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Article

Spatial distribution of macronutrients in soils of Markandeya river basin, Belgaum(d), Karnataka(s), India

P. Ravikumar, **R. K. Somashekar**

Department of Environmental Science, Bangalore University, Bangalore – 560056, India

E-mail: prakruthiravi@gmail.com, nisargaravi@gmail.com

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Abstract

Markandeya River basin stretches geographically from 15^0 56’ to 16^0 08’ N latitude and 74^0 37’ to 74^0 58' E longitude**,** positioned in the midst of Belgaum district in the northern part of Karnataka state. Spatial distributions for twenty different soil quality characteristics were analyzed in the soil samples collected from 30 selected agricultural fields in the study area. Nutrient index reflected the nutrient status of soil and hence it was calculated by using already determined chemical parameters like organic C, available N, available phosphorus, and available potash. The present study revealed that there is not much variation in soil fertility status of soils developed on various landforms in the area. The soils had variable organic matter content and decomposition rates accounting to 0.06 to 1.5 % of organic carbon. Further, it is evident that all the soil samples were having low available nitrogen (29.1-189.5 Kg/ha) content, 50% of the samples has low to medium available P (0.96 to 15.1 Kg/ha) and 90% of the samples showed adequate supply of available potash (313.3-1500.8 Kg/ha). Sodium Absorption Ratio (SAR) and Exchangeable Sodium Percentage (ESP) indicated that the soils were excellent for irrigation.

Keywords Markandeya river basin; nutrient index; salt index; soil reaction index; organic carbon.

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1 Introduction

Soil analysis has been used as an aid in assessing soil fertility and plant nutrient management for many years. Soil analysis and its interpretation is an important management tool (a) in assessing the need to apply nutrients in fertilizers and/or manures to maintain soil fertility of our agricultural soils not only for the present but for the future also (Zhang and Zhang, 2007) and (b) to make the agricultural land remain capable of sustaining crop production at an acceptable level (Zhang et al., 2006). Among the aids available to manage soil fertility, soil sampling and analysis is the first of three equally important steps in managing the nutrients required by plants. The second is the interpretation of the analytical data leading to the third step, recommendations for nutrient additions, as fertilizers or manures, to optimize crop yields while minimizing any adverse environmental impact from their application. Currently there are well tried and tested recommendations for nutrient additions to soil. Recently however soil audits, involving additional analyses, based on the ratio of certain cations in soil (Base Cation Saturation Ratios) and recommendations based on different approaches to the interpretation of analytical data are being offered to farmers as a better approach to plant nutrient management. The productive capacity of a soil depends on often complex and sometimes little understood interactions between the biological, chemical and physical properties of soil. Good farm practice aims to manage the various factors that make up each of these three properties to optimize the yields of crops in environmentally friendly ways. Soils invariably contain total quantities of plant nutrients that greatly exceed the amounts that are immediately available to plants. Soil fertility fluctuates throughout the growing season each year due to alteration in the quantity and availability of mineral nutrients by the addition of fertilizers, manure, compost, mulch, and lime or sulfur, in addition to leaching. Hence, soil analysis is an aid in managing soil nutrients efficiently to maintain soil fertility for those nutrients like phosphorus (P), potassium (K) and magnesium (Mg) that are retained in soil in plant available forms. If the amount of any of these nutrients in such forms in soil is too small then yield is jeopardised, but increasing reserves in agricultural soils to very high levels is a necessary expense.

The present study is mainly focused on testing of soil samples in Markandeya river basin to determine their current fertility status and to provide information to the farmer regarding nutrient availability in soils. The baseline data so generated can form the basis for the fertilizer recommendations for maximizing crop yields and further to maintain the optimum fertility in soil year after year.

2 Materials and Methods

2.1 Study area

The River Markandeya is one of the major tributaries of River Ghataprabha, subsequently joins the River Krishna in the Northern Karnataka. River Markandeya originates in Bailur in Western Ghats and flows for a length of 66 km towards east before joining Ghataprabha near Gokak. A dam (16° 2′ 0″ N latitude and 74° 38′ 30″ E longitude) has been constructed across the river Markandeya to establish reservoir at Shirur village in Gokak taluk. The study area, Markandeya River basin stretches geographically from 15^0 56’ to 16^0 08’ N latitude and 74^0 37’ to 74^0 58' E longitude**,** positioned in the midst of Belgaum district in the northern part of Karnataka state. The study area is having a catchment area of 432 Km^2 (43,200 ha).The gross command area is around 328.31 Km^2 covering part of Gokak (237.98 Km^2), Saundatti (26.13 Km^2), Hukkeri (50.6 Km^2) and Belgaum (13.6 Km^2) taluks of Belgaum District. The reservoir water is directed via Markandeya Left Bank Canal (MLBC, 15 Km) and Markandeya Right Bank Canal (MRBC, 71 Km) to irrigate an area of around 8.9 Km^2 (890 Ha) and 182.15 Km^2 (18,215 ha) respectively. Thus, the net irrigable area is around 191.05 Km^2 (19105 ha) covering part of Gokak (95.83 Km^2), Saundatti (80.37 Km^2), Hukkeri (8.90 Km^2) and Belgaum (5.95 Km^2) taluks of Belgaum District. Markandeya Irrigation project is aimed at providing enhanced irrigation facilities and an improved drinking water system to the villages of four taluks of Belgaum district by means of canal system.The Location map of the Markandeya river basin along with the sampling points is shown in Fig. 1.

