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Geospatial variability of soil physico-chemical properties of Moridhal watershed in Dhemaji district of Assam, India using Remote sensing and GIS

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ABSTRACT

Remote sensing and GIS have opened new vistas towards understanding spatial variability of properties of the soil and ensuring resource use in a sustainable manner. The current study was conducted to assess the variability of physical and chemical properties of the flood-prone soils of the Moridhal watershed under Dhemaji district of Assam. The watershed was delineated using toposheets (1:50,000) and geocoded FCC (False Colour Composite) of Resourcesat-2, LISS-4. Four physiographic units of the Moridhal watershed were delineated which included upper piedmont plain, lower piedmont plain, alluvial plain and flood plain. A total of 170 geo-tagged soil samples collected from different physiographic units were analyzed for various physico-chemical properties. The assessed physico-chemical properties of the watershed showed wide spatial variability. The results showed an increasing trend in the amount of very fine sand and silt from the upper piedmont plain to the floodplain. Bulk density, particle density and porosity of the studied area varied from 1.10 to 1.67 g/cm^3, 2.16 to 2.74 g/cm^3 and 24.99 to 54.68 %. The pH was extremely acidic to slightly acidic and the soils were found to be moderate to high in organic carbon. The CEC of the soils ranged from 3.88 to 19.40 cmol(p$^+$)/kg and the available nitrogen, phosphorus and potassium varied from low to high. The spatial distribution showed that about 20,408 ha soils of the study area contained more than 40-60 per cent sand, 24,833 ha soils had 20 to 40 per cent silt and 13,915 ha of soils exhibited 20 to 30 per cent clay. Nearly 97.85 % of the watershed area had medium status of available nitrogen as well as available P_2O_5 content, while 79.96 % of soils had low available K_2O content.

Keywords: GIS, IDW, physico-chemical properties, Remote sensing, Watershed

INTRODUCTION

More than 70% of India's population is dependent either directly or indirectly on agriculture, as agriculture is the primary sector and the backbone of the Indian economy (Ramamurthy, 1969). Soil is the base of life, sustaining all living species found on the planet. Plants rely on the nutritional characteristics of the soil to develop and complete their life cycle (Maurya *et al.* 2019). Soil survey and soil mapping is an essential activity, as it plays a large part in the information about soil properties. Soil physical properties are a set of soil properties that affect a number of physical, chemical, and biological processes in soils (Saikhe *et al.* 1998 and Singh *et al.* 1999). Soil survey is responsible for a precise and systematic inventory of various soils, their kind, nature, and range of distribution, in order to produce estimates about their characteristics and potentialities (Brown *et al.* 1978).

Geographical information system (GIS) is a powerful tool for monitoring large amounts of data and may assist spatial statistical investigations, thus there is a tremendous possibility to increase the precision of soil surveys through the use of GIS. Robinson and Metternicht (2006) applied three distinct approaches, including Kriging, IDW, and Radial basis function (RBF) for the prediction of soil salinity, acidity, and organic matter levels. Borgohain *et al.* (2021) applied the Inverse Distance Weighted Interpolation technique to estimate soil erosion maps of Pabho watershed of Assam. Bhunia *et al.* (2018) used Inverse distance weighted interpolation technique for estimating surface maps of various soil properties in Medinipur block of Paschim Medinipur district in West Bengal. Kumar *et al.* (2012) used different statistical and geostatistical approaches to estimate the spatial distribution of soil organic carbon. According to Tabari (2011) and Lin (2004) ordinary Kriging and IDW were

