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Soil fertility assessment for ensuring food security in lower Himalayan range using GIS techniques

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ABSTRACT

Mountainous regions are highly vulnerable to food security as compared to plains because of lack of farmland and higher probability of disasters. Soil fertility plays a crucial role in agricultural production. In the present investigation, soil fertility of Nainital district, a hilly region in Himalayan range, was analyzed to map its spatial distribution. A soil database was created by taking 180 surface soil samples using stratified multistage random sampling method from fields of median sized farmers alongwith geographical location, from each block covering whole Nainital district of Uttarakhand, and were assessed for combined soil fertility with a soil fertility index (SFI). Spatial variability of soil chemical properties was computed and the respective surface maps were prepared using inverse distance weightage (IDW) algorithm embedded in Quantum GIS (QGIS). The layers of three important soil nutrients *i.e.* available nitrogen, available phosphorous and exchangeable potassium were coalesced to evaluate overall soil fertility. The soils of Nainital district were observed to be mostly under medium to highly fertile category, except in specific cases where available phosphorus was quite low. The results indicated 6.89%, 80.44%, and 12.67% of total geographical area (TGA) under less fertile, moderately fertile and highly fertile category, respectively.

1. INTRODUCTION

Agricultural land resources are limited over mountainous regions (Chapin *et al.,* 2011; Xingwu *et al.,* 2015) and agricultural productivity is quite low in comparison to agricultural land over plain regions at similar latitudes. From the advent of agriculture, there has been an innate interest in soil and land quality (Carter *et al.,* 2004) because soil macro-nutrients are indispensable for higher crop productivity under static land resources. The limited availability of agricultural land and the ever increasing food demand due to the exploding population is though enhancing food insecurity day by day (Zuazo *et al.,* 2008). Until 2025, food production must grow by at least 40% to meet the needs of a 33% increase in population, and to satisfy the requirement of balanced nutrition (Akhter *et al.,* 2010). However, susceptibility to food insecurity over hilly regions is more (Mann, 2013). Thus for fulfillment of this challenge, there is a need of assessing soil fertility accurately, and responding to the soil fertility by adopting tailored cropping systems/cropping sequences and management practices. Soil quality is generally defined in terms of soil fertility/productivity. The traditional approach to soil fertility management has been to treat fields as homogenous areas and to calculate fertilizer requirements on a whole field basis. However, it has been reported for years by scientists from across globe that fields are not homogeneous, and sampling techniques to describe field variability is essential (Santra *et al.,* 2008). Soil properties and erodibility status in relation to land uses in a Giri river micro-watershed was carried out in Solan district of Himachal Pradesh (Sharma *et al.,* 2016).

To develop an economically and ecologically sound management plan of soil fertility, spatial distribution of soil available nitrogen, phosphorous, and exchangeable potassium is needed. Spatial variability across the field had been difficult to describe till new tools such as global positioning systems (GPS) and geographic information systems (GIS) were not introduced. GIS is a powerful set of tools for collecting, storing, retrieving, transforming and displaying spatial data (Burrough and McDonnell, 1998). GIS can be used for mapping soil fertility (Patil *et al.,* 2011; Basavaraja *et al.,* 2017). The objective of this study was to analyze macro-nutrient status (available nitrogen, available phosphorus, and exchangeable potassium content) in Nainital district of Uttarakhand, which can provide guidance to understand the status of soil fertility spatially and temporally.

2. MATERIALS AND METHODS

Study Area

The Nainital district of Uttarakhand, situated at 29°0'-29°36'21"N, 78°50'53"-80°0"E covers an area of 4132.15 sq km (Fig.1). It is further divided into eight blocks namely, Betalghat, Bhimtal, Dhari, Haldwani, Kotabagh, Okhalkanda, Ramgarh, and Ramnagar. These blocks can be categorized under three different categories as per their altitudes such as Haldwani, Ramnagar, and Kotabagh blocks fall under low altitude (150-700 m) category; Bhimtal and Dhari blocks under mid altitude (700-1800 m) category and other blocks Betalghat, Okhalkanda, and Ramgarh areas fall in high altitude category (>1800 m). The study area exhibits a diverse set of climatic conditions from sub-tropical in lower altitude and sub-tropical to temperate in higher altitude. The maximum and minimum temperature in plain areas ranges from 42-46ºC and 1-9°C, respectively. The annual rainfall over study area varies from 1200-2647 mm with average annual rainfall is 1246 mm. Nainital district comes under western Himalayan agro-climatic zone (ACZ) which as per National Agricultural Research Project (NARP) is further divided into two sub-zones *i.e.* hill zone, and bhabar and *tarai* zone. Major soil types found in Nainital district are sandy loam, alluvial sandy loam, brown forest soil and red black clay soil.

