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Characterization and Classification of the Soils of Dorika Watershed of Assam using GIS and Remote Sensing Techniques

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A study was conducted for characterization and classification of the soils of Dorika watershed in Assam. The watershed was delineated into four distinct physiographic units *viz*., piedmont plain, hill slopes, alluvