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Assessment of some extractable macro and micro-nutrients along with multivariate analysis of their spatial distribution in soils of Haridwar district of Uttarakhand

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ABSTRACT

An investigation was carried out to analyze the general soil properties and extractable macro- (N, P, K, Ca, Mg, S) and micro-nutrients (Zn, Cu, Fe, Mn, B, Mo) in the soils of Haridwar district and the relationships between general soil properties and soil extractable nutrients. Surface (0-15 cm) soil samples (n=300) were taken from the all six developmental blocks of Haridwar district. The ranges for general properties were: sandy loam to sandy clay loam texture, 5.18-8.31 soil pH and 0.074-0.731 dSm^{-1} electrical conductivity (EC) (1:2 soil-water suspension) and 1.49-9.84 g kg^{-1} soil organic carbon content. The amount of alkaline $KMnO_4$ extractable N in these soils ranged from 105.0-290.05 kg ha^{-1} while Olsen's or Bray's extractable P content ranged from 5.88-67.42 kg ha^{-1}. Neutral 1 N ammonium acetate extractable K, Ca and Mg varied from 89.6-548.8 kg ha^{-1}, 1102 - 4359 mg kg^{-1} soil and 30-1002 mg kg^{-1} soil, respectively. Calcium chloride (0.15 percent) extractable S ranged from 5.3-29.4 mg kg^{-1} soil. The contents of DTPA extractable Zn, Cu, Fe, and Mn were 0.13-9.14 mg kg^{-1} soil, 0.01-1.8 mg kg^{-1} soil, 1.26-61.77 mg kg^{-1} soil and 0.66-41.87 mg kg^{-1} soil, respectively. Hot water-soluble B ranged from 0.31-1.19 mg kg^{-1} soil and ammonium oxalate (pH 3.3) extractable Mo varied from 0.25-1.59 mg kg^{-1} soil. The nutrient index (N.I.) computed for different extractable soil nutrients for the entire district of Haridwar showed that the overall the district was low in N, medium in K S, Zn and high in all other nutrients (P, Ca, Mg, Cu, Fe, Mn, B and Mo).

Keywords: Macro-nutrients, micro-nutrients, nutrient index, soil properties, mapping

INTRODUCTION

In general, Haridwar district can broadly be divided into 3 physiographic units viz. the structural hills (*Shiwaliks*), the upper piedmont plain or the *Bhabar* and the *Tarai* or the lower piedmont plain. The part of *Shiwalik* falling in the district has middle and upper *Siwaliks* composed of sand stones, conglomerates, sands, clay, loam etc. The second unit lying just below the foothills of Siwaliks locally called as Bhabar. This unit is characterized by Boulders, cobbles, pebbles sands and clays etc. with relatively dry terrains. Just below the *Bhabar* zone lies the *Tarai* or plains or the lower piedmont plain. This area is characterized by coarse to fine grained sand, gravels, clays etc. According to Watson *et al.*, (2002), agricultural soil fertility quality is most commonly described as a soil's capacity to provide nutrients to crops. Human activities have had a significant impact on this quality (Bi *et al.,* 2009; Huang *et al.,* 2007; Jiang *et al.,* 2006). Research indicated that soil fertility can be improved by appropriate agricultural practices such as tillage (Hussain *et al.,* 1999; Kong *et al.,* 2006), fertilizer application (Guo *et al.,* 2010), incorporation of crop residues into soil (Bi *et al.,* 2009). In the absence of judicious use of macronutrient and micronutrient fertilizers to correct existing nutrient deficiencies and imbalances, crop productivity cannot be sustained (Tisdale *et al.,* 1997).Besides nitrogen (N), phosphorus (P) and potassium (K) deficiency, deficiencies of sulfur (S) (Khurana *et al.,* 2008; Piotrowska-Dlugosz *et al.,* 2017) and micronutrients [zinc (Zn), boron (B), iron (Fe), copper (Cu) and manganese (Mn)] (either single nutrient deficiency or multi-nutrient deficiency) have been reported in different soils of the world, including in India (Alloway, 2008; Kihara *et al.,* 2020).