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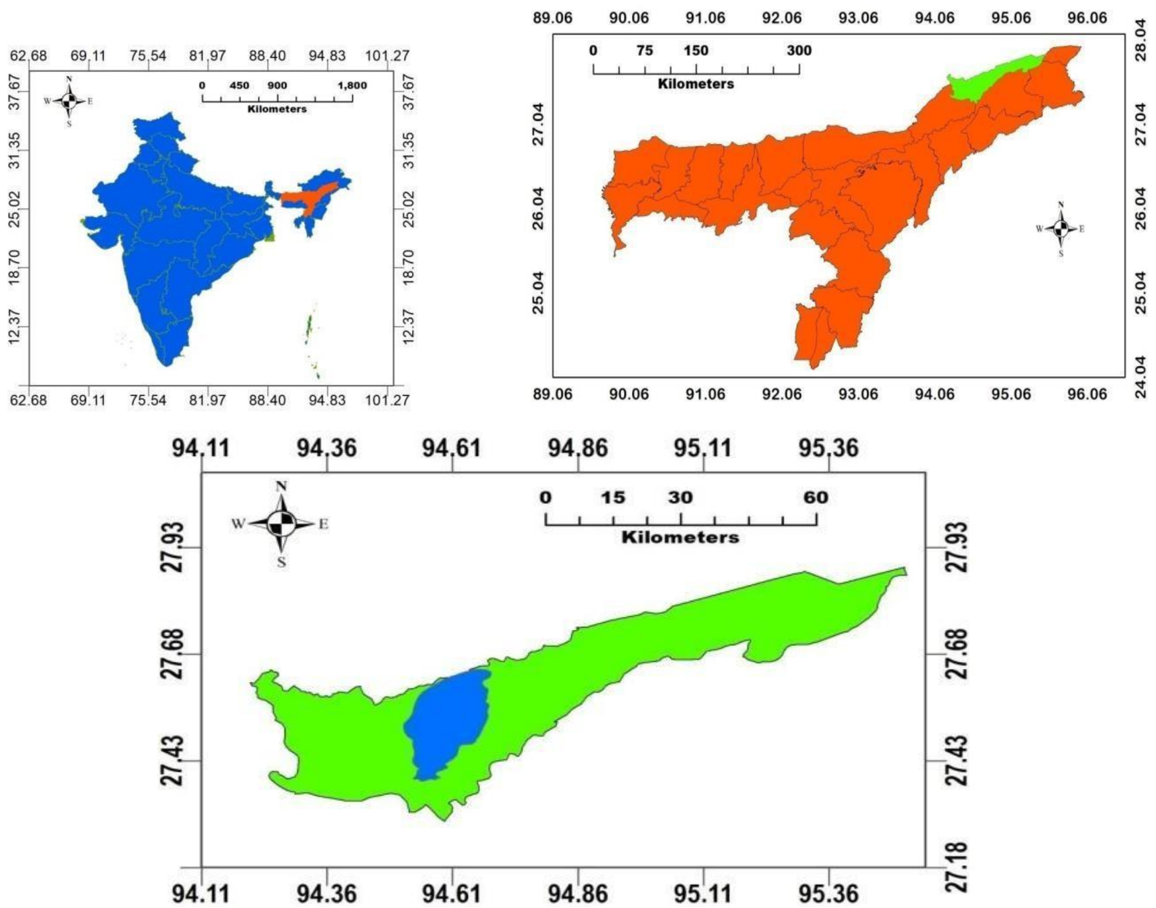
the geostatistical techniques that are most frequently used to predict soil properties. AbdelRahman *et al.* (2020) used the Inverse distance weighted interpolation technique to estimate surface maps of soil properties in the newly reclaimed area of south part of Behera Governorate. This study was carried out in order to assess some soil physico-chemical characteristics in the flood prone areas of Moridhal watershed in Dhemaji district of Assam, India. The primary goal of this investigation is to prepare thematic maps of the assessed soil properties utilizing GIS approach.

MATERIAL AND METHODS

Site Description:

The research area is the Moridhal watershed in Dhemaji district, which is part of Assam's North Bank Plain Zone (Fig.1). The watershed is situated between 94°52' E to 94°69' E longitude and 27°38' N to 27°64' N latitude. Geocoded FCC of Resourcesat-2 LISS-IV data acquired in 2015 was visually interpreted and in conjunction with Survey of India toposheets (1:50,000) the physiographic map was prepared. The watershed covers 30,730 ha area among which 1,844 ha (6.0 %) area was covered by upper piedmont plain; 239 ha (7.78 %) by lower piedmont plain; 9,888 ha (32.17 %) and 16,607 ha (54.04 %) by alluvial plain and flood plain (Fig. 2), respectively. In the studied watershed area, major land use was observed to be under cultivable land (69.13%) followed by waste land (12.08 %), grazing land (7.87 %), build up land (6.32 %), wetland (4.03 %) and forest land (0.58%). The climate in the region is humid subtropical, with an annual rainfall average of 3064 mm. The mean annual temperature was more than 23.6$^{\circ C}$, with a 5°C difference between the mean summer temperature (26.2$^{\circ C}$) and the mean winter temperature (23.0$^{\circ C}$). It showed that the studied region falls under hyperthermic soil temperature regime. The soil moisture regime of the area was found to be Udic.



(c)

Fig.1: Location map of Moridhal watershed

(a) Assam in India (b) Dhemaji district in Assam (c) Moridhal watershed in Dhemaji district

