.67" E longitude in Dharwad taluk of Dharwad district in the northern transition zone of Karnataka, India (Figure 1). The study area lies in the Decca plateau region in the hot semi-arid agro-ecological region 6 and sub-region 6.4, having medium to high available water content with a length of growing period of 150-180 days. The climate is characterized by hot and humid summer and mild and dry winter.

The study area receives an annual average rainfall of 755.2 mm, which is distributed over May to October and annual temperature ranging from 24 to 28°C and having Ustic soil moisture and isohyperthermic soil temperature regimes (Amara

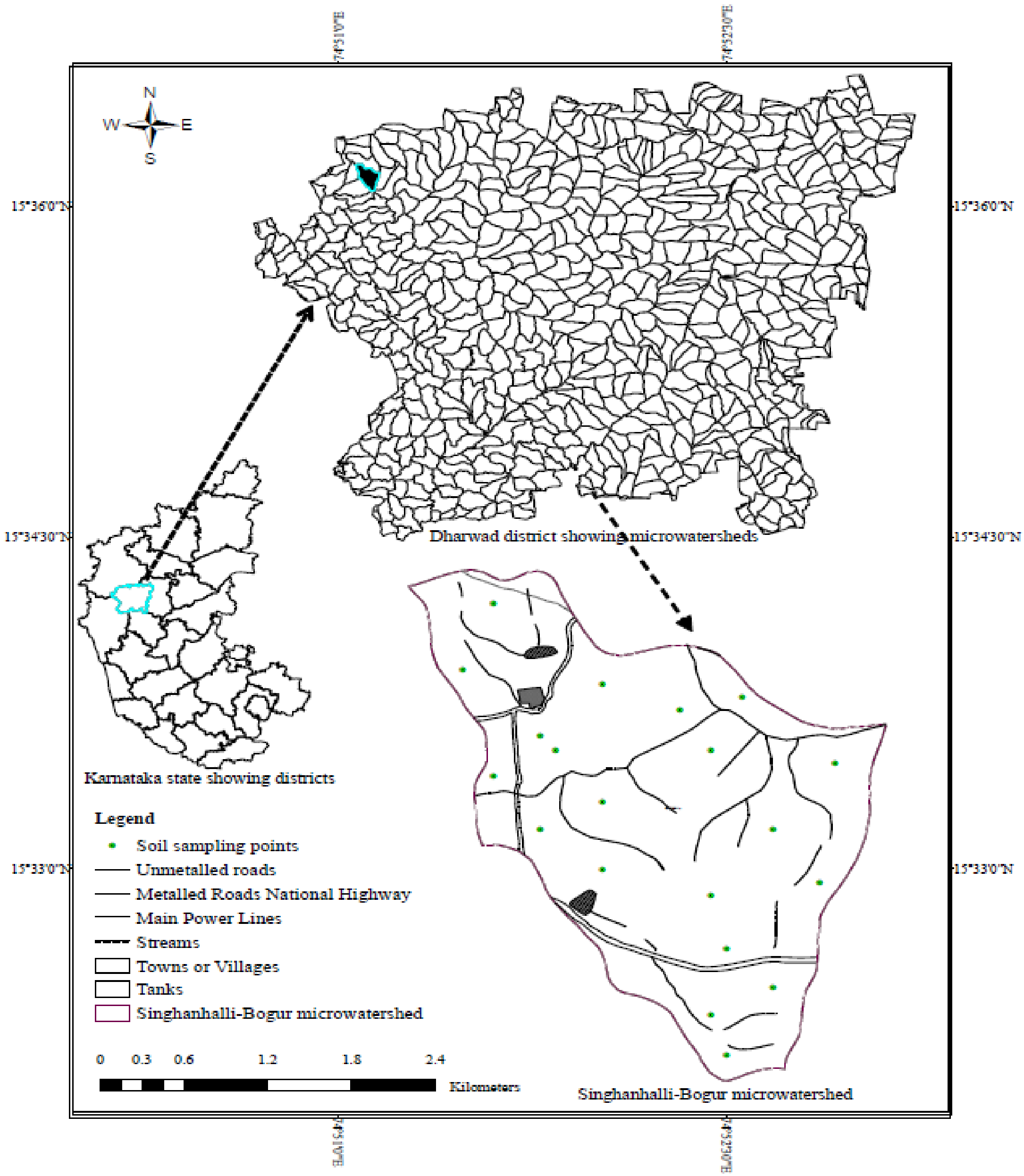

Figure 1. Map of study area

et al., 2013). The highest elevation is 754 m above mean sea level and the relief is very gently to strongly sloping. The general slope is towards the northeast, southeast and southwest but it is more in the southwest direction. The drainage pattern is parallel. Soils are derived from chlorite schist with shale as dominant parent material containing banded iron oxide quartzite.