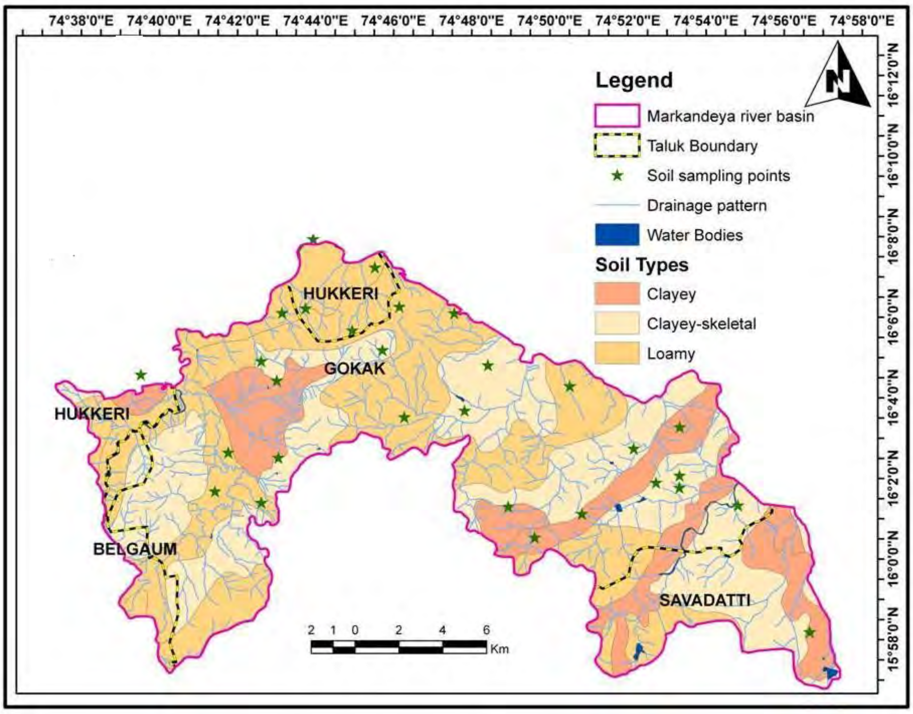

Fig. 1 Location Map of Markandeya river basin.

2.2 Methodology

2.2.1 Soil sample collection and analysis

A total of thirty representative soil samples (numbered RMS1 to RMS30) were collected from plough layer (15 to 30 cm depth) spread over different villages in the Markandeya river basinduring February 2009 (post-monsoon) using a hand auger / soil auger. The soil samples collected were air-dried under shade, pounded to break large clods in a ceramic mortar using wooden mallet, sieved (<2mm) and stored in clean polyethylene containers at 10°C prior to physico-chemical analyses.

The soil analyses were conducted in accordance with the standard techniques of Jackson (1965a, b, 1968; 1973, 1982) and Black (1965a, b, 1968, 1982). The methods used for determining the various qualitative and quantitative soil quality indicators in the processed soils are detailed below:

1) pH and electrical conductivity (EC, dS/m) were determined in the supernatant solution of 1:5 soil/water ratio (w/v) using a pH meter and conductivity bridge / meter (Jackson, 1973) respectively.

2) Exchangeable base cations (viz., Ca^{2+}, Mg^{2+}, Na^{+} and K^{+}) in soil were extracted by leaching the soil with 1N ammonium acetate at pH 7.0 (w/v), kept for overnight and then filtered using Whatman filter paper No. 42 and final volume was made up to 100 ml using distilled water. The ammonium acetate leachate (viz., filtrate) is used to estimate calcium (Ca^{2+}) and magnesium (Mg^{2+}) by EDTA titrimetric method (Jackson, 1973). The potassium (K^{+}) and sodium (Na^{+}) in the filtrate was determined using flame photometer (Chapman, 1965).

3) Organic carbon and Soil Organic matter (SOM) were determined following the wet digestion method of Walkley and Black (1934).

4) Total nitrogen was determined by Kjeldahl digestion, distillation and titration procedures as described by Jackson (1958a and b) and Bremner et al. (1982).

5) Available Phosphorus in the soil samples was determined by leaching the soil with 0.002N H_2SO_4 (1 soil : 200 H_2SO_4 suspension, w/v) and shaken for at least 30 minutes and filtered through Whatman filter paper No. 50 to get a clear solution. the amount of phosphorus in the extract was estimated by chlorostannous reduced phosphomolybdate blue colour method using spectrophotometer at wavelength of 690 nm (Jackson, 1973),

6) Water holding capacity of soil is the amount of maximum water, which can be held in the saturated soil. It is measured as the amount of water taken up by unit weight of dry soil when immersed in water under standardized conditions. Take a filter paper in a funnel and weigh it. Pour 10ml of water with a pipette wetting the entire filter paper and collect excess of water until the last drop falls. Add 5g of soil in the funnel and find the weight of the soil with wet filter paper. Pipette out 25ml of water and add gradually until the last drop of water drips out of the funnel. Note the final weight.