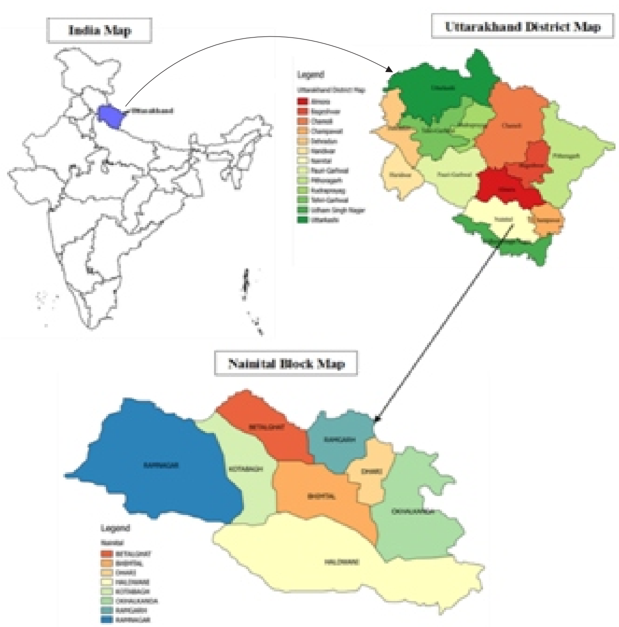

Fig. 1. Location map of Nainital district

Creation of Soil Databases

A hardcopy printed map (with latitude and longitude lines) of Nainital district was scanned and digitized at block level using USGS, WGS-84 geographical coordinate system in QGIS 2.8.1 environment. Soil samples were collected during the year 2011-2012 from 180 locations from fields of median sized farmers alongwith the geo-graphical location with the help of Oregon 550 GPS (Fig. 2) by using stratified multistage random sampling method. The collected soil samples were air dried in shade, passed through a 2 mm sieve and analyzed for available nitrogen, available phosphorus and exchangeable potassium by using different methods mentioned in Table 1. Later, a database on analyzed soil properties was created in "Comma Separated Value" (CSV) format and imported in QGIS environment for creating thematic layers of available nitrogen, available phosphorus and exchangeable potassium.

Generation of Thematic Layers of Soil Properties

Thematic maps of macro-nutrients of soil were prepared using IDW interpolation algorithm embedded in QGIS 2.8.1. The IDW directly implements the assumption that a value of a soil variable at an unsampled location is a weighted average of known data points within a local neighborhood surrounding the unsampled location (Uygur *et al.,* 2010). It is a simple spatial interpolant that often yields satisfactory results (Robinson and Matternicht, 2006) and produces quite improved outputs for soil organic matter (SOM), nitrogen and some other parameters (Mueller *et al.,* 2001). The following equation was used as interpolator (Burrough and McDonnell, 1998).

$$\tilde{Z}\,(x_0) = \frac{\sum_{i=1}^{n} z\,(x_i) d_{ij}^{-r}}{\sum_{i=1}^{n} d_{ij}^{-r}}$$

Where, $\tilde{Z}$ is the value of parameters to be estimated; x_0 = estimation point, x_i = data points. The weights (r) are related to distance by d_{ij}, which is the distance between the estimation point and the data points.

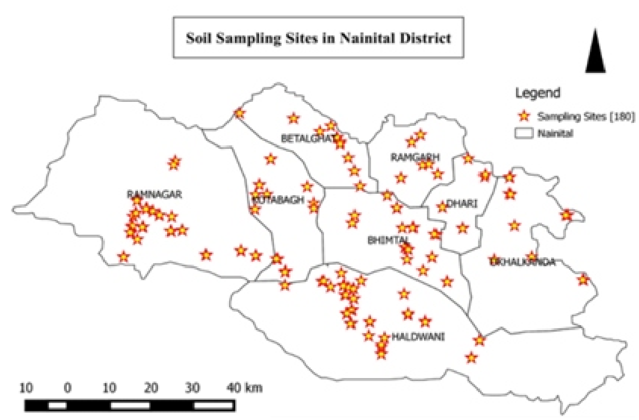

Fig. 2. Soil sampling sites

After interpolation of point data of available N, available P and exchangeable K, layers were classified into three categories (high, medium and low), each depending upon general plant requirements.