Shukla *et al.,* (2021) that there was widespread occurrence of multinutrient deficiencies across different states of India. There were occurrences of two-nutrient (namely S + Zn, Zn + B, S + B, Zn + Fe Zn + Mn, S + Fe, Zn + Cu and Fe + B), three-nutrient (namely S +

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Zn + B, S + Zn + B and Zn + Fe + B) and four-nutrient (namely Zn + Fe + Cu + Mn and Zn + Fe + Cu + Mn + B) deficiencies in different extents. Over the years intensive agriculture has drastically affected the macro and a micro nutrient status of soil of these regions. As a result, it is critical to assess the fertility status of soils of this region on a regular basis. Therefore, an investigation was conducted in six blocks of Haridwar district of Uttarakhand to examine some important soil properties and to establish the relationship between soil properties and extractable macronutrients and micronutrients in these soils.

MATERIALS AND METHODS

The study area lies from 29º 35' to 30^0 40' N latitude and 77º 43 ' to 78º 22' E longitude. The minimum and maximum elevation of the study area was 211 and 277meters, respectively with a geographical area of 2360 km^2. The district has been divided into six developmental blocks *viz.*, Roorkee, Bhagwanpur, Laksar, Khanpur, Bahadrabad and Narsan. Surface (0-15 cm) soil samples were collected based on Global Positioning System (GPS) from all six development blocks. The soil samples were air-dried and ground by a wooden roller and then passed through a 2 mm sieve. Various chemical analyses were conducted on the processed soil samples. Soil samples were analyzed for soil texture, pH, electrical conductivity, organic carbon, and extractable N, P, K, Ca, Mg, S, Zn, Fe, Cu, Mn, B, and Mo. Soil electrical conductivity and pH were determined in 1:2 soil-water suspensions (Jackson, 1967, Bower and Wilcox, 1965). To assess the readily oxidizable organic carbon content of the soil samples, the modified Walkley and Black method was employed (Jackson, 1967). The alkaline potassium permanganate method was used to estimate the amount of extractable nitrogen in soil samples (Subbiah and Asija, 1956). Phosphorus was extracted from neutral to alkaline soils using 0.5 M $NaHCO_3$ (pH 8.5) as described by Olsen *et al.*, (1954). In acidic soils (pH 4.5-5.5), P was extracted by using 0.03 N NH_4F + 0.025 N HCl, as described by Bray and Kurtz (1945). Estimation of extractable K, Ca and Mg was carried out using 1N ammonium acetate (pH 7.0) by employing method proposed by Schollenberger and Simon (1945). The extractable contents of Ca and Mg in neutral normal ammonium acetate extract of soils were estimated by titrating the extracts with EDTA solution, as suggested by Cheng and Bray (1951). Sulfur content in soil samples was estimated using 0.15% $CaCl_2$ solution and measured using a colorimeter in accordance with the turbidimetric method (Williams and Steinberg, 1969). Using DTPA (pH 7.3) extractant, the amounts of extractable Zn, Cu, Fe, and Mn in soil were determined (Lindsay and Norvell, 1978). Hot $CaCl_2$ extractable boron content in the soil samples was estimated using the method given by Srivastava and Pachauri (2020). Molybdenum in the soil samples was extracted using the 1M ammonium oxalate (pH 3.3) and estimated by colorimetry (Grigg, 1953). Soil samples were categorized into low, medium, and high categories based on the limits presented by Prajapati *et al.,* (2021).

The percentile proportion of soil samples falling into the low, medium, and high nutrient categories was used to generate the nutrient index (Ramamoorthy and Bajaj, 1969), which is represented by the expression:

$$NI = (L \times 1+ M \times 2+H \times 3)/100$$

Where, NI stands for Nutrient Index Value, L stands for percentage of soils low in extractable nutrient, M stands for percentage of soils medium in extractable nutrient, and H stands for percentage of soils high in extractable nutrient. Accordingly regions with a nutrient index value more than 2.33 were designated as high, those with an NI value between 1.67 and 2.33 as medium, and those with an NI value less than 1.67 as low in their native supply of that nutrient (Ramamoorthy and Bajaj, 1969). Simple correlation analysis and Principal component analysis was carried out using R studio software. Significance of correlation coefficient was tested at 0.1, 1 and 5 % level of significance.