$$\%\boldsymbol{WHC} = \frac{(\boldsymbol{W4} - \boldsymbol{W3}) - (\boldsymbol{W2} - \boldsymbol{W1})}{(\boldsymbol{W3} - \boldsymbol{W2})} \boldsymbol{X100} \ \ldots\ldots \boldsymbol{Equation\ 1}$$

where W1 = Weight of funnel + dry filter paper

W2 = Weight of funnel + wet filter paper

W3 = Weight of funnel + wet filter paper + 5g dry soil

W4 = Weight of funnel + wet filter paper + wet soil

7) Exchangeable sodium percentage (ESP) and Sodium Absorption Ratio (SAR) is estimated by calculation, by considering the values of exchangeable Na, exchangeable Ca, exchangeable K and exchangeable Mg.

$$\boldsymbol{ESP} = \boldsymbol{Exchangeable} \frac{\boldsymbol{Na}}{\boldsymbol{Ca} + \boldsymbol{Mg} + \boldsymbol{K} + \boldsymbol{Na}} \boldsymbol{X100} \ \ldots\ldots \boldsymbol{Equation\ 2}$$

$$\boldsymbol{SAR} = \boldsymbol{Exchangeable} \frac{\boldsymbol{Na}}{\sqrt{\frac{\left(\boldsymbol{Ca}/\boldsymbol{Mg}\right)}{\boldsymbol{2}}}} \ldots\ldots \boldsymbol{Equation\ 3}$$

where the ionic concentrations of Ca, Mg, K and Na are expressed in meq/100g.

2.2.2 Fertility of soil

The nutrient status considers the instant availability of nutrients in soil. In order to evaluate the soil fertility status in Markandeya river basin, different indices like soil reaction index, salt index and nutrient index with respect to organic carbon (%), Available Nitrogen (Kg/ha), Available Phosphorus(Kg/ha) and Available Potash (Kg/ha)were calculated based on the specific rating chart and criteria (Table 1).

The Nutrient Index in soil was evaluated for the soil samples analysed using the equation 4 and the obtained results were interpreted by comparing with the rating chart given in Table 2.

$$\boldsymbol{NutrientIndex} = \frac{(\boldsymbol{1Xno.ofsamplesinlowcategory}) + (\boldsymbol{2Xno.ofsamplesinmediumcategory}) + (\boldsymbol{3Xno.ofsamplesinhighcategory})}{\boldsymbol{Totalnumberofsamples}} \ldots\ldots \boldsymbol{Equation\ 4}$$

Table 1 Limits for soil test values used for rating the soils (Verma et al., 2005).

Nutrient Index			
Soil Constituent	**Low (I)**	**Medium (II)**	**High (III)**
Organic Carbon (%)	<0.4	0.4-0.75	>0.75
Available Nitrogen (Kg/ha)	<271	271-543	>543
Available Phosphorus (Kg/ha)	<12.4	12.4-22.4	>22.4
Available Potassium (Kg/ha)	<113	113-280	>280
Soil Reaction Index			
Soil pH	**I**	**II**	**III**
	Acidity (< 6.0)	Neutral (6.0-8.0)	Neutral (Above 8.0)
Salt Index			
Electrical Conductivity (dS/m)	**I**	**II**	**III**
	Normal (< 1.0)	Critical (1.0 – 2.0)	Injurious (> 2.0)

Table 2 Nutrient Index with Range and Remarks.

Nutrient index	**Range**	**Remarks (OC, P, K, N)**
I	Below 1.67	Low
II	1.67 – 2.33	Medium
III	Above 2.33	High

3 Results and Discussion

The descriptive statistics of physico-chemical parameters of soil from the study area are presented in Table 3.

Table 3 Descriptive statistics showing summarized results of soil characteristics.

Parameters	**Markandeya river basin (n = 30)**			
	Mean	**SD**	**Min**	**Max**
pH	7.63	0.31	7.11	8.10
EC (dS/m)	0.058	0.069	0.014	0.310
Na (meq/100g)	1.82	1.56	0.44	8.35
K (meq/100g)	1.12	0.68	0.10	2.90
% K20	0.05	0.03	0.01	0.14
P (mg/100g)	0.02	0.02	0.00	0.07
Ca (meq/100g)	30.81	9.91	14.20	57.00
Mg meq/100g	11.38	4.84	3.81	26.05
% OC	0.61	0.30	0.06	1.50
% OM	1.06	0.52	0.10	2.59
WHC (%)	69.43	21.40	36.20	139.60
Available P (Kg/ha)	26.95	25.36	0.96	78.82
Avail. N2 (Kg/ha)	53.48	28.14	29.10	189.50
Avail K (Kg/ha)	577.17	350.82	44.80	1,500.8
SAR	0.29	0.24	0.07	1.24
ESP	4.17	3.10	0.87	15.30

3.1 pH

The measure of soil pH is an important parameter which helps in identification of chemical nature of the soil (Shalini *et al.*, 2003) as it measures hydrogen ion concentration in the soil to indicate the acidity or alkalinity nature of the soil. Soil acidity (pH) in the range 5.5-7.5 though rarely affects the growth of most crops directly, but can influence the availability of other nutrients. The soil samples from Markandeya river basin has favourable pH, with pH varying from 7.11 to 8.1, indicating slightly alkaline nature. The lowest pH value of 7.11 was found in sample no. RMS13, while a maximum pH of 8.1 was found in sample no. RMS22 and RMS24 (Table 4). The alkaline nature in the soil samples may be due to high amount of leaching of exchangeable anions as observed in the field.

Table 4 Measured pH of soil samples in the Markandeya river basin.