Combine Soil Fertility Index (SFI) Assessment

The assessment of combine soil fertility index (SFI) was carried out by adopting an approach of classifying available nitrogen, available phosphorus and exchangeable (available) potassium into low, medium and high category and assigning 1, 2 and 3 code, respectively to these categories (Table 1). Three classes of the three layers (available nitrogen, available phosphorous and available potassium) were combined by adding three layers in raster calculator function of QGIS to assess the combine SFI. Resultant combined map was further reclassified into three categories *viz.,* low fertile, medium fertile and highly fertile soils (Table 2). The schematic representation of the entire methodology has been mentioned in the Fig. 3.

3. RESULTS AND DISCUSSION

Chemical Characteristics and Descriptive Statistics of Soil Properties

The descriptive statistics of macro-nutrient (nitrogen, phosphorous and potassium) status in different blocks of Nainital district are presented in Table 3. The available nitrogen (N) of soils in the Ramnagar block ranged between 285.52 to 850.06 kg ha^{-1} with a mean value of 529.84 kg ha^{-1}, while in Haldwani block it ranged between 169.25 to 890.25 kg ha^{-1} with a mean value of 547.03 kg ha^{-1}. The available nitrogen (N) in Kotabag and Ramgarh blocks ranged between 350.12-618.25 kg ha^{-1} and 365.45-1122.54 kg ha^{-1}, respectively. Similarly in the other blocks *i.e.* Bhimtal, Betalghat, Dhari, and Okhalkanda, the available nitrogen content was observed to be higher with a mean value of 517.20 kg ha^{-1}, 494.12 kg ha^{-1}, 802.52 kg ha^{-1} and 498.78 kg ha^{-1}, respectively. Thus, it can be inferred that available nitrogen in soils of Nainital district is falling mostly in the range of medium to high. The value of coefficient of variation (CV) indicated that the available nitrogen has a highest variation in Betalghat (CV = 33.35%) followed by Ramgarh (CV = 33.17%), Okhalakhand (CV = 31.07%), Bhimtal (CV = 30.99%), Haldwani (CV = 29.58%), Ramnagar (CV = 26.26%), Kotabag (CV = 14.17%) and Dhari (CV = 10.89%).

The highest mean values of available phosphorus were recorded at Bhimtal (33.944 kg ha^{-1}) and lowest at Dhari (21.37 kg ha^{-1}) block. Order of decreasing availability of phosphorus in different blocks are: Bhimtal > Ramgarh > Ramnagar > Haldwani > Okhalkanda > Kotabhag > Betalghat

Table: 2
Classification of soil fertility by fertility index

S.No.	Range	Fertility class
1.	3-5	Low fertile
2.	5-7	Medium fertile
3.	7-9	Highly fertile