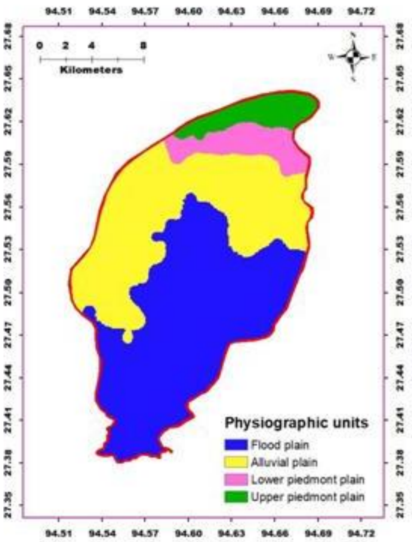


Fig. 2: Physiographic map of Moridhal watershed

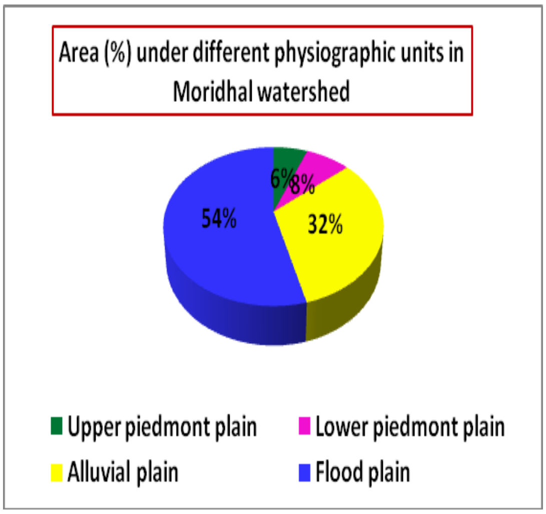


Fig. 3: Physiography wise distribution of area in the Moridhal watershed

Soil sample collection

On a random basis, 170 GPS-based surface and core soil samples were collected up to a depth of 0-25 cm from each physiographic unit. Efforts were made to keep the sampling distance between 1.5 km and 2.0 km. The number of soil samples representing different physiographic units was 19, 50, 26, and 75 from upper piedmont plain, lower piedmont plain, alluvial plain, and flood plain, respectively. The collected surface samples were air dried, grinded and passed through a 2 mm sieve. The samples were analyzed for various soil parameters which include: sand, silt and clay by International pipette method (Piper, 1966), bulk density, particle density (Black *et al.,* 1965), pH and cation exchange capacity (Jackson, 1973), organic carbon (Walkley and Black, 1934), available nitrogen (Subbiah and Asija, 1956), available phosphorus (Bray and Kurtz, 1945) and available potassium (Jackson, 1973).

Statistical and geo-statistical analysis

Snedecor and Cochran's (1967) technique for doing simple statistical analysis was used in the study. These analyses included maximum, minimum, mean, CV (Coefficient of variation) and correlation. Arc.GIS was used to conduct spatial analysis. Spatial variability in soil properties was calculated for 0-25 cm depth. The thematic maps for various soil physico-chemical properties were prepared under GIS environment using their numerical values. For this, the computed values of all the sample sites were digitized from the location map using ArcMap 10.4. For unsampled location the soil parameter values were estimated using Inverse Distance Weighted (IDW) function. The interpolated maps were reclassified to get the map units and legends. The boundary of Moridhol watershed was then marked over the interpolated maps to get the final map.

RESULTS AND DISCUSSION

The soil samples collected from different physiographic units of Moridhal watershed exhibited following properties:

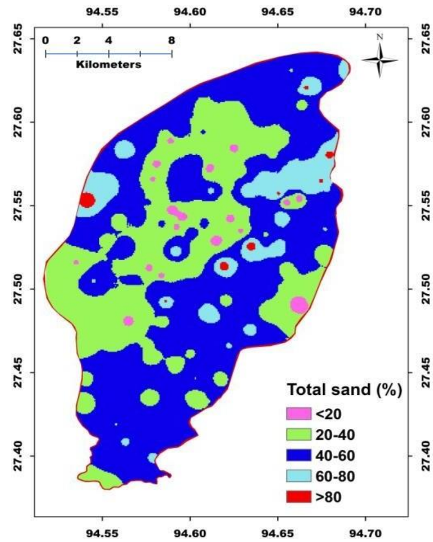
Physical properties

The textural properties of soils were described by parameters like total sand, very fine sand, silt and clay content. The total sand, very fine sand, silt and clay content of the whole watershed ranged from 5.1 to 86.0, 2.2-39.2, 8.0 to 61.0 and 6.0-46.8 % and CV values were found to be 42.06, 38.26, 37.90 and 42.13 % respectively (Table 1). Among the different physiographic units, the alluvial plain soils had highest total sand (Mean 48.2 %) and very fine sand content (Mean 25.21 %). The CV value with respect to total sand (47.14 %) and very fine sand (37.68 %) was highest in the flood plain. The highest value of silt content (Mean 31.6 %) was found in flood plain and lowest in upper piedmont plain (Mean 27.9 %). The clay content was found to be highest (Mean 26.9 %) in flood plain and the lowest value of clay content (Mean 21.3 %) was found in the alluvial plain. Deka *et al.* (2009) and Yadav *et al.* (2022) also reported finer texture soils in lower elevation areas and coarser texture soils in higher elevation areas.