Sl. No	pH values	Range (No. of samples; %)
1	6.5 to 7.00	----
2	7.00 to 7.5	7.11-7.5 (10; 33.34)
3	7.5 to 8.0	7.51-7.94 (14; 46.66)
4	8.0 to 8.5	8.02-8.1 (6; 20)

3.2 Electrical conductivity (salinity)

Conductivity, as a measure of current carrying capacity, gives a clear idea of the soluble salts present in the soil. It plays a major role in the salinity of soils. Lesser the EC value, low will be the salinity value of soil and vice versa. Even though, soil conductivity is influenced by many factors, high conductivities are usually associated with clay-rich soil and low conductivities are associated with sandy and gravelly soils. This is a result of the shape and physical properties of the particles which make up the soil. A salt affected soil is defined as soil that has been adversely affected the growth of most crops by the presence anion or cation of soluble salts. This type of soil is commonly seen in arid and semi-arid regions; in irrigation command areas; in regions with poor drainage and in areas where poor quality water is used for irrigation, because there is insufficient rainfall to flush them from the upper soil layers, which include both sodic and saline soils.

Table 5 Saline conditions and categories of crop tolerance.

EC (dS/m)	Category	Range (No. of samples; %)
< 0.7	All crops	0.014-0.310 (30;100)
0.7 – 2.0	Most crops	----
2.0 – 10.0	Salt tolerant crops	----
10.0 – 32.0	Most halophytes	----
33.0 >	No crops (sea water)	----

The soluble salts concentration above 4 dS/m in soil moisture inhibits the seed germination and growth of most commercial crops, which adversely affects the biomass production and economic yield. In the present study, it is very much clear from the results that the salinity problem is not critical as the saline criterion was < 0.7, indicating the good quality of soil and considered suitable for agriculture (Table 5).

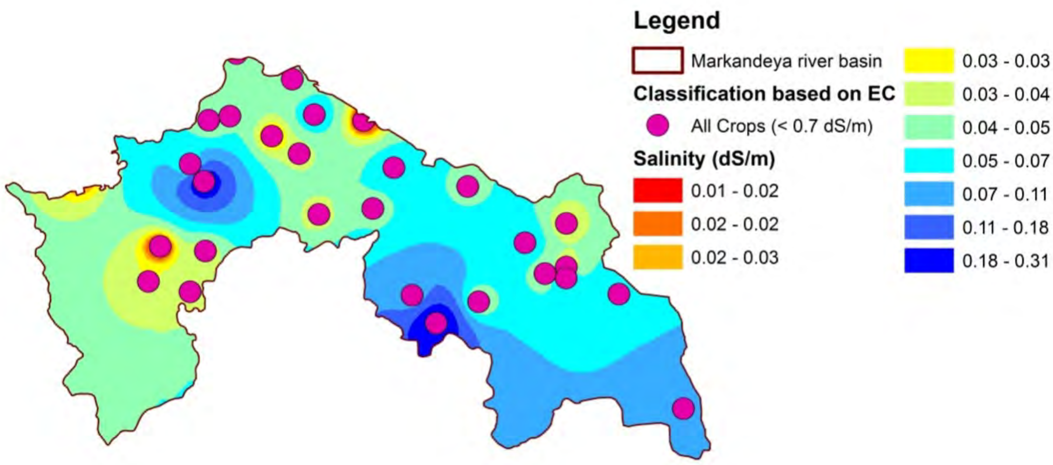

Fig. 2 Spatial distribution of salinity in soil samples.

3.3 Water holding capacity

Water holding capacity is the amount of water that can be retained / held by the soil when all the pores in the soil have been filled with water. Under this condition, soil is saturated with water, accompanied by very poor or no drainage. The WHC of the soil samples ranged from 36.2 to 95.6 % in the study area. The standard for WHC of soil is 5% and thus all the samples have water holding capacity well within the standard. WHC was more in the surface soil layer which had greater accumulation of organic matter, litter, root mass, etc., thereby indicating relatively stronger influence of soil organic matter on water holding capacity as observed by Woomer and Swift (1994). Most locations in the study area had clayey type soil, which could hold more amount of water.

3.4 Exchangeable calcium

In Markandeya river basin, the values varied from 14.2 to 57.0 meq/100g with a minimum concentration of 14.2 meq/100g in the sample RMS14 and a maximum value of 57 meq/100g in sample RMS30.

3.5 Exchangeable magnesium

In the Markandeya river basin, the concentrations varied from 3.81 to 26.05 meq/100g with a minimum concentration of 3.81 meq/100g in the sample RMS14 and a maximum value of 26.05 meq/100g in sample RMS30.

3.6 Exchangeable sodium

In the Markandeya river basin, the values varied from 0.44 to 8.35 meq/100g with a minimum value of 0.44 meq/100g (sample RMS25) and a maximum value of 8.35 meq/100g (sample RMS29).