The soils are coarse textured and shallow at the higher elevations but gradually, fineness and depth increases towards the lower elevations. The main soil types are black and red soils but the red soils are in higher proportion than the black soils. The natural vegetation mainly comprised of trees and shrubs including Acacia (*Acacia auruculiformis*), Neem (*Azadirachta indica*) and Eucalyptus (*Eucalyptus sideroxylon* and *Eucalyptus regnana*).

Soil sampling and analysis

A total of 133 surface samples (comprising of 108 soil samples from red soils and 25 soil samples from black soils), which were well distributed in the study area were collected for from a depth of 0 to 20 cm. The exact sample locations (latitude and longitude) were recorded with the help of a hand held GPS device. The soil samples were collected in polythene bags and transported with proper handling to the laboratory for analysis. The large lumps were broken and spread on drying sheet made of brown papers and then air-dried in shade. The air-dried samples were ground with a wooden pestle and mortar and passed through 2 mm sieve to separate the coarse fragments (materials greater than 2 mm). The fine earth samples were stored in suitable sample bottles for various analyses. For easy identification, labels showing a short description of grid number and sample location were placed inside of each bottle as well as on the outside. For the analysis of organic carbon, some portion of the fine earth samples were further ground more finely and passed through 0.2 mm sieve. The finely ground samples were stored in separate sampling bottles and labeled as in the case of the main samples. The coarse fragments were washed, dried, weighed and expressed as per cent of whole soil sample.

The processed soil samples were analyzed following standard analytical procedures for various parameters including pH, Electrical Conductivity (EC), Soil Organic Carbon (OC), available N, available P_2O_5 and available K_2O. Soil pH was determined in 1:2.5 soil-water suspension by potentiometric method (Jackson, 1967). Electrical conductivity was determined in 1:2.5 soil-water extract using Conductivity Bridge and expressed as dSm^{-1} (Jackson, 1973). The organic carbon content of a finely ground soil sample was determined by Walkely and Black's wet oxidation method as described by Jackson (1967). Available nitrogen was estimated by alkaline $KMnO_4$ method (Subbaiah and Asija, 1956). Available phosphorus was extracted with sodium bicarbonate (0.5 M) at pH 8.5 (Olsen's reagent) and the amount of phosphorus was estimated by chloro-stannous reduced phospho-molybdate blue colour method using Spectrophotometer at wavelength of 660 nm (Jackson, 1973). Available potassium in soil was extracted by neutral normal ammonium acetate and subsequent estimation was by flame photometry (Jackson, 1973). Arc Map 10.1 with spatial analyst function of Arc GIS software was used to prepare soil fertility maps. The interpolation method employed was spline. The extent of area in low, medium and high category of nutrients was estimated on the basis of standard ratings.

Soil fertility maps

A dbf file consisting of data for X and Y coordinates in respect of sampling site location was created. A shape file (Vector data) showing the outline of the study area was created in Arc view 10.1 The dbf file was opened in the project window and in X-field, X-coordinates was selected and in Y-field, Y-coordinates was selected. The Z field was used for different nutrients. The boundary shapefile of the study area was also opened and from the `surface menu` of Arc view spatial analyst "Interpolate grid option" was selected. On the output "grid specification dialogue", output grid extend chosen was same as Singhanhalli-Bogur microwatershed boundary and the interpolation method employed was krigging. Then map was reclassified based on the ratings of respective nutrients.

RESULTS AND DISCUSSION

Soil fertility refers to the inherent capacity of the soil to supply nutrients in adequate amounts and in suitable proportions for crop growth and crop yield. The soil fertility gives an idea of the status of a soil with respect to its ability to supply elements essential for plant growth without a toxic concentration of any element. The trend in increasing the yield by adopting high yielding varieties has resulted in the deficiency of nutrients in soils, and has reflected as deficiency symptoms in many crops. Therefore, it is important to know the fertility status of soils for making fertilizer recommendations. The status of soil fertility constraints was assessed and spatial distribution of nutrient-related constraints was interpreted in form of maps.

Physical properties of soils

Coarse fragments (gravel content)

The soils were non-gravelly to gravelly, but the red soils contained high gravel content than the black soils. The percentage of coarse fragments in the black soils ranged from 2.6 to 15.3 per cent with a mean of 8.3 per cent and standard deviation of 3.5, whereas the percentage coarse fragments of the red soils ranged from 2.0 to 60.6 per cent with a mean of 22.0 per cent and standard deviation of 13.2 (Table 1). The red soils contained higher coarse fragments than the black soils. This might be due to nature of parent material and weathering.