Table 1: Physical properties of Moridhal watershed

Parameters	Minimum	Maximum	Mean	CV (%)
Physiographic unit: Upper piedmont plain				
Sand (%)	24.20	82.20	47.37	27.42
Very fine sand (%)	12.31	39.21	25.21	28.69
Silt (%)	9.60	42.65	27.87	30.69
Clay (%)	8.20	36.45	24.77	36.54
Bulk density (g/cm^3)	1.10	1.65	1.39	8.67
Particle density (g/cm^3)	2.16	2.68	2.44	4.86
Porosity (%)	38.43	52.80	43.08	8.28
Physiographic unit: Lower piedmont plain				
Sand (%)	5.20	82.11	47.25	45.72
Very fine sand (%)	2.24	26.60	14.76	33.99
Silt (%)	9.50	60.00	29.21	46.10
Clay (%)	7.70	46.80	23.53	46.96
Bulk density (g/cm^3)	1.10	1.66	1.39	10.47
Particle density (g/cm^3)	2.16	2.74	2.44	5.80
Porosity (%)	24.99	54.68	39.83	13.99
Physiographic unit: Alluvial plain				
Sand (%)	27.40	76.30	48.16	27.59
Very fine sand (%)	12.31	30.12	19.64	20.32
Silt (%)	14.30	43.45	30.52	23.07
Clay (%)	9.40	38.40	21.32	36.61
Bulk density (g/cm^3)	1.19	1.61	1.42	8.71
Particle density (g/cm^3)	2.33	2.68	2.51	3.82
Porosity (%)	33.12	50.85	43.45	10.30
Physiographic unit: Flood plain				
Sand (%)	5.10	86.01	41.46	47.14
Very fine sand (%)	2.33	35.22	14.93	37.68
Silt (%)	8.01	61.00	31.58	37.82
Clay (%)	5.98	44.20	26.96	40.43
Bulk density (g/cm^3)	1.18	1.67	1.40	9.40
Particle density (g/cm^3)	2.17	2.69	2.43	5.81
Porosity (%)	29.72	50.79	41.34	12.41
Whole watershed				
Sand (%)	5.10	86.01	44.85	42.06
Very fine sand (%)	2.24	39.21	16.75	38.26
Silt (%)	8.01	61.00	30.31	37.90
Clay (%)	5.98	46.80	24.84	42.13
Bulk density (g/cm^3)	1.10	1.67	1.40	9.49
Particle density (g/cm^3)	2.16	2.74	2.45	5.50
Porosity (%)	24.99	54.68	41.66	12.30

The overall distributions of total sand, very fine sand, silt and clay content in the Moridhal watershed area were presented in Fig. 4 to Fig. 7. Altogether, five classes were demarcated on the total sand map (Fig.4). The distribution of sand over the watershed showed that about 20,408 ha of soils (66.41 per cent) contained more than 40-60 per cent sand. Another 7,892 ha (25.68 per cent) contained 20-40 per cent sand. Smaller area of the watershed comprising 243 ha exhibited sand content of less than 20 per cent, while another 93 ha area exhibited sand content of more than 80 per cent. The distribution of very fine sand in the watershed is shown in Fig. 5. Altogether, four classes were demarcated in the very fine sand map. About 8,861 ha (28.84 per cent) area contained very fine sand in between 15 to 20 per cent, while 7,275 ha (23.67 per cent) area had very fine sand ranging between 20 to 25 per cent. Another 14,515 ha (47.23 per cent) of soils contained less than 15 per cent very fine sand. On the other hand 78 ha soils exhibited very fine sand of more than 25 per cent. The silt contents in the studied soils (Table 1) were grouped into five classes on the silt map (Fig. 6).



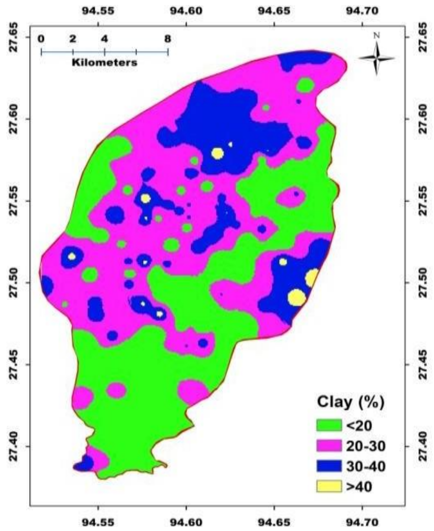
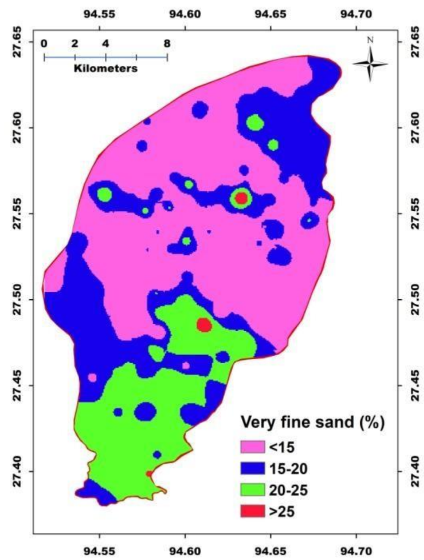


Fig. 4: Total sand map of Moridhal watershed Fig. 5: Very fine sand map of Moridhal watershed