RESULTS AND DISCUSSION

General properties of soils

General properties *viz.,* pH, EC, organic carbon content and texture of the soils of Haridwar district are shown in Table 1. In the district Haridwar, soil texture varied from sandy loam to sandy loam. The soils of the Haridwar district were acidic to slightly alkaline in reaction as the pH of the district varied from 5.18-8.31.

The highest average pH (7.92) was observed in Khanpur block. Acidic soil pH in many blocks could be ascribed to decomposition of the organic matter in the soil and subsequent release of organic acids which could lower the pH in soils of lower buffering capacities (Aziz *et al.*, 2012). Kumar *et al.,* (2015) also reported that the pH ranged from 4.36-8.57 in the soils of sub-tropical regions of Uttar Pradesh. The electrical conductivity of the soil varied from 0.074-0.731 dS m^{-1} with an average of 0.232 dS m^{-1}. Among all the blocks, the highest mean value of electrical conductivity was found in Khanpur block (0.315 dS m^{-1}). Similar results were obtained by Prajapati *et al.,* (2021) in the soils of Tehri Garhwal where EC varied from 0.099-0.931 dSm^{-1}. The organic carbon content varied from 1.49-9.84 g kg^{-1} soil with an average of 6.7 g kg^{-1} soil. Among all the blocks, the highest average organic carbon content was found in Narsan block (7.70 g kg^{-1} soil).

Table 1: General properties of soils of Haridwar district (The mean values are in the parenthesis)

Blocks	pH(1:2)	EC (dSm^{-1})	OC (g kg^{-1})	Texture
Roorkie	5.43-7.96(7.20)	0.109-0.731(0.228)	1.49-9.47(6.06)	Sandy loam – Sandy clay loam
Laxar	6.17-8.29(7.78)	0.074-0.417(0.239	2.79-9.84(7.39)	Sandy loam – Clay loam
Khanpur	6.65-8.31(7.92)	0.125-0.532(0.315)	2.0-9.84(6.80)	Sandy loam – Sandy clay loam
Narsan	5.18-7.54(6.54)	0.093-0.566(0.198)	2.2-9.80(7.70)	Sandy loam – Sandy clay loam
Bhagwaanpur	6.82-8.11(7.52)	0.095-0.393(0.204)	1.50-9.80(6.60)	Sandy loam – Sandy clay loam
Bahadarabad	6.52-8.18(7.67)	0.081-0.385(0.208)	2.0-8.73(6.24)	Sandy loam – Sandy clay loam
Entire district	5.15 – 8.31 (7.44)	0.74 – 0.731 (0.232)	1.49 – 9.84 (6.7)	Sandy loam – Sandy clay loam

Extractable macronutrients

The extractable concentrations of macro-nutrients in soils of different blocks of Haridwar district are depicted in Table 2. The extractable N in the soils of Haridwar district varied from 105.0-297.7 kg ha^{-1} with a mean value of 204.71 kg ha^{-1}. The block with the highest average extractable N was Bahadarabad block (216.23 kg ha^{-1}). Arya *et al.,* (2019) reported similar results of extractable N in the soils of Almora district of Uttarakhand, where the range was 50.4 – 140.0 mg kg^{-1} soil. The extractable P in the soils of Haridwar district varied from 5.88-67.42 kg ha^{-1} with an average of 36.88 kg ha^{-1}. In the entire district, the block with the highest average extractable P was Bhagwaanpur block (40.82 kg ha^{-1}). The extractable K in the soils of Haridwar district varied from 89.6-548.8 kg ha^{-1} with an average of 245.56 kg ha^{-1}. In the entire district, the block with the highest average extractable K was Roorkie block (259.57 kg ha^{-1}).The extractable Ca in the soils of Haridwar district varied from 1102 - 4359 mg kg^{-1} with an average of 2409.64 mg kg^{-1}. In the entire district, the block with the highest average extractable Ca was Khanpur block (2585 mg kg^{-1}). Kavitha and Sujatha (2015) also reported similar trends in various agro-ecosystems of