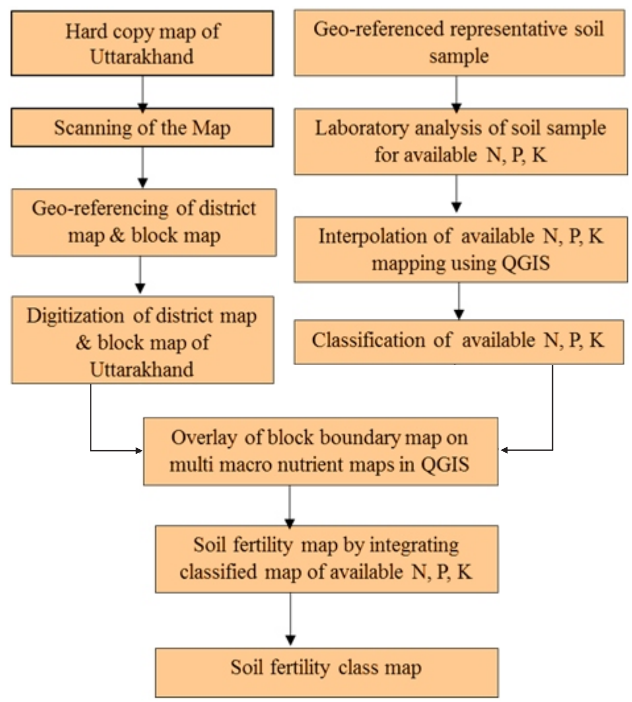

Fig. 3. Flow diagram of approach adopted for evaluating soil fertility index

Table: 1
Criteria used for nutrient assessment of soils in (kg ha^{-1})

S.No.	Nutrient	Suggested by	Range	Code (Category)
1.	Available Nitrogen	Subbiah and Asija (1956)	<280	1 (Low)
			280 - 560	2 (Medium)
			>560	3 (High)
2.	Available Phosphorous	Olsen *et al.* (1954)	<22.9	1 (Low)
			22.9 - 56.45	2 (Medium)
			>56.45	3 (High)
3.	Available Potassium	Muhr *et al.* (1965)	<130.09	1 (Low)
			130.09 - 337.28	2 (Medium)
			>337.28	3 (High)

Table: 3
Descriptive statistics of analytical results of soil samples collected over study area (N = 180)

S.No.	Blocks	Nutrient	Minimum	Maximum	Range	Mean	SD	CV (%)
1	Ramnagar	N	285.52	850.58	565.06	529.84	139.11	26.26
		P_2O_5	13.00	65.40	52.40	27.45	12.43	44.57
		K_2O	26.82	638.48	611.66	211.81	138.08	66.08
2	Haldwani	N	169.25	890.25	721.00	547.03	161.82	29.58
		P_2O_5	6.82	115.05	108.23	26.29	18.05	68.68
		K_2O	30.56	716.95	686.39	297.31	160.70	54.05
3	Kotabag	N	350.12	618.25	268.13	512.84	72.67	14.17
		P_2O_5	14.77	49.87	35.10	24.53	10.62	43.29
		K_2O	80.47	634.78	554.31	267.73	170.30	63.61
4	Ramgarh	N	365.45	1122.54	757.09	642.01	212.96	33.17
		P_2O_5	11.72	85.30	73.58	29.29	21.62	73.83
		K_2O	179.31	696.72	517.41	411.68	178.46	43.35
5	Bhimtal	N	125.65	784.45	658.80	517.20	160.31	30.99
		P_2O_5	13.01	138.73	125.72	33.94	24.23	71.37
		K_2O	104.54	1024.39	919.85	503.43	243.11	48.29
6	Baitalghat	N	230.25	836.25	606.00	494.12	164.79	33.35
		P_2O_5	7.41	46.28	38.87	23.97	11.28	47.03
		K_2O	29.69	743.92	714.23	321.75	167.56	52.08
7	Dhari	N	475.98	770.21	294.23	802.52	87.39	10.89
		P_2O_5	8.36	37.88	29.52	21.37	9.32	43.60
		K_2O	214.37	701.68	487.31	432.99	152.89	35.31
8	Okhalakhand	N	222.45	756.21	533.76	498.78	154.97	31.07
		P_2O_5	8.36	68.43	60.07	25.66	15.21	59.26
		K_2O	69.95	833.64	763.69	359.51	211.35	58.79

Note: All data presented except CV are in kg ha^{-1}

> Dhari. Ramgarh and Kotabag recorded highest (CV = 73.82%) and lowest (CV = 43.28%) values of phosphorus variability, respectively.

The exchangeable potassium content was observed to be higher with mean values varying from 211.81 kg ha^{-1} for Ramnagar to 503.43 kg ha^{-1} for Bhimtal block. It was found highly variable over study area, with CV values ranging from 35.31% to 66.08%. It can be inferred from the preceding results that all the macro-nutrients are highly varying and need to be dealt with the location specific strategies to maintain sustainability.

The spatial distribution of available nitrogen (N) indicates low available nitrogen (<280 kg ha^{-1}) in 0.13% area, medium (280 kg ha^{-1} - 560 kg ha^{-1}) in 76.84% area, and high (>560 kg ha^{-1}) in 23.01% area of the district (Fig. 4). In Dhari and Ramgarh blocks, the status of available nitrogen was medium and high, while in other blocks namely, Ramnagar, Haldwani, Bhimtal, and Betalghat it was low to medium.