Chemical properties of soils

Soil reaction (pH)

The soil pH generally affects the solubility of minerals and can influence the plant growth by stimulating activity of beneficial microorganisms (Amara and Patil, 2014). Optimum soil reaction should be near neutral. The pH of soils the study area ranged from slightly acidic to alkaline (Figure 2). The red soils were slightly acidic to alkaline with pH ranging from 5.2 to 8.3 with a mean of 6.3 and standard deviation of 0.6 (Table 1). The acidic nature of the red soils might be due to the acidic nature of parent material of the study area from which these soils were developed. The black soils showed neutral to alkaline soil reaction with pH ranging from 6.4 to 8.6 with a mean of 7.7 and standard deviation of 0.5. The neutral to alkaline nature of the black soils might be due to high exchangeable bases (Sitanggang et al., 2006; Pulakeshi et al., 2014).

Table 1. Fertility status of soils.

Soil parameters	Black soil			Red soil		
	Mean	SD	Range	Mean	SD	Range
Coarse fragment (%)	8.3	3.5	2.6 - 15.3	22.0	13.2	2.0 - 60.58
pH	7.7	0.5	6.4 - 8.6	6.3	0.6	5.2 - 8.27
Electrical conductivity (dS m^{-1})	0.2	0.1	0.1 - 0.4	0.1	0.1	0.02 - 0.94
Organic carbon (g kg^{-1})	5.1	2.3	2.6 – 13.7	9.1	4.7	1.2 – 25.4
Available N (kg ha^{-1})	215.3	41.8	127.4 - 309.4	262.4	49.4	172.9 - 564.2
Available P_2O_5 (kg ha^{-1})	23.6	4.7	11.5 – 31.0	20.8	6.1	7.0 - 30.7
Available K_2O (kg ha^{-1})	216.4	129.6	81.1 - 587.8	195.9	131.4	20.3 - 800
Available S (mg kg^{-1})	8.4	7.7	0.6 - 32.6	10.6	7.5	1.1 - 35.6
Available Mn (ppm)	17.1	10.1	2.8 - 36.1	20.8	8.2	0.2 - 88.7
Available Fe (ppm)	1.2	0.7	0.5 - 3.0	3.4	1.4	0.5 - 7.1
Available Zn (ppm)	0.4	0.2	0.1 - 0.9	0.5	0.2	0.03 – 1.0
Available Cu (ppm)	0.5	0.2	0.1 – 1.0	0.6	0.3	0.1 – 1.0
Exchangeable Ca (cmol(p+) kg^{-1})	23.8	8.2	8.6 - 35.8	8.6	3.9	3.2 - 28.6
Exchangeable Mg (cmol(p+) kg^{-1})	14.9	4.8	6.0 - 23.2	5.0	2.4	1.9 - 16.5

Electrical conductivity

The Conductance of a soil gives a clear idea of the soluble salts present in the soil. In the present study, the electrical conductivity was observed to be normal (Figure 3). This indicated that the study area was free of salinity problems. The soils were moderately drained to well-drained. Therefore, the normal EC status of soils of the study area might be due to the free drainage properties exhibited by soils. The electrical conductivity of the black soils ranged from 0.06 to 0.44 dS m^{-1} with a mean of 0.15 dS m^{-1} and standard deviation of 0.1, whereas the electrical conductivity of the red soils ranged from 0.02 to 0.94 dS m^{-1} with a mean of 0.1 dS m^{-1} and standard deviation of 0.1 (Table 1). According to Pulakeshi et al. (2014), low EC of soils might be due to the higher leaching induced by heavy rainfall in the absence of adequate amount of soil organic matter or decomposition of organic matter at high temperature. The study area has an average annual rainfall of 755.2 mm (Amara et al., 2013). This amount of rainfall is capable of flushing soluble salts from minerals and rocks below the root zone and eventually depositing them into deep groundwater systems or into the nearby Tupari Halla stream. Therefore, it is of the view that the use of non-saline water for irrigation by farmers could result to high electrical conductivity in the study area. Karajanagi (2013) held a similar view for soils of Malaprabha Command Area in Karnataka.

Organic carbon

The organic carbon content of the soils in the study area ranged from low to high, but majority of the samples contained high organic carbon content (Figure 4). The organic carbon of the black soils ranged from 2.6 to 13.7 g kg^{-1} with a mean of 5.1 g kg^{-1} and standard deviation of 0.2, whereas the organic carbon content of the red soils ranged from 1.2 to 25.4 g kg^{-1} with a mean of 9.1 g kg^{-1} and standard deviation of 0.5 (Table 1). According to results obtained by Pulakeshi et al. (2012) and Karajanagi (2013) of soils in the same agroecological region, the high organic carbon content of the soils might be attributed to the application of high input of FYM and crop residues and prevalence of favourable temperature and rainfall in the study area. It is possible that the degradation and removal of organic matter might be taken place at slower rate especially in areas with high vegetation cover. As a result, there might be more chances of accumulation of organic matter in the soil.