3.7 Exchangeable potassium

Potassium (K) is the third most required element by the plants, which plays a key role in water balance in plants or regulation of osmosis (Singh and Tripathi, 1993). It is the most abundant metal cation in plant cell (2 to 3 % by dry weight). In the Markandeya river basin, its values varied from 0.1 to 2.9 meq/100g, with a minimum value of 0.1 meq/100g in the sample RMS30 and a maximum value of 2.9 meq/100g in sample RMS25. Under ordinary field condition, with an adequate nutrient supply, K^+ removal by crops is high, often being three to four times that of phosphorus and equal to that of nitrogen. This tendency is termed as 'luxury consumption' because the excess K^+ adsorbed apparently does not increase crop yield to any extent. A certain amount of this element is needed for optimum yields and this is termed as 'required potassium'. All K^+ above this critical level is considered as luxury; the removal of which is ultimately wasteful. The various forms of potassium in the soil can be classified on the basis of their availability (a) Relatively unavailable form (90-98%), (b) Relatively available form (1-2% of the total amount of these elements in an average mineral soil) and (c) Slowly available form (It is fixed form of K^+, which cannot be replaced by ordinary exchange method and is referred to as non-exchangeable K^+).

The available Potash (K) values varied from 44.8 to 1500.8 kg/ha in the study area, with 90 % of the soil samples showing adequate supply of available potassium (Table 6). Soil samples with deficient and doubtful supply of potassium can be enriched with garden compost which contains 0.48% K_2O or vermicompost containing about 0.7% K_2O.

Table 6 Classification of soil quality based on measured available potash concentration in soil (Muhr et al., 1965a, b; Verma et al., 2005).

Sl. No	**Supply of Available Potash (K)**	**Quantity (Kg/ha)**	**Range (No. of samples; %)**
1	Deficient supply of (K)	< 113	44.8-112 (2; 6.67)
2	Doubtful supply of (K)	113 to 280	201.6 (1; 3.33)
3	Adequate supply of (K)	> 280	313.3-1500.8 (27; 90)

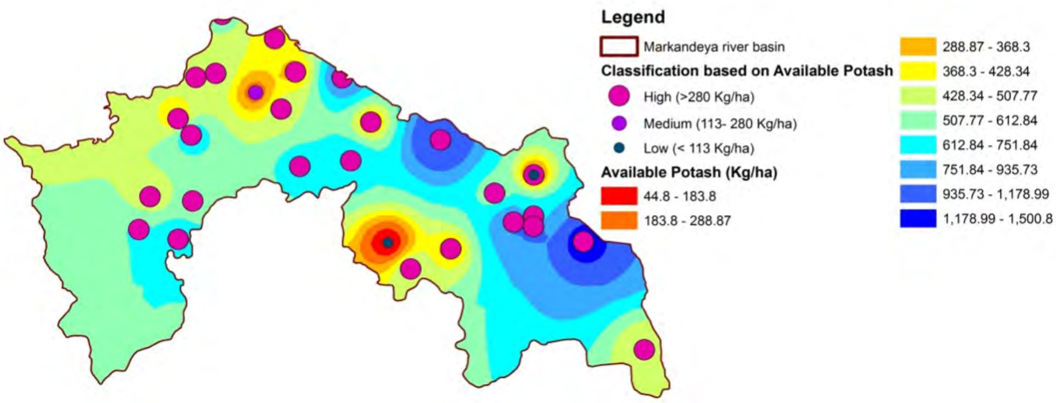

Fig. 3 Spatial distribution of available potash in soil samples.

3.8 Percent Organic carbon (OC) and Percent Organic Matter (OM)

The importance of organic matter in the soil is implied in the definition of soil, which recognizes fertility status of the soil, as a unique feature distinguishing soil from the parent rock / other non-fertile soils. It increases the soil fertility / nutrient status and controls erosion and runoff of the soil and water, besides it is a major determinant of improved soil structure, moisture content and general nutrient status of the soil. It varies from place to place and it is generally enhanced in thickly vegetated areas. The variation largely depends on soils, climate, plant and animal species (Brady, 1995) although it is impossible to determine the optimum level of organic matter required by the plants, as it is not a single value required for all the plants, for all the soils. The percentage of organic carbon ranged from 0.06 to 1.5 in study area, indicating variable organic matter content and decomposition rates**,** with 46.66 % of the sample showing medium percent organic carbon (i.e., <0.75). The organic matter content varied from 0.1-2.59 % in the study area. The quality of soil may be graded depending upon the organic carbon content (%) as given in Table 7 and accordingly, majority of the soil samples (i.e., 73.33 %) appear to possess low to medium percent organic carbon content and it is necessary to apply organic wastes as an important source of nutrient to these agricultural fields.

Table 7 Classification of soil quality based on organic carbon content (Muhr et al., 1965a, b; Verma et al., 2005).

Sl. No	Percent of organic carbon	Rating	Range (No. of samples; %)
1	< 0.40	Low	0.06-0.39 (8; 26.67)
2	0.4 to 0.75	Medium	0.45-0.75 (14; 46.66)
3	> 0.75	High	0.84-1.5 (8; 26.67)

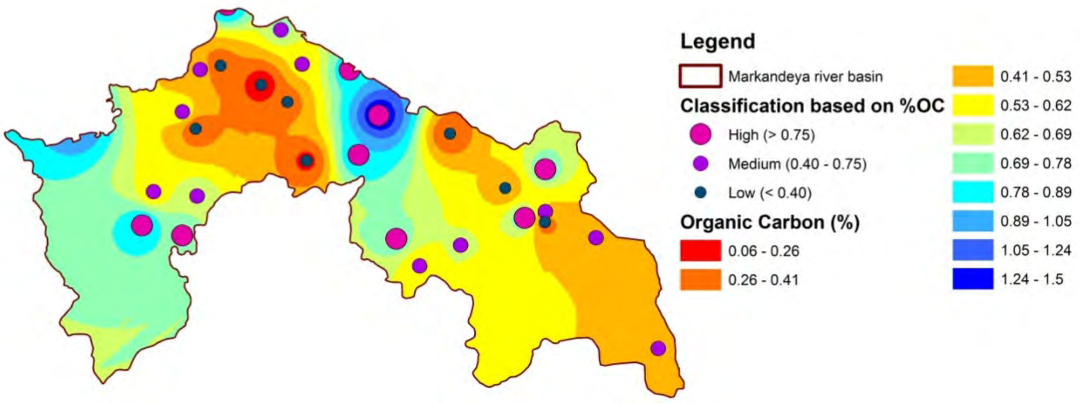

Fig. 4 Spatial distribution of organic carbon (%) in soil samples.