Table 2: Extractable macro-nutrient concentration in soils of Haridwar district (The mean values are in the parenthesis)

Blocks	Extractable N (kg ha^{-1})	Extractable P (kg ha^{-1})	Extractable K (kg ha^{-1})	Extractable Ca (mg kg^{-1})	Extractable Mg (mg kg^{-1})	Extractable S (mg kg^{-1})
Roorkie	105.0-290.05 (184.83)	5.88-64.29 (35.16)	89.6-470.4 (259.57)	1503-3457 (2341)	152-668 (320)	6.2-28.4 (14.7)
Laxar	115.0-290.05 (207.89)	7.84-65.86 (38.42)	145.6-448.0 (218.93)	1653-3908 (2514)	121-607 (289)	5.3-25.8 (14.0)
Khanpur	110.0-297.6 8(206.86)	7.84-65.07 (32.71)	123.2-537.6 (235.15)	1423-4359 (2585)	91-850 (304.97)	7.1-29.4 (13.4)
Narsan	110.0-290.05(205.34)	10.19-65.86(33.51)	112.0-548.8(248.63)	1102-3657(2147)	30-1002 (300)	6.2-22.2 (11.9)
Bhagwaanpur	110.0-297.68 (207.14)	7.84-67.42 (40.82)	112.0-470.4 (112.0)	1353-3858 (2529)	61-942 (354)	6.2-23.1 (12.1)
Bahadarabad	114.5-297.70 (216.23)	9.41-65.86 (40.67)	112.0-492.9 (238.11)	1353-3707 (2342)	91-699 (330)	8.0-24.9 (13.7)
Entire district	105.0 – 297.7 (204.71)	5.88 – 67.42 (36.88)	89.6 – 548.8 (245.56)	1102 – 4359 (2409.6)	30.0–1002 (316.6)	5.3–29.4 (13.3)

Thrissur district of Kerala, where extractable Ca content was ranging from 20.6-3515 mg kg^{-1}. The extractable Mg in the soils of Haridwar district varied from 30 -1002 mg kg^{-1} with an average of 316.61 mg kg^{-1}. In the entire district, the block with the highest average extractable Mg was Bhagwaanpur block (354 mg kg^{-1}). The extractable S in the soils of Haridwar district varied from 5.3-29.4 mg kg^{-1} with an average of 13.32 mg kg^{-1}. In the entire district, the block with the highest average extractable S was Roorkie block (14.7 mg kg^{-1}). Bungla *et al.,* (2019) also reported similar findings from the soils of Pithoragarh district of Uttarakhand where available S ranged from 4.2 to 84.5 mg kg^{-1}soil.