Available macronutrients

Available nitrogen

The available nitrogen content of the soils ranged from low to medium, with majority of samples low in nitrogen (Figure 5). Similar observations were also made by Binita et al. (2009). The available nitrogen status of the black soils ranged from 127.4 to 309.4 kg ha^{-1} with a mean of 215.3 kg ha^{-1} and standard deviation of 41.8, whereas the available nitrogen status of the red soils ranged from 172.9 to 564.2 kg ha^{-1} with a mean of 262.4 kg ha^{-1} and standard deviation of 49.4 (Table 1). The low nitrogen status of the soils might be due to the continuous removal of nitrogen by crops and the inadequate or non-application of N fertilizers in return. The low nitrogen status could hinder the growth of most vegetables in the study area as farmers do not have the necessary financial capability to address nitrogen deficiency. Of all the elements provided by

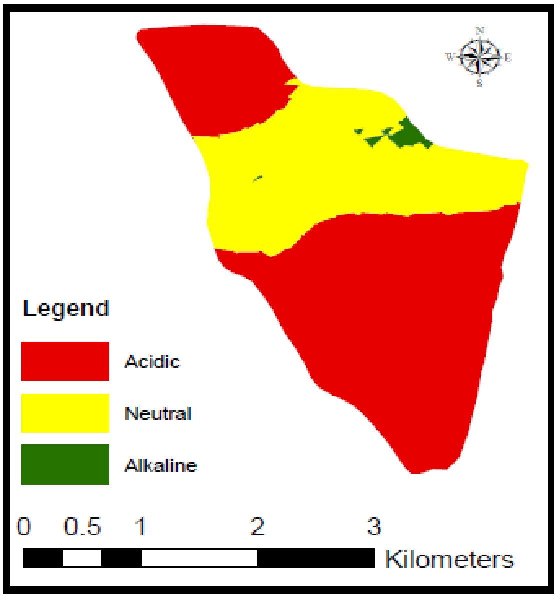

Figure 2. Soil pH status of study area.

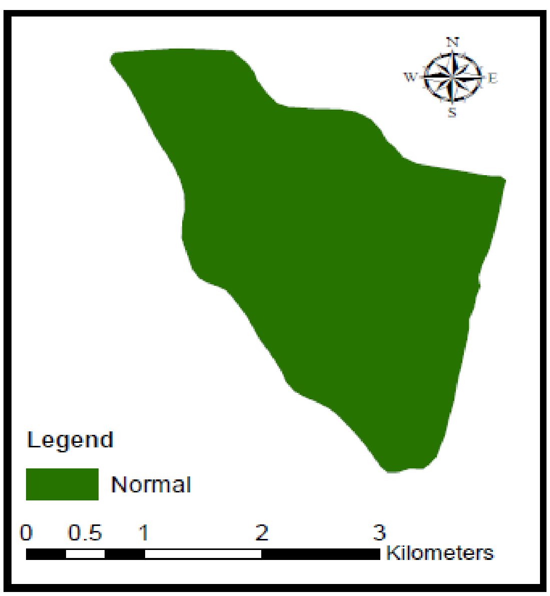

Figure 3. Electrical conductivity status of study area

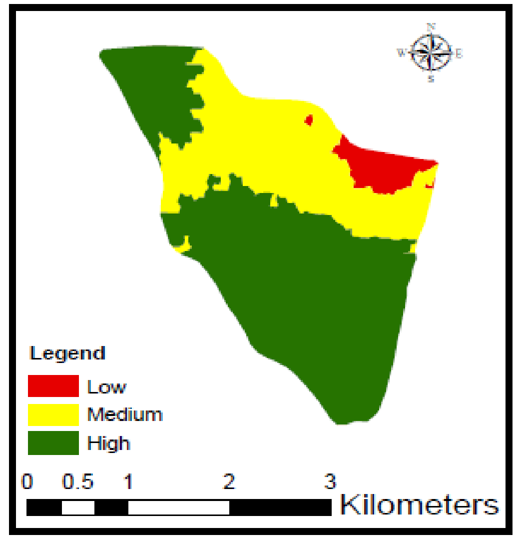

Figure 4. Organic carbon status.

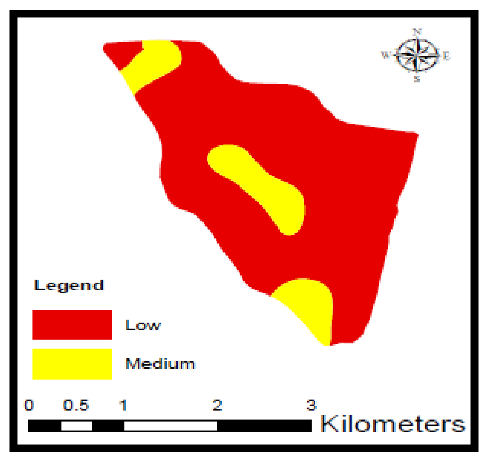

Figure 5. Available Nitrogen status of study area

the soil for the nutrition of plants, nitrogen is undoubtedly the best indicator of changing levels of soil fertility. It is the change in the level of soil nitrogen that occurs under the various systems of management which is of greatest significance in indicating trends in soil fertility. The low levels of nitrogen in the study area are an alarming evidence of declining soil fertility which may like cause deterioration in the structure of the soil and lowered capacity to absorb water.