3.9 Available nitrogen

Plants take up nitrogen generally as nitrates under aerobic conditions and as ammonium ions during anaerobic conditions. Nitrogen is most often the limiting nutrient for the plant growth. In Markandeya river basin, nitrogen content is very low (<272 Kg/ha) in all the soil samples (Table 8). Excess Soil moisture content is one of the important factors affecting nitrification in water logged soils and is having a major contribution to vary the process. When excess water is found in water logged areas, soil suppresses the process of nitrification because of deficient oxygen. Unlike in dry soils as in case of our study area soils however, do have enough moisture for the bacterial metabolism and the moistening of such soils rapidly increases the rate of biosynthesis of nitrogen.

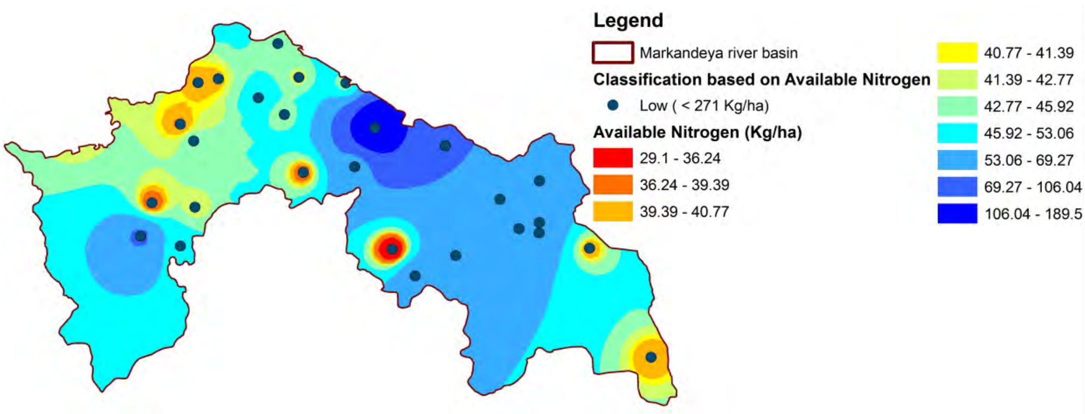

Fig. 5 Spatial distribution of available nitrogen in soil samples.

Table 8 Concentration of Nitrogen in the soil (Muhr et al., 1965a, b; Verma et al., 2005).

Sl. No.	Quantity of nitrogen (Kg/ha)	Rating	Range (No. of samples; %)
1	Less than 271	Low	29.1-189.5 (30;100)
2	Between 272 to 553	Medium	-----
3	More than 553	High	----

3.10 Available phosphorus

Phosphorus is the second most important macronutrient available in the biological systems, which constitutes more than 1% of the dry organic weight. It is also a second most limiting factor that often affecting plant growth, which exists in the soil in both organic and inorganic forms. In the Markandeya river basin, the available phosphorus content ranged between 0.96 to 78.82 kg/ha (Fig 6), with 50 % of the soil samples showing low to medium available phosphorus. The remaining samples showed adequate to abundant phosphorus quantity (Table 9). Soils from Agricultural fields with low to medium phosphorus content in the study areas can be supplemented by applying phosphorous rich fertilizers as required by a specific crop.

Table 9 Measured concentration of available phosphorus in soil (Muhr et al., 1965a, b).

Sl. No	Grade	Concentration (Kg/ha)	Range (No. of samples; %)
1	Low phosphorus	Less than 12.4	0.96-6.45 (12;40)
2	Medium phosphorus	12.4 to 22.4	12.7-15.1 (3;10)
3	Adequate phosphorus	More than 22.4	24.77-31.87 (3;10)
4	Abundant phosphorus	Still higher	40.35-78.82 (12;40)

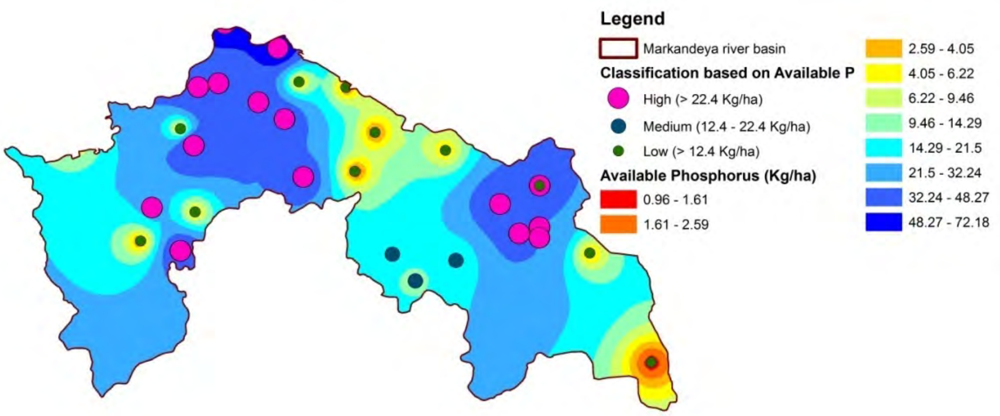

Fig. 6 Spatial distribution of available phosphorus in soil samples.