Extractable micronutrients

The extractable contents of micro-nutrients in soils of different blocks of Haridwar district are depicted in Table 3. On the whole, the overall concentration of extractable Zn varied from 0.13-9.14 mg kg^{-1} with an average of 1.04 mg kg^{-1}. In the entire district, the block with the highest average DTPA extractable Zn was Narsan block (1.51 mg kg^{-1}). Arya *et al.,* (2019) also found similar results in the soils of Almora district of Uttarakhand, where the extractable Zn content varied from 0.10 – 20.70 mg kg^{-1}. The DTPA extractable Cu content in the soils of Haridwar district varied from 0.01-1.8 mg kg^{-1}with an average of 0.55 mg kg^{-1}. In the entire district, the block with the highest average DTPA extractable Cu was Narsan (0.85 mg kg^{-1}). Prajapati *et al.,* (2021) also found similar results in Tehri Garhwal district of Uttarakhand, where DTPA extractable Cu content varied from 0.25– 11.03 mg kg^{-1}. The DTPA extractable Fe content in the soils of Haridwar district varied from 1.26-61.77 mg kg^{-1} with an average of 14.97 mg kg^{-1}. In the entire district, the block with the highest average extractable Fe was Narsan block (29.75 mg kg^{-1}). Singh *et al.* (2006) also reported similar results in soils of Uttaranchal hills under different vegetations,where extractable Fe content varied from 14.0-284.0 mg kg^{-1}. The DTPA extractable Mn content in the soils of Haridwar district varied from 0.66-41.87 mg kg^{-1} with an average of 5.90 mg kg^{-1}. In the entire district, the block with the highest average extractable Mn was Narsan block (8.73 mg kg^{-1}). Chander *et al.* (2014) also found similar results in the soils of sub-humid and wet-temperate zones of H.P., where DTPA extractable Mn varied from 2.1-34.9 mg kg^{-1}. The hot water-soluble B content in the soils of Haridwar district varied from 0.31-1.19 mg kg^{-1} with an average of 0.61 mg kg^{-1}. In the entire district, the block with the highest average content of hot water -soluble B was Laxar block (0.74 mg kg^{-1}). Athokpam *et al.* (2013) also recorded similar results in the soils of Senapati district of Manipur, where the hot water-soluble B was ranging from 0.05-1.00 mg kg^{-1}. The extractable Mo content in the soils of Haridwar district varied from 0.25-1.59 mg kg^{-1} with an average of 0.63 mg kg^{-1}. In the entire district, the block with the highest average extractable Mo was Bhagwaanpur block (0.71 mg kg^{-1}).

Table 3: Extractable micro-nutrient concentration in soils of Haridwar district (The mean values are in the parenthesis)

Blocks	Extractable Zn (mg kg^{-1})	Extractable Cu (mg kg^{-1})	Extractable Fe (mg kg^{-1})	Extractable Mn (mg kg^{-1})	Extractable B (mg kg^{-1})	Extractable Mo (mg kg^{-1})
Roorkie	0.22-2.38 (0.96)	0.09-1.35 (0.38)	1.54-54.15(11.36)	0.66-41.87(6.93)	0.31-0.98(0.54)	0.31-1.12 (0.55)
Laxar	0.26-2.68 (0.93)	0.21-1.67 (0.52)	1.26-53.68(10.8)	2.02-20.62 (4.3)	0.35-1.19(0.74)	0.28-1.59 (0.62)
Khanpur	0.16-3.19 (0.85)	0.25-1.80 (0.65)	2.33-53.84(10.69)	0.69-8.19 (3.41)	0.35-0.91(0.59)	0.25-1.15 (0.57)
Narsan	0.30-6.88 (1.51)	0.27-1.61 (0.85)	4.76-61.77(29.75)	1.86-3.74 (8.73)	0.42-0.95(0.66)	0.34-1.22 (0.70)
Bhagwaanpur	0.23-9.14 (1.22)	0.16-1.01 (0.49)	3.21-39.63(15.3)	2.54-30.5 (6.96)	0.42-0.84(0.61)	0.31-1.34 (0.71)
Bahadarabad	0.13-2.76 (0.79)	0.01-0.79 (0.42)	1.43-51.05(11.96)	1.99-15.18(5.07)	0.35-0.70(0.54)	0.31-1.15 (0.65)
Entire district	0.13 - 9.14 (1.04)	0.01 – 1.80 (0.55)	1.26 – 61.77 (14.97)	0.66 – 41.87 (5.90)	0.31–1.19 (0.61)	0.25 – 1.59 (0.63)