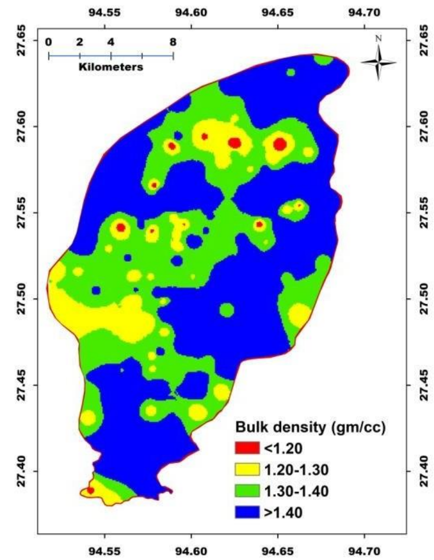
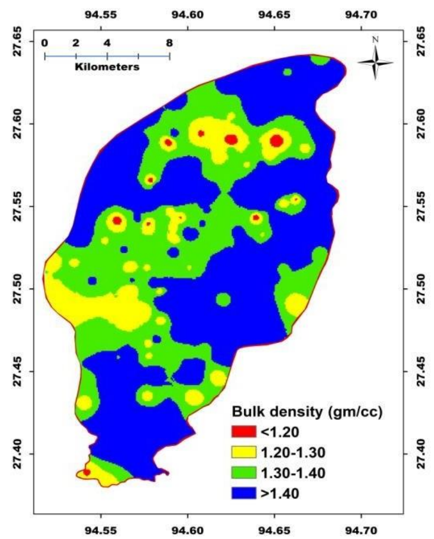


Fig. 6: Silt map of Moridhal watershed Fig. 7: Clay map of Moridhal watershed



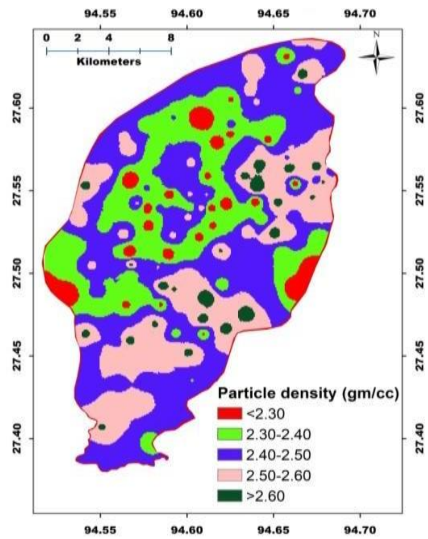


Fig. 8: Bulk density map of Moridhal watershed Fig. 9: Particle density map of Moridhal watershed

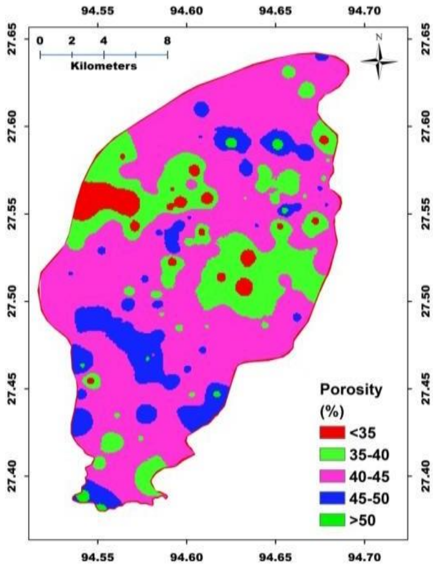


Fig. 10: Porosity map of Moridhal watershed

The map depicts that about 24,833 ha (80.81 per cent) of the watershed area contained 20 to 40 per cent silt and 2,558 ha area (8.32 per cent) had less than 20 per cent silt. Another 17 ha area was found to have silt content above 60 per cent. Wide variation in spatial distribution was observed in respect of clay content in the study area. The clay map (Fig. 7) showed that major portion (13,915 ha constituting 45.28 per cent) of the watershed area exhibited 20 to 30 per cent clay. Another 4,383 ha area (14.26 per cent) had clay content between 30 to 40 per cent. About 12,222 ha (39.77 per cent) exhibited clay content of less than 20 per cent, while 207 ha area had clay content more than 40 per cent. The bulk density, particle density and porosity of the whole watershed (Table 1) ranged from 1.10 to 1.67 g/cm^3 (Mean 1.40 g/cm^3) 2.16 to 2.74 g/cm^3 with a (Mean 2.45 g/cm^3) and 24.99 to 54.68 % (Mean 41.66%). The values of CV for these three parameters were found to be 9.49, 5.50 and 12.30%, respectively. Among the different physiographic units, the highest value of bulk density was found in the alluvial plain (1.61 g/cm^3), which may be due to the high amount of sand and low amount of organic matter. The alluvial piedmont plain regions showed the highest value of particle density (2.51 g/cm^3) which may be due to the low organic matter and soil clay content. The alluvial plain also showed the highest value with respect to porosity (43.45 %), which was due to the increased infiltration and reduced runoff? The lower piedmont plain soils showed the lowest value of porosity (40.67 %), which may be due to less amount of finer particles. It was observed that in the studied watershed area, about 16,195 ha soils (52.70 per cent) had bulk density values of more than 1.40 g/cm^3, while another 11,942 ha soils (38.86 per cent) had bulk density between 1.30 to 1.40 g/cm^3 (Fig. 8). Smaller area of the watershed (113 ha) exhibited bulk density of less than 1.20 g/cm^3. The distribution of particle density in the watershed is depicted through five classes in the particle density map (Fig. 9). It was observed that major portion of the watershed area comprising 17,743 ha (57.74 per cent) had particle density ranging between 2.40 to 2.50 g/cm^3, while 6,065 ha (19.74 per cent) area had particle density in between 2.50 to 2.60 g/cm^3. Another 977 ha (3.18 per cent) soil had particle densities of less than 2.30 g/cm^3 and 421 ha soils had particle density of more than 2.60 g/cm^3. The porosity of the studied soils was grouped into five classes on the porosity map (Fig. 10). The map depicts that about 20,897 ha (68.00 per cent) soils of the watershed area had porosity of 40-45 per cent and 2,885 ha area (9.39 per cent) exhibited soil porosity ranging between 45-50 per cent. While, 772 ha area (2.51 per cent) had porosity of less than 35 per cent, another 106 ha area had soil porosity of above 50 per cent.