3.11 Exchangeable Sodium Percentage (ESP)

The exchangeable sodium percentage (ESP) identifies the degree to which the adsorption / exchange complex of soil is saturated with sodium. The ESP levels of 15 yield pH values of 8.5 and above. Higher levels may bring the pH to at least 10. It is important to note that sodium has been found partially to take the place of potassium in the nutrition of certain plants. Exchangeable Sodium percentage values for all the soil samples in the Markandeya river basins varied between 0.87 to 15.3 (Table 10; Fig. 7), which fall under excellent category suggesting good indication of a fertile soil status.

Table 10 Classification of soil samples based on ESP values.

Sl. No.	ESP	Category	Range (No. of samples; %)
1	< 20	Excellent	0.87-15.3 (30; 100)
2	20 to 40	Good	----
3	40 to 60	Permissible	----
4	60 to 80	doubtful	----

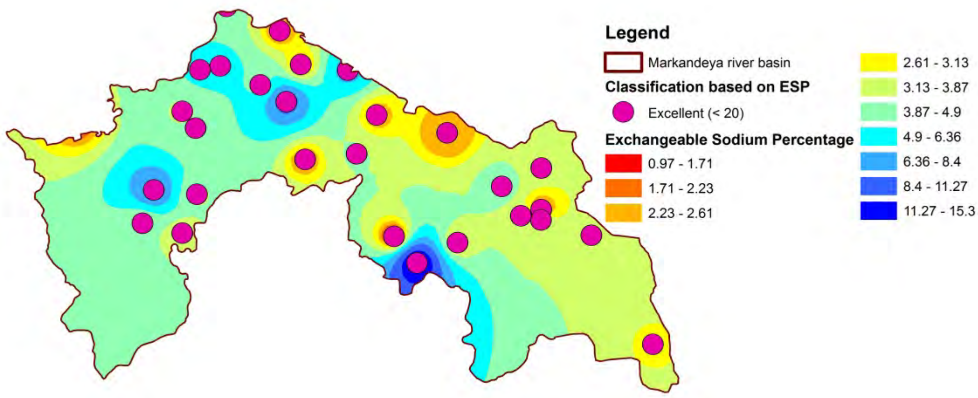

Fig. 7 Spatial distribution of exchangeable sodium percentage in soil samples.

3.12 Sodium Absorption Ratio (SAR)

Sodium Absorption Ratio is considered as a better measure of sodium hazard in irrigation as SAR of water is directly related to the absorption of sodium by soil and is a valuable criterion for determining the suitability of water for irrigation. When the concentration of sodium ion is high in irrigation water, Na+ tends to be absorbed by clay particles, displacing magnesium and calcium ions. This exchange process of sodium in water for Ca2+ and Mg2+ in soil reduces the permeability and eventually results in soil with poor internal drainage. In agricultural practice, sodium concentration is also expressed in terms of sodium absorption ratio. SAR values in all the soil samples analyzed ranged from 0.066 to 1.242, belonging to excellent category for the purpose of irrigation (Table 11; Fig. 8).

Table 11 SAR based Classification of soil samples.

Sl. No.	SAR	Category	Range (No. of samples; %)
1	Less than 10	Excellent	0.066-1.242 (30;100)
2	10 to 18	Good	----
3	18 to 26	Fair	----
4	More than 26	Poor	----

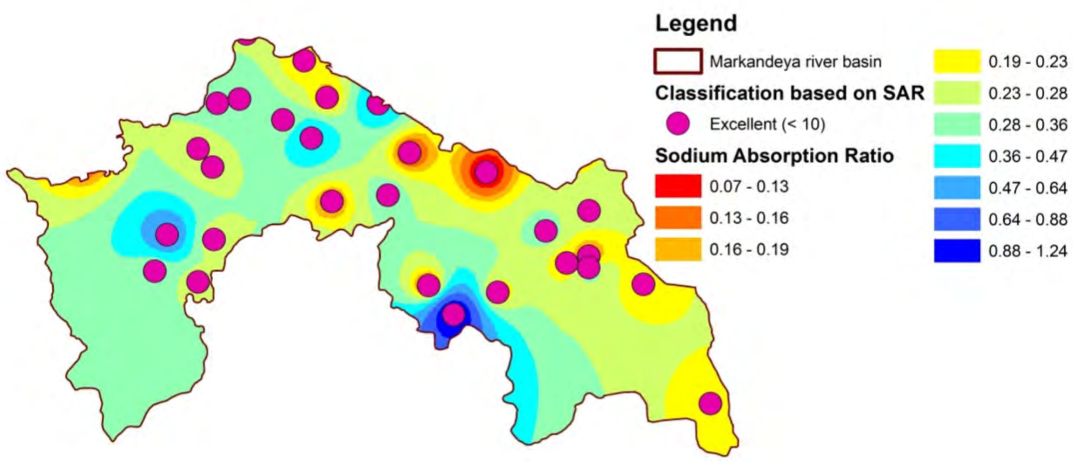

Fig. 8 Spatial distribution of sodium absorption ratio in soil samples.