Per cent samples in low, medium and high categories and the computed nutrient index (N.I.) for different soil extractable macronutrients in different blocks of Haridwar district are shown in Table 4. The soil samples deficient in soil extractable N were 98, 92, 92, 90, 86 and 80 per cent in Roorkie, Laxar, Khanpur, Narsan, Bhagwaanpur and Bahadarabad, respectively. In the entire Haridwar district only 89.7 per cent soil samples were found deficient in soil extractable N due to sufficient mineralization of soil organic matter. The majority of soil samples from all the 6 blocks of Haridwar district were found high in soil extractable P. The soil samples deficient in extractable soil K were 4, 2, 2 and 8 percent in Roorkie, Narsan, Bhagwaanpur and Bahadarabad, respectively. In the entire Haridwar district, 2.6 pe r cent soil samples were found deficient in extractable soil K. All Blocks of Haridwar were found high in extractable Calcium and magnesium. The soil samp le s deficient in extractable soil S were 12, 4.0, 14, 38, 22 and 8 percent in Roorkie, Laxar, Khanpur, Narsan, Bhagwaanpur and Bahadarabad, respectively. In the entire Haridwar district, only 16.3 % soil samples were found deficient in extractable soil S.

Table 4: Per cent distribution of soil samples in different categories of available macronutrients in different blocks

	No.	Categories	N	P	K	Ca	Mg	S
Roorkie	50	Low	98	12	4	0	0	12
		Medium	2	24	54	0	0	48
		High	0	64	42	100	100	40
		NI	1.02	2 .52	2.38	3.0	3.0	2.28
Laxar	50	Low	92	4	0	0	0	4
		Medium	8	22	82	0	0	64
		High	0	74	18	100	100	32
		NI	1.08	2.7	2.18	3.0	3.0	2.28
Khanpur	50	Low	92	6	0	0	0	14
		Medium	8	38	70	0	0	68
		High	0	56	30	100	100	18
		NI	1.08	2.5	2.3	3.0	3.0	2.04
Narsan	50	Low	90	0	2	0	0	38
		Medium	10	36	60	0	0	40
		High	0	64	38	100	100	22
		NI	1.1	2.04	2.36	3.0	3.0	1.84
Bhagwanpur	50	Low	86	4	2	0	0	22
		Medium	14	24	52	0	0	64
		High	0	72	46	100	100	14
		NI	1.14	2.68	2.44	3.0	3.0	1.92
Bahadarabad	50	Low	80	4	8	0	0	8
		Medium	20	20	58	0	0	62
		High	0	76	34	100	100	30
		NI	1.2	2.72	2.26	3.0	3.0	2.22
Entire Haridwar District	300	Low	89.70	5.00	2.6	0.00	0.00	16.30
		Medium	10.30	27.33	62.7	0.00	0.4	57.70
		High	0	67.00	34.7	100	99.6	26.00
		NI	1.10	2.61	2.32	3.00	3.00	2.10

Per cent distribution of soil samples in different categories of available macronutrients in different blocks

Per cent distribution of soil samples in different categories of available micronutrients in different blocks

The data related to the percent distribution of extractable micro-nutrients in different categories along with nutrient index (NI) are presented in Table 5. The soil samples deficientin soil extractable Zn were 12, 10, 12, 8, 10 and 30 per cent in Roorkie, Laxar, Khanpur, Narsan, Bhagwaanpur and Bahadarabad, respectively. In the entire Haridwar district, 13.7 percent soil samples were fund to be deficient in soil extractable Zn. The soil sample deficient in soil extractable Cu were 2, 4 and 8 percent in Roorkie, Bhagwanpur and Bahadarabad, respectively. The soil samples deficient in in soil extractable Fe were 34, 10, 6, 2, 6 and 28 in Roorkie, Laxar, Khanpur, Narsan, Bhagwaanpur and Bahadarabad, respectively. In the entire Haridwar district, 14.3 per cent soil samples were found to be deficient in soil extractable Fe. The soil samples deficient in soil extractable Mn were 4, 10, 2 and 2 percent in Roorkie, Khanpur, Narsan and Bahadarabad, respectively. In general, 3 percent soil samples were found deficient in soil extractable Mn. No soil sample in all the blocks of Haridwar was low in hot water-soluble B and Mo.

Nutrient Indices

The nutrient index (N.I.) was worked out for different blocks of Haridwar district for different soil extractable nutrients and shown in Table 4 and 5. Roorkie block was low in N, medium in Fe, Mn, Cu, Zn, S but high in rest of the nutrients. Laxar block was low in N, medium in Zn, Mn S and high in rest of the nutrients. Khanpur block low in N, medium in K, S, Zn, Mn and high in rest nutrients. Narsan block was low in N, medium in P, S and High in rest nutrients. Bhagwanpur block was low in N, medium in Zn, S and high in rest nutrients. Bhadarabad block was low in N, medium in K, S, Zn, Fe and high in rest other nutrients. The nutrient index (N.I.) computed for different extractable soil nutrients for the entire district of Haridwar showed that the overall the district was low in N, medium in K S, Zn and high in all other nutrients (P, Ca, M g Cu, Fe, Mn, B and Mo).

Table 5: Per cent distribution of soil samples in different categories of available micronutrients in different blocks

	No.	Categories	Zn	Cu	Fe	Mn	B	Mo
Roorkie	50	Low	12	2	34	4	0	0
		Medium	64	66	32	72	54	0
		High	24	32	34	24	46	100
		NI	2.12	2.3	2.0	2.22	2.46	3.0
Laxar	50	Low	10	0	10	0	0	0
		Medium	74	50	34	80	8	0
		High	16	50	56	20	92	100
		NI	2.06	2.5	2.46	2.22	2.92	3.0
Khanpur	50	Low	12	0	6	10	0	0
		Medium	82	32	42	68	32	0
		High	6	68	52	22	68	100
		NI	1.94	2.68	2.46	2.12	2.68	3.0
Narsan	50	Low	8	0	2	2	0	0
		Medium	48	20	10	38	18	0
		High	44	80	88	60	82	100
		NI	2.36	2.8	2.86	2.58	2.82	3.0
Bhagwaanpur	50	Low	10	4	6	0	0	0
		Medium	56	36	24	22	24	0
		High	34	60	70	78	76	100
		NI	2.24	2.56	2.64	2.78	2.76	3.0
Bahadarabad	50	Low	30	8	28	2	0	0
		Medium	62	36	22	48	42	0
		High	8	56	50	50	58	100
		NI	1.78	2.48	2.22	2.48	2.58	3.0
Entire Haridwar District	300	Low	13.70	2.30	14.30	3.00	0.00	0.0
		Medium	64.30	40.00	27.30	54.70	29.7	0.0
		High	22.00	57.70	58.40	42.30	70.33	100.0
		NI	2.08	2.55	2.44	2.39	2.70	3.00

Correlation coefficient between soil extractable nutrients and general soil properties

As shown in Figure 1, soil pH showed a significant and positive correlation with Ca (r = 0.329***) and P (r = 0.135*), but showed a significant and negative correlation with K (r = -0.160**), Zn (r = -0.341***), Cu (r =-0.208***), Fe (r = -0.678***), Mn (r =-0.639) and Mo (r = -0.161**). A positive correlation between soil pH and soil extractable Ca and P possibly indicated higher soil retention of these nutrients at neutral soil pH and lower leaching losses of especially, K and B. A significant negative correlation between soil pH and soil extractable Fe and Mn indicated a decrease in solubility of Fe and Mn with increase in soil pH. Soil EC showed a significant and positive correlation with Ca (r = 0.236***), S (r = 0.158**), Cu (r = 0.154**), K (r = 0.158), Cu (r = 0.147) and B (r = 0.139). Relatively higher EC values are indicator of lower leaching losses due to physiographic position of soils, therefore, a positive correlation between soil EC and soil extractable P, K, Zn, B and Cu could be attributed to this reason (Smaling *et al.*, 1993). Soil organic carbon overall showed a significant and positive correlation with N (r = 0.271***), Zn (r =0.189**), Cu (r =0.227***), Fe (r =0.173**), B (r =0.145*) and Zn (r =0.140*) significance and P (r = 0.141). A significant positive correlation between soil organic C content and these elements implied that presence of soil organic matter played significant role in retention of these nutrients.