Chemical properties

The pH value of the studied soils varied from extremely acidic to slightly acidic (4.2 to 6.3) with a mean value of 5.3 and CV was found to be 7.79 per cent (Table 2). Among the

Table 2: Chemical Properties of Moridhal watershed

Parameters	Minimum	Maximum	Mean	CV (%)
Physiographic unit: Upper piedmont plain				
pH	4.8	5.9	5.4	5.1
OM (%)	0.55	2.10	1.31	31.43
CEC [cmol (p+) kg^{-1}]	5.0	17.5	9.5	32.57
Available Nitrogen (kg/ha)	269.7	482.9	362.39	17.62
Available P_2O_5 (kg/ha)	22.8	58.7	35.30	27.64
Available K_2O (kg/ha)	37.2	148.9	71.32	42.02
Physiographic unit: Lower piedmont plain				
pH	4.6	6.3	5.4	7.5
OM (%)	0.56	2.82	1.72	31.20
CEC [cmol (p+) kg^{-1}]	4.3	19.4	9.6	35.87
Available Nitrogen (kg/ha)	194.4	520.6	357.57	21.89
Available P_2O_5 (kg/ha)	25.9	67.2	45.96	24.25
Available K_2O (kg/ha)	39.4	549.2	139.07	73.61
Physiographic unit: Alluvial plain				
pH	4.2	6.1	5.0	8.6
OM (%)	1.10	2.48	1.54	24.37
CEC [cmol (p+) kg^{-1}]	5.6	17.4	9.8	33.61
Available Nitrogen (kg/ha)	225.3	444.1	309.67	18.81
Available P_2O_5 (kg/ha)	18.5	60.0	37.86	28.52
Available K_2O (kg/ha)	43.3	369.5	108.5	70.93
Physiographic unit: Flood plain				
pH	4.5	6.3	5.3	7.6
OM (%)	0.89	2.96	1.91	22.82
CEC [cmol (p+) kg^{-1}]	3.8	16.5	9.7	29.97
Available Nitrogen (kg/ha)	137.98	570.75	356.85	24.09
Available P_2O_5 (kg/ha)	19.75	66.94	42.28	30.04
Available K_2O (kg/ha)	41.13	508.44	128.83	94.77
Whole watershed				
pH	4.2	6.3	5.3	7.79
OM (%)	0.55	2.96	1.73	28.65
CEC [cmol (p+) kg^{-1}]	3.88	19.40	9.7	32.34
Available Nitrogen (kg/ha)	137.98	570.75	350.46	22.56
Available P_2O_5 (kg/ha)	18.47	67.20	41.91	28.78
Available K_2O (kg/ha)	37.23	549.16	122.31	74.78

different physiographic units, the highest value of pH was observed in the upper piedmont as well as lower piedmont plain with a mean value of 5.4. The acidic nature of the soils of Brahmaputra valley of Assam could be due to leaching of the bases under high rainfall and acidic nature of parent material (Chakravarty *et al.*, 1992; Karmakar and Rao, 1998). Out of the total geographical area of the watershed 24,721 ha soils (80.44 %) were found to be strongly acidic (Fig. 11). About 11 ha (0.04 %) of soils were extremely acidic having pH value between 4.0-4.5. On the other hand, 1,200 ha (3.91 %) soils were very strongly acidic (pH 4.5-5.0) and 4,675 ha (15.21 %) soils were moderately acidic (pH 5.5-6.0). On contrary, about 123 ha (0.40 %) of soils were slightly acidic having pH values between 6.0-6.5. The organic matter content of studied soils varied from medium to high (5.50 to 29.60 g/kg) with a mean value of 17.31 g/kg (Table 2). The highest amount of organic matter (Mean 19.10 g/kg) was found in flood plain areas. The organic matter status of the soils in the flood plain was higher because of intensive cropping associated with the application of organic manures by the farmers during the cultivation of different crops in their fields as well as transportation and leaching of bases and clay particles from upper elevation to lower elevation. Debnath *et al.* (2009) also reported a higher amount of organic matter in rice-growing soils of the Terai zone of West Bengal where the farmers usually apply more organic manure. The organic carbon map (Fig. 12) of the study area showed that about 29,178 ha soils (94.95 %) of the watershed area had high organic matter content. On the other hand, 1,463 ha soils (4.76 %) had medium and 89 ha soils (0.29 %) had low range of organic matter. The CEC of the studied soils varied from 3.88 to 19.40 cmol (p^+)/kg with a mean value of 9.69 cmol (p^+)/kg. Higher values of CEC were observed in the alluvial plain (Mean 9.76 cmol (p^+)/kg) and flood plain (Mean 9.75 cmol (p^+)/kg). This might be due to the presence of more clay content which is evident from the significant positive correlation of CEC with clay ($r = 0.662^{**}$). The findings are in conformity with the findings of Deka *et al.* (2012) and Verma *et al.* (2010) those who also reported that a higher proportion of clay resulted in to increase in CEC of the soil. On the other hand, relatively lower values of CEC were found in upper piedmont plain (Mean 9.52 cmol (p^+)/kg) and lower piedmont plain (Mean 9.64 cmol (p^+)/kg), which was due to the presence of more sand particles. About 17,267 ha soils (56.19 per cent) of the watershed area exhibited CEC values between 7-10 cmol (p^+) kg^{-1} (Fig. 13). Another 11,779 ha (38.33 per cent) area had CEC values ranging between 10-13 cmol (p^+)kg^{-1}. About 807 ha soils had CEC values less than 7 cmol (p^+) kg^{1} while, 876 ha soils had CEC values more than 13 cmol (p^+) kg^{-1}.