Available phosphorus

The available phosphorus content of the soils ranged from low to medium with majority of samples low in phosphorus (Figure 6). The available phosphorus content of the black soils ranged from 11.5 to 31.0 kg ha^{-1} with a mean of 23.6 kg ha^{-1} and standard deviation of 4.7, whereas the available phosphorus content of the red soils ranged from 7.0 to 30.7 kg ha^{-1} with a mean of 20.8 kg ha^{-1} and standard deviation of 6.1 (Table 1).

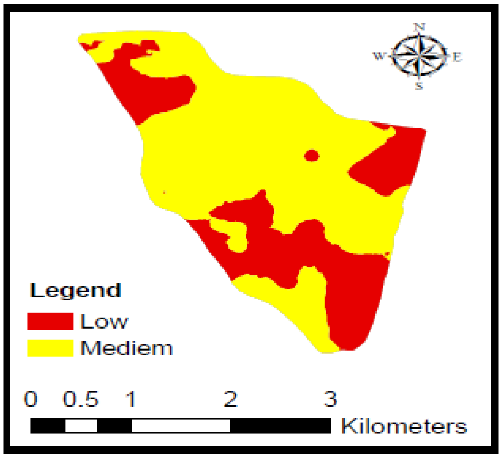

Figure 6. Available phosphorus status of study area.

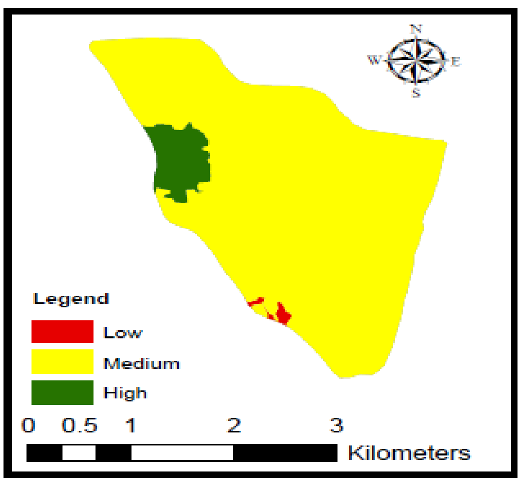

Figure 7. Available potassium status of study area.

However, the red soils showed low values of available phosphorus than the black soils. According to Ravikumar *et al.* (2009), the high available phosphorus in the red soils could be attributed to the low CEC, low clay content and acidic soil reaction of less than 6.5, whereas in the case of the low status of available phosphorus in the black soils, Patil *et al.* (2011) and Karajanagi (2013) reported that this could be related to its high phosphorus removal than replenishment and also high P fixation capacity.

Available potassium

The available potassium status of the soils ranged from low to medium, with majority of samples being medium in available potassium (Figure 7). The available potassium content of the black soils ranged from 81.1 to 587.8 kg ha^{-1} with a mean of

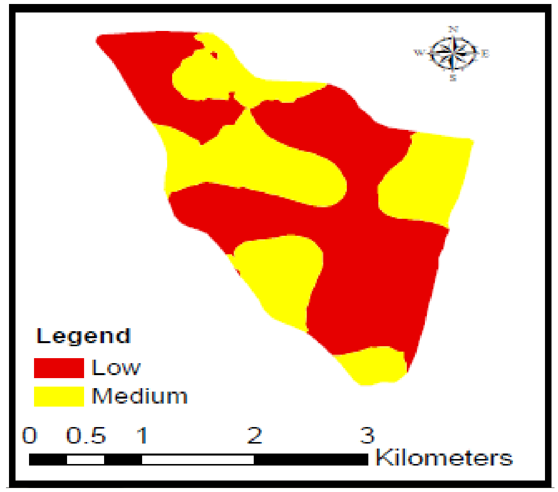

Figure 8. Available Sulphur status of study area

216.4 kg ha^{-1} and standard deviation of 129.6, whereas the available potassium content of the red soils ranged from 20.3 to 800 kg ha^{-1} with a mean of 195.9 kg ha^{-1} and standard deviation of 131.4 (Table 1). The results indicated that the black soils contained higher available K than the red soils. This might be attributed to the predominance of K rich micaceous and feldspars minerals in parent material (Ravikumar, 2004). Major portion of areas under medium and low K status were observed in the red soils because these soils have less fine fractions. The low potassium content could affect water absorption and retention, stem and root growth, crops' shelf life (Binita et al., 2009; Dhanya et al., 2009; Karajanagi, 2013; Pulakeshi et al., 2014).