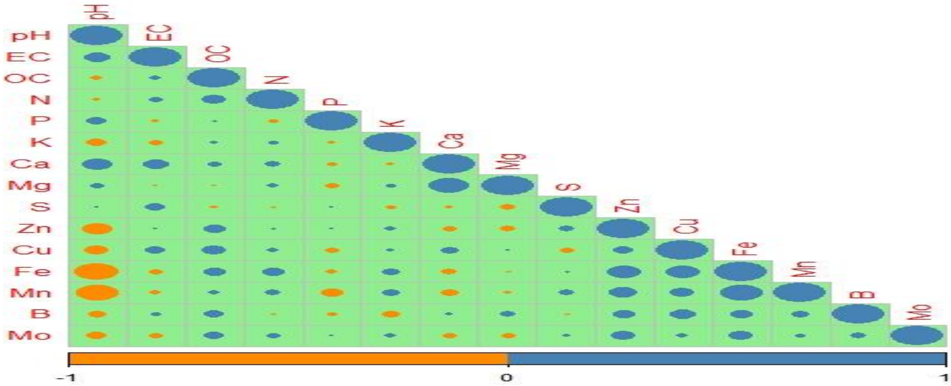

Figure 1: Pearson's correlation correlogram between different soil parameters of Haridwar district

Principal component analysis (PCA)

Since assessment of soil physico-chemical properties, extractable macro and micro nutrient was done across different blocks of Haridwar district it is obligatory to see whether the sites can be grouped based on different soil parameters. So, multivariate analysis i.e., principal component analysis (PCA) was carried out on different soil parameters of blocks of Haridwar district. Results of PCA accomplished in respect of Haridwar district generated two principal components which explained 20.1% and 12.2 % of total variance for PC1 and PC2, respectively. As evident in figure 2 the biplot of axis 1 was strongly correlated with Mo, Mn, Zn, Fe and axis 2 was strongly correlated with EC, Mg and Ca. From the biplot it is clear that most of the points are concentrated near one another and all the ellipses corresponding to each block are heavily overlapping thus no group (closely corelated soil parameters) are clustering towards any one block. This indicates that soils of Haridwar block do not differ from one another on the basis of group of properties. However, difference may be observed if individual soil parameters are studied.

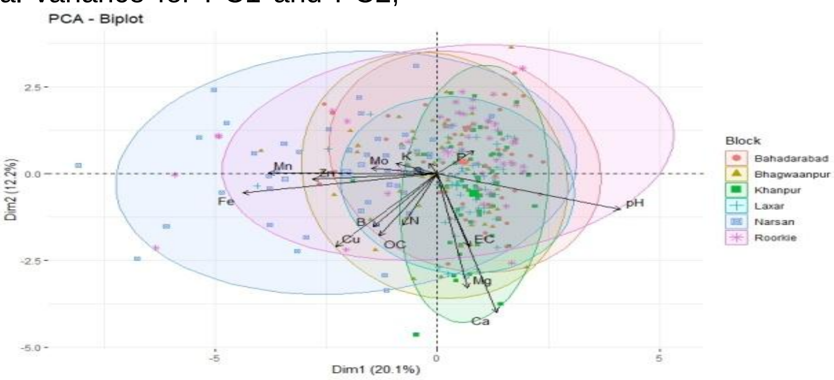

Figure 2: Loading's plot formed by principal components 1 and 2 with different soil parameters of six blocks of Haridwar district

CONCLUSION

From the results of this study, it may be concluded that the soils of Haridwar district had a widely variable pH from acidic to slightly alkaline. The nutrient index (N.I.) computed for different extractable soil nutrients for the entire district of Haridwar showed that overall the district was low in N, medium in K S, Zn and high in all other nutrients (P, Ca, Mg,Cu, Fe, Mn, B and Mo). The deficiencies of micronutrients and sulphur were site specific; therefore, the relevant chemical fertilizers should be recommended based on their site-specific deficiencies. In order to augment crop production, preserve soil health and quality in the district, site specific nutrient recommendations and adequate availability of specific nutrient fertilizers need to be ensured.

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