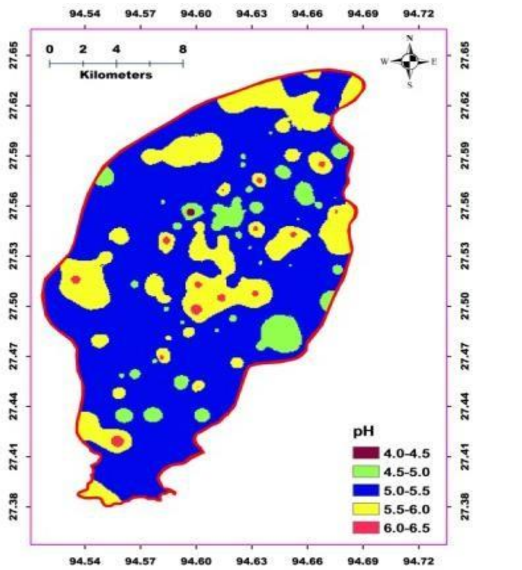


Fig. 11: pH map of Moridhal watershed

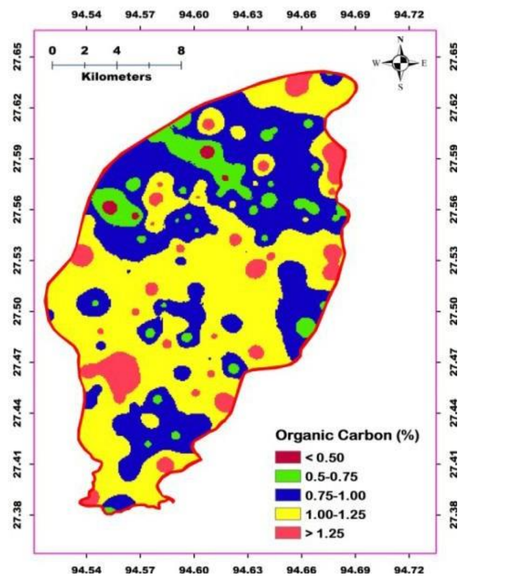


Fig. 12: Organic carbon map of Moridhal watershed

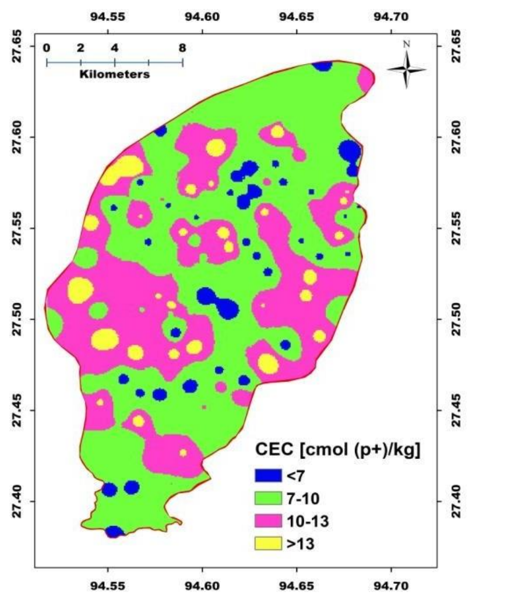


Fig 13: CEC map of Moridhal watershed

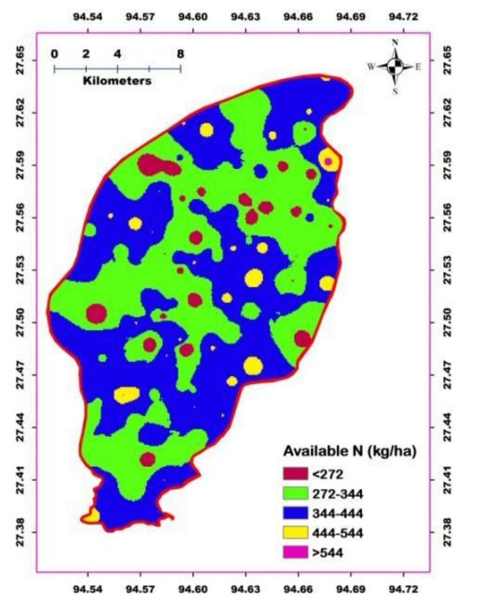


Fig 14: Available nitrogen map of Moridhal watershed

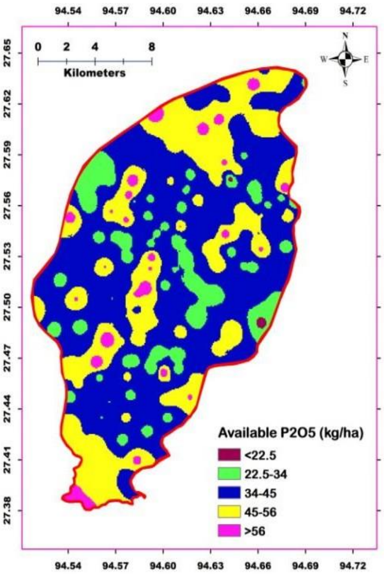


Fig 15: Available P_2O_5 map of Moridhal

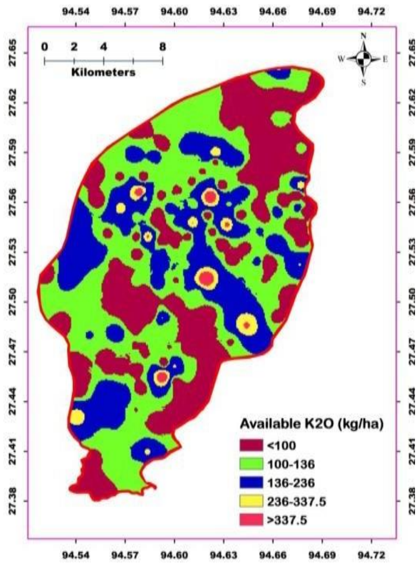


Fig 16: Available K_2O map of Moridhal watershed

Available nitrogen of the studied soils varied from low to high (137.98 to 570.75 kg/ha) with a mean value of 350.46 kg/ha (Table 2). The mean values of available nitrogen in upper piedmont plain soils, lower piedmont plain soils, alluvial plain soils and flood plain soils were found to be 362.39, 357.57, 309.67 and 356.85 kg/ha, respectively. The variation in available nitrogen content in four physiographic units might be attributed to the climatic and altitudinal conditions favorable for the accumulation of higher organic matter content. Similar relationships were also reported by Khadka (2016) and Deka *et al.* (2017). The available nitrogen map content of the Moridhal watershed area (Fig. 14) showed that 97.83 % (30,065 ha) of the watershed area had medium status of available nitrogen. In contrary, 11 ha soils (0.04 %) had high available nitrogen content and 654 ha soils (2.13 %) had low available nitrogen content.

Available P_2O_5 content in studied soils varied from low to high (18.47 to 67.20 kg/ha) with a mean value of 41.91 kg/ha (Table 2). The mean values of available phosphorus in upper piedmont plain soils, lower piedmont plain soils, alluvial plain soils and flood plain soils were found to be 35.30, 45.96, 37.86 and 42.28 kg/ha, respectively. The highest value of available phosphorus was found in lower piedmont plain soils (45.96 kg/ha), which was due to the acidic pH prevailing in the lower piedmont plain soils. The available phosphorus in the studied soils was found to have a significant positive correlation with pH ($r = 0.317^{**}$) which is in conformity with the findings of Dutta *et al.