Available sulphur

The available sulphur content of the soils of the study area ranged from low to medium, but most of the samples were low in available sulphur (Figure 8). The available sulphur content of the black soils ranged from 0.6 to 32.6 mg kg^{-1} with a mean of 8.4 mg kg^{-1} and standard deviation of 7.7, whereas the available sulphur content of the red soils ranged from 1.1 to 35.6 mg kg^{-1} with a mean of 10.6 mg kg^{-1} and standard deviation of 7.5 (Table 1). The low amounts of sulphur might be due to the acid reaction and low EC status of the soils. The red soils contained higher available sulphur than black soils. This could be attributed to the fact that black soils have gypsuferous nature of sulphur which is non-available. The low and medium level of available sulphur in the study area might be due to the lack of sulphur addition and continuous removal of S by crops. Past studies by Srikanth et al. (2008), Binita et al. (2009) and Karajanagi (2013) have also reported low to medium sulphur for similar soils of Karnataka. Therefore, it is of the view that Karnataka soils are generally low to medium available sulphur. The low sulphur status is more likely to

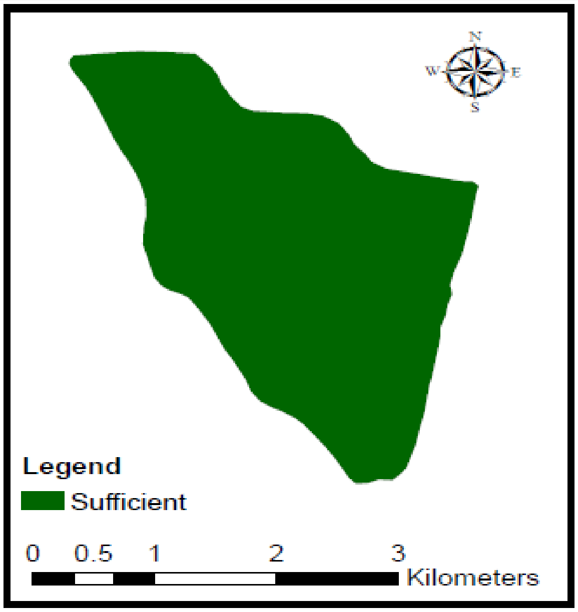

Figure 9. Available Mn status of study area.

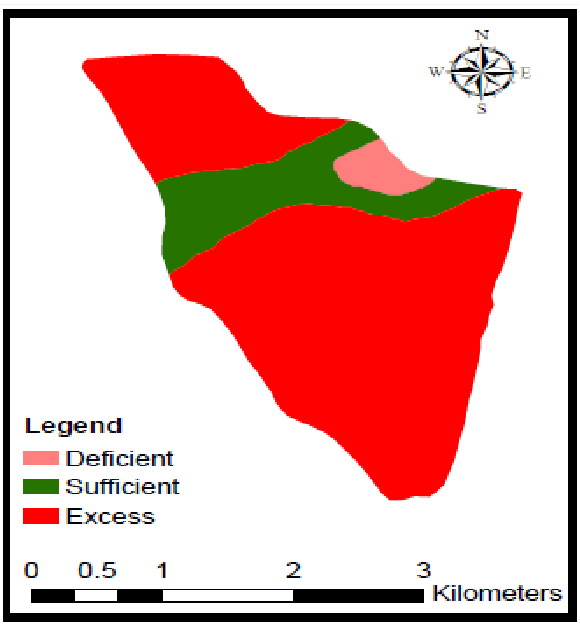

Figure 10. Available Fe status of study area

cause sulphur deficiency especially in red soils with low organic matter (less than 2%) and under high rainfall conditions. However, even for the black soils which showed medium to high organic matter, often, the breakdown of the organic matter and the mineralization process may not be rapid enough to meet the sulphur requirement of the crop.

Available micronutrients

Available manganese

The entire study area, constituting of black and red soils, was found to be sufficient in available manganese (Figure 9). The available manganese content of the black soils ranged from 2.8 to 36.1 ppm with a mean of 17.1 ppm and standard deviation of 10.1, whereas the available manganese content of the red soils ranged from 0.2 to 88.7 ppm with a mean of 20.8 ppm and standard deviation of 8.2 (Table 1). This could be attributed to the pH and nature of the parent material. The sufficiency of manganese in the soils might be due to high organic matter content. Highly toxic concentrations of manganese in soils can cause swelling of cell walls, withering of leafs and brown spots on leaves in plants. Deficiencies can also cause these effects. Between toxic concentrations and concentrations that cause deficiencies, a small area of concentrations for optimal plant growth can be detected.