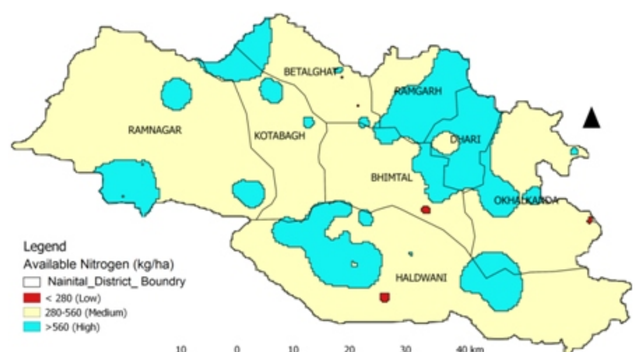

Fig. 4. Spatial distribution of available nitrogen in the study area

Fertility rating limits proposed by Muhr *et al.* (1965) suggested that the high available phosphorus content (>56.45 P_2O_5 kg ha^{-1}) was found only in 0.60% of area, medium (22.9 kg ha^{-1} - 56.45 kg ha^{-1}) was observed in 84.76% of area, and low available phosphorus (<22.9 P_2O_5 kg ha^{-1}) was observed in 14.62% of the area (Fig. 5). Also, most of areas of Nainital district contained low to medium amount of available phosphorous, while higher available phosphorus content was observed in Haldwani and some parts of Bhimtal and Ramgarh blocks. Overall, the available P_2O_5 status was found under low to medium category over the study area. This might be due to the low soil pH, presence of high organic carbon (OC) and organic bound phosphorus, which after decomposition increases complex of Al and Fe, apt for P fixation thus reducing availability of phosphorus (Tisdale *et al.,*1997). Satisfactory quantity of P_2O_5 in certain areas may be attributed to application of phosphatic fertilizers in the rice-wheat cropping system resulting into buildup of P_2O_5. The use efficiency of applied phosphatic fertilizers is very low because of fixation, and thereafter, partial and slow conversion in available form (Setia *et al.,* 2012).

The status of available potassium (K_2O) in the soil indicated that the available potassium content was low (<130.09 kg ha^{-1}) in 0.017% of area, medium (130.09 to 337.28 kg ha^{-1}) in 55.12% of area, and high (>337.28 kg ha^{-1}) in 44.15% of area. Overall, the K_2O status over the entire area was high in comparison to the other macro-nutrients (Singh *et al.,* 2010). The availability of potassium in Ramnagar block was low, while in Haldwani and Kotabag blocks, it was found under low to medium category (Fig. 6). High potassium content was observed in Bhimtal, Ramgarh, Haldwani, Okhalkanda, Kotabhat, Betalghat and Dhari blocks.

Assessment of Combined SFI

The spatial distribution of combined soil fertility status in the study area is shown in Fig. 7. The SFI was computed by assigning ranks 1, 2, 3 to low, medium and high availability of soil nutrients, respectively, as per national standard to each soil nutrient. The values of pixels in the combined map ranged from 3.0 to 9.0. Significant difference in SFI was found in the Nainital district due to the climatic, topographic and land use variation. The lowest SFI, though scattered, was found in different regions of Ramnagar, Kotabag, Haldwani, Okhakanda, Betalghatand and Bhimtal blocks. Superior values of SFI are found mainly in Dhari, Ramgarh, Ramnagar, Bhimtal and Haldwani blocks. Most parts of Nainital district are dominated by moderately fertile soils. Approximately, 80.44% (3323.99 sq. km) of total study area falls under moderately fertile soils, while low and highly fertile soils contribute 6.89% (284.66 sq. km) and 12.67% (523.51 sq. km) area, respectively to the total study area.