* (2022). The available phosphorus map (Fig. 15) showed that major portion of the studied area (97.85 %) had medium status of available phosphorus content. About 635 ha of soils (2.07 %) of the area were rated as high and 27 ha of soils (0.09 %) were rated as low with respect to available phosphorus content.

The available K_2O of the studied soils varied from low to high (37.23 to 549.16 kg/ha) with a mean value of 122.31 kg/ha (Table 2). Among the physiographic units, the highest available potassium (Mean 139.07 kg/ha) was found in the lower piedmont plain (Table 2). The lowest amount of available potassium (Mean 71.3 kg/ha) was observed in the upper piedmont plain. It might be due to an appreciable amount of negative sites in the organic matter and clay fraction of soil which resulted in higher absorption of available potassium. These results are in accordance with the findings of Deka *et al.* (2012). The available potassium content map of the watershed (Fig. 16) revealed that about 117 ha of soils (0.38 %) of the studied area had high available potassium content. On the other hand, the available potassium content was medium in 6,042 ha soils (19.67 %) and low in 24,571 ha soils (79.96 %).

CONCLUSIONS

The soils of four different physiographic units of the Moridhal watershed showed wide spatial variability with respect to physico-chemical properties. About 20,408 ha soils of the study area contained more than 40-60 per cent sand, 24,833 ha of soils had 20 to 40 per silt and 13,915 ha soils exhibited 20 to 30 per cent clay. An increasing trend of finer particle from piedmont plain to flood plain indicated the washing down of finer particles towards downstream. The pH of the soils in the studied area ranged from severely acidic to slightly acidic. Nearly 97.85 % of the watershed area had medium status of available nitrogen as well as available P_2O_5 content, while 79.96 % of soils had low available K_2O content.

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