Available iron

Iron (Fe) is an essential trace element to both animals and plants. Iron may be present in the dissolved state or in a colloidal state that may be peptized by organic matter. The available Fe status of the study area varied from deficient to excess, with majority of the samples deficient to sufficient in Fe. Only 16.5 per cent of the study area was found to contain excess Fe (Figure 10). The black soils were deficient to sufficient in Fe, having an available iron content ranging from 0.5 to 3.0 ppm with a mean of 1.2 ppm and standard deviation of 0.7, whereas the red soils were deficient to sufficient and excess, having an available iron content ranging from 0.5 to 7.1 ppm with a mean of 3.4 ppm and standard deviation of 1.4 (Table 1). The low Fe content in black soils as compared to red soils could be attributed to the low field capacity of soils, which could have resulted to precipitation of Fe^{2+} by $CaCO_3$ and subsequent decrease in availability of Fe. This variation might be due to the soil management practices and cropping pattern adopted by different farmers. Iron deficiency is a limiting factor of plant growth in many parts of Indian especially in high rainfall zones and waterlogged areas. Generally, Iron is present at high quantities in soils, but its availability to plants is usually very low, and therefore iron deficiency is a common problem in major parts of India (Yeresheemi et al., 1998; Vara Prasad Rao et al, 2008; Binita et al., 2009; Dhanya et al., 2009; Pulakeshi et al., 2014).

Available zinc

The available Zn status of soils in the study area ranged from deficient to sufficient (Figure 11). Major portion of the study area was deficient in available zinc. The available zinc content of the black soils ranged from 0.1 to 0.9 ppm with a mean of 0.4 ppm and standard deviation of 0.2, whereas the available

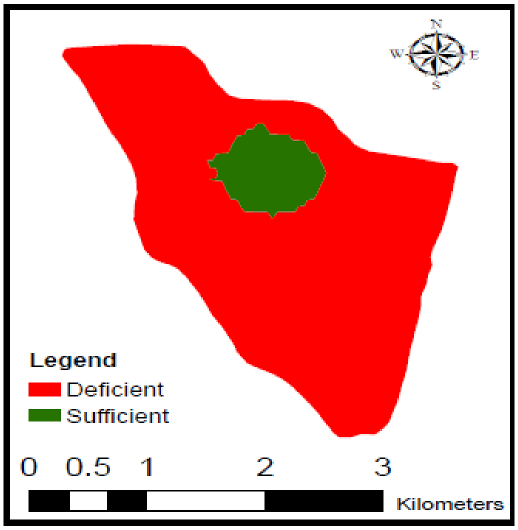

Figure 11. Available Zn status of study area.

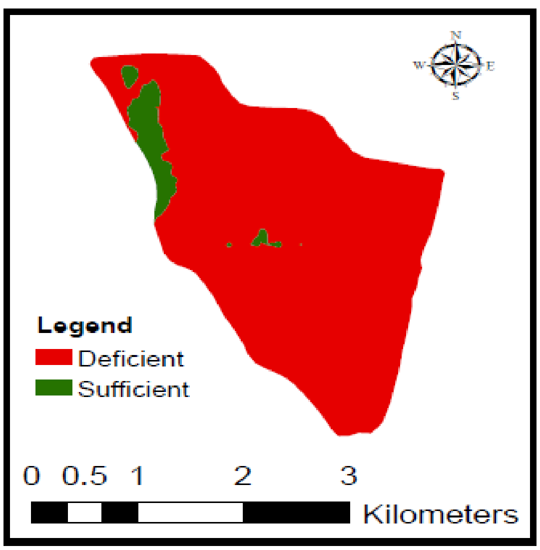

Figure 12. Available Cu status of study area.

zinc content of the red soils ranged from 0.03 to 1.0 ppm with a mean of 0.5 ppm and standard deviation of 0.2 (Table 1). The sufficiency of Zn in the red soils could be due to the high organic carbon values in these soils (Srikanth et al., 2008). However, since some of the soils were alkaline in nature and contained some appreciable amounts of $CaCO_3$, though not in quantities that could make them calcareous, yet the presence of these appreciable amounts of $CaCO_3$ might have resulted to precipitation of zinc as hydroxides and carbonates under alkaline pH range. Therefore, their solubility and mobility may decrease, hence resulting in reduced availability (deficiency) as observed in the study area.

Available copper

Major portion of the study area was deficient in available copper (Figure 12). The available copper content of the black soils ranged from 0.1 to 1.0 ppm with a mean of 0.5 ppm and standard deviation of 0.2, whereas the available copper content of the red soils ranged from 0.1 to 1.0 ppm with a mean of 0.6 ppm and standard deviation of 0.3 (Table 1). Raghupathi (1989) reported that the available copper content in North Karnataka soils ranged from 0.4 to 1.2 ppm. Similar results have also been observed by Ravikumar et al. (2009). In the present study, the available copper content of black soils was observed to be lower than red soils. This might be attributed to the high $CaCO_3$ and clay content in black soils than red soils, which could have favoured copper fixation. In addition, the pH and texture of soils might have influenced nutrient concentrations in the soils. Lighter, slightly acidic soils might be more responsive (Raghupathi, 1989). Soil pH has a significant effect on nutrient availability. High pH (greater than 7.5) greatly limits the solubility of many elements (i.e. Zn, Cu, Mn, Fe), while low soil pH (less than 7.5) can lead to deficiencies of P or Ca and toxicities of Al, Fe or Mn. Moreover, the low soil temperature, poor aeration, and the presence of a hardpan as revealed by soil physical constraints assessment might have contributed to the deficient Cu status in the study area (Amara and Patil, 2014; Pulakeshi et al., 2012; Karajanagi, 2013).

Exchangeable calcium and magnesium

Major portion of the study area was sufficient in exchangeable Ca status (Figure 13). The soils of the study area were moderate to high in exchangeable Ca. The exchangeable calcium content of the black soils ranged from 8.6 to 35.8 cmol(p+) kg^{-1} with a mean of 23.8 cmol(p+) kg^{-1} and standard deviation of 8.2, whereas the exchangeable calcium content of the red soils ranged from 3.2 to 28.6 cmol(p+) kg^{-1} with a mean of 8.6 cmol(p+) kg^{-1} and standard deviation of 3.9 (Table 1). The exchangeable Mg content of the soils of the study area ranged from low to medium (Figure 14). The exchangeable Mg content of the black soils ranged from 6.0 to 23.2 cmol(p+) kg^{-1} with a mean of 14.9 cmol(p+) kg^{-1} and standard deviation of 4.8, whereas the exchangeable Mg content of the red soils ranged from 1.9 to 16.5 cmol(p+) kg^{-1} with a mean of 5.0 cmol(p+) kg^{-1} and standard deviation of 2.4 (Table 1). The low exchangeable Mg as compared to exchangeable Ca in these soils might be attributed to the type and amount of clay as well as the replacement of Mg by Ca on the exchange complex. However, the red soils were observed to contain lower exchangeable Mg than the black soils. This could be due to the easy leaching of bases and low organic carbon values.

In addition, availability of calcium and magnesium to the crops do not generally present problems in the black soils, as these soils are mostly alkaline, have high CEC and more often calcareous in nature. According to Nandi and Dasog (1992),

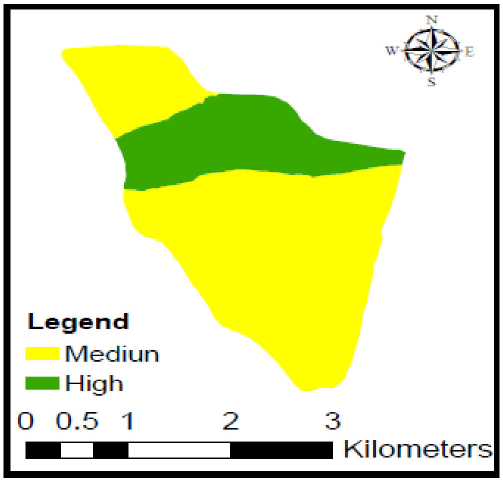

Figure 13. Exchangeable Ca status of study area

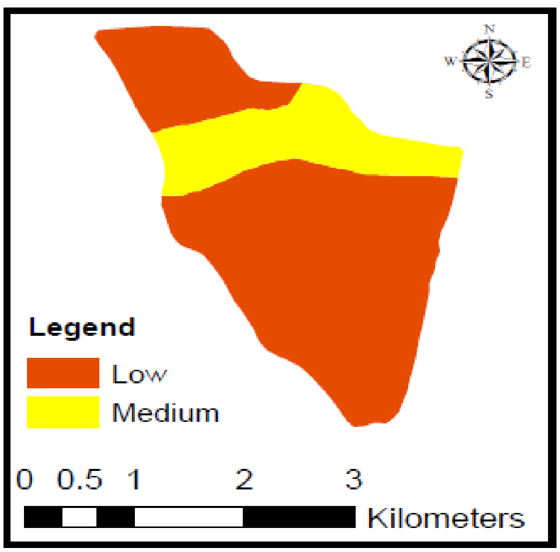

Figure 14. Exchangeable Mg status of study area

high values of CEC and exchangeable Ca and Mg in soils are an indication of dominance of smectite type of clay mineral in the black soil of Karnataka.

CONCLUSION AND RECOMMENDATIONS

There was considerable spatial variability in the soil parameters of the study area except for available Manganese. The soil health status of the study area varied from poor to medium due to moderate to severe soil physical constraints resulting from shallow depth, poor aggregate stability, moderately developed tillage pan, high content of coarse fragments and medium organic matter. The results of the study are of potential practical use in determining site specific nutrient management practices, that would help in improving fertilizer use efficiency, reducing cost of cultivation and preventing environmental pollution.

Disclosure of conflict of interest

The authors declare that there are no conflicts of interest

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