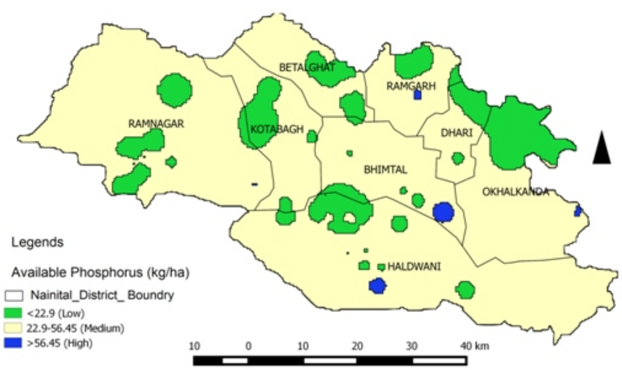

Fig. 5. Spatial distribution of available phosphorus in the study area

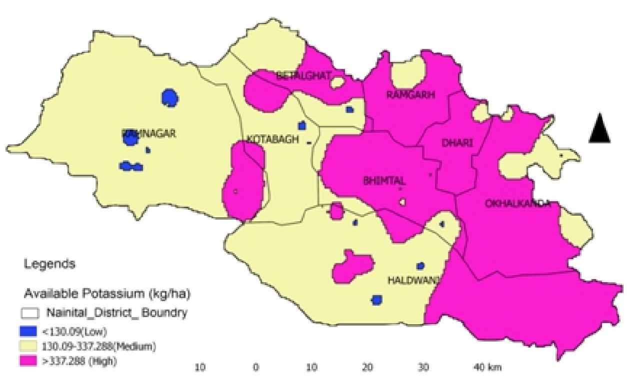

Fig. 6. Spatial distribution of available potassium in the study area

Suitable Cropping Systems for Attaining Food Security

The soils of Nainital are ranging from moderately to highly productive making the region suitable for high valued vegetables and horticultural crops. Crops like potato, peas, tomatoes, cabbage, beans, capsicum, brinjal, radish, okra, garlic, turmeric, ginger, plum peach, litchi, apricot, pear, citrus etc. can be cultivated in organic mode over the regions of high soil fertility levels with manure application to fulfill the requirement of crop's nutrient uptake, while in regions recorded of moderate soil fertility, same vegetable crops may be grown with additional application of organic manure. Field crops such as maize, legumes, oilseed (soybean, mustard) may also be grown with additional dose of organic fertilizers. The soils with low nutrient status are suitable for cultivation of soybean, legumes, mustard, etc. by adopting integrated nutrient management involving organic and inorganic fertilizers.

4. CONCLUSIONS

On the basis of 180 representative surface soil samples collected from Nainital district in lower Himalayan region, it can be inferred that soil macro-nutrients exhibit high spatial variability. Soil fertility is also significantly varying due to natural factors like temperature, rainfall, soil erosion, weathering etc., and manmade factors such as land use, cultural operations, conservation practices and grazing etc. Soil fertility shows increasing trend with decreasing altitudes. It may be due to the fact that soils get eroded from upper hill regions due to high velocity of rainwater, and get

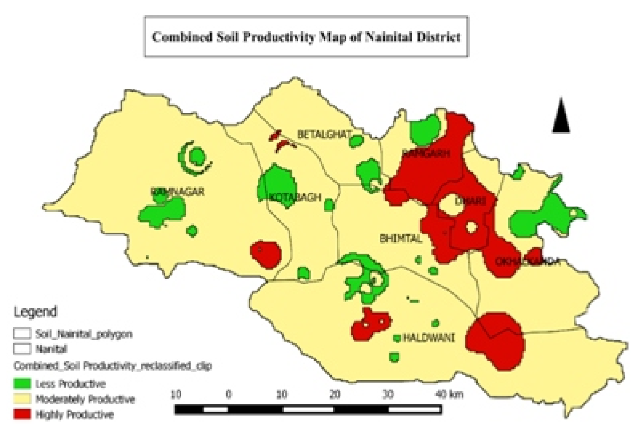

Fig. 7. Overall Soil productivity map of the study area

settled in the regions of low altitudes. Eroding soil also brings with it nutrients important for plant growth. Highly fertile soils were also found in the forest regions, while the less fertile soils were found in the regions of higher altitudes. Application of appropriate dose of fertilizer and manure at suitable time will enhance/maintain crop productivity. It may also be concluded that investigation of spatial variability of soil properties through geo-spatial techniques is appropriate for regional applications. The information will further help in expressing site specific appropriate fertilizer recommendation.

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