3.13 Soil fertility assessment

A close study of the physico-chemical parameters analyzed reveals some interesting and important information about the quality of soil in the study area. The study area poses no significant problem, barring a few cases where the salinity of the soil is slightly high and there is virtually no area, which is unsuited for sustained irrigation. Most of the area is problem free - as the soils are fertile having adequate supply of most of the nutrients and are located in rain fed areas receiving sufficient rainfall.

It is possible to classify soil samples to Soil Reaction Index class of I (Acidity, < 6.0), II (Neutral, 6.0-8.0) and III (Neutral, > 8.0) based on soil pH. Accordingly, pH varying from 7.11 and 8.1 grouped 80% of the samples to fall under soil reaction index class II and 20% to soil reaction index class III, which shows that the soils of the study area are under the neutral and alkaline range. Soil samples further can be grouped into salt index class of I (normal, < 1.0dS/m), II (critical, 1.0 – 2.0 dS/m) and III (injurious, > 2.0 dS/m) respectively based on their conductivity values. Accordingly, all the samples fall under Salt index category of I, having normal salt concentration ranging from 0.014 to 0.310 dS/m.

Alternatively, separate nutrient index was calculated for each of the parameters namely, %OC, available nitrogen, available potash and available phosphorus. The organic carbon content of soil samples was in the range of 0.06 to 1.5 % and majority of the samples belong to low to medium level with a nutrient index value of 2.0. The available phosphorus values fall in low to high range, with a nutrient index value of 2.1. The available nitrogen content fall under low range in the study area, with a nutrient index of 1.0 while majority of samples had high available potash content with a nutrient index of 2.83 (Table 12).

Table 12 Soil test summary and nutrient indices.

Soil Parameters	% Sample			Nutrient Index
	Low	Medium	High	
% OC	26.67	46.66	26.67	2.00
Avail. N	100	- -	- -	1.00
Avail. P	40	10	50	2.10
Avail. K	6.67	3.33	90	2.83

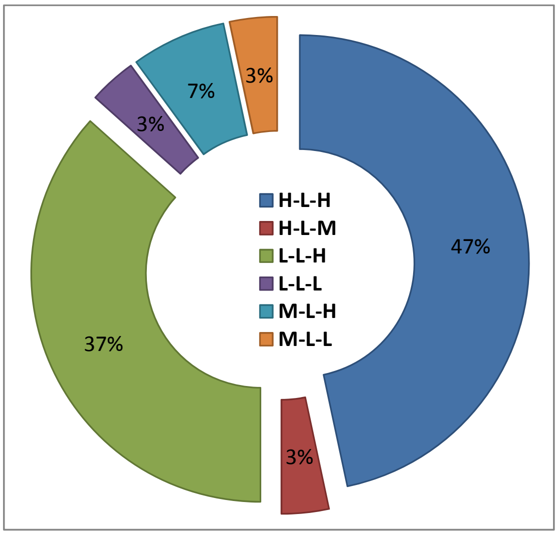

Fig. 9 Soil fertility categories in the Markandeya river basin.

Further, the soils of Markandeya river basin can be characterized into six soil fertility categories (w.r.t. available N, P & K) based on the criteria given in Table 1. The six soil fertility categories include High-Low-High (HLH), High-Low-Medium (HLM), Low-Low-High (LLH), Low-Low-Low (LLL), Medium-Low-High (MLH) and Medium-Low-Low (MLL) and their percentage share is represented in Fig. 9. With the help of nutrient indices, a rating chart / criteria given in Table 2 and equation 4, it is possible to classify overall nutrient status in the soil samples from the study into different nutrient level (i.e., low, medium or high). It is evident from Table 13 that the overall nutrient status of soils from Markandeya river basin is characterized as medium-low-high-low (MLHL) category. There exist wide variations in soil fertility status in the Markandeya river basin in comparison to the results obtained for soil fertility categories by Verma et al. (2005). In a similar study by Ravikumar and Somashekar (2013), the soils of Varahi River basin was categorised as low-medium-low (LML) based on the nutrient index calculated w.r.t. available organic carbon, available P and available K.

Table 13 Nutrient Index values for the soil samples of the study areas.

Characteristics	Nutrient index values	Remarks
Organic carbon (OC)	2.00	Medium
Available phosphorus (P)	2.10	Low
Available potash (K)	2.83	High
Avail. N	1.00	Low

4 Conclusion

Nutrient index calculated classified overall nutrient status in the soils from Markandeya river basin as medium-low-high-low (MLHL) class. The present study revealed that there is wide variation in soil fertility status of soils developed on various land forms in the study area, but, by and large, the soils are low in available N and low available P, medium in organic carbon and high in available K contents. Irrigational quality parameters (SAR and ESP) indicated that the soils were excellent for irrigation. But, the deficient nutrients have to be restored through chemical fertilizers and/or organic manures to maintain soil health. Hence, soil samples with deficient and doubtful supply of potassium can be enriched with garden compost that contains 0.48% K_2O or vermicompost containing around 0.7% K_2O. Finally, for efficient and sustainable crop production in these soils, a farming system that is both soil enriching and restoring needs to be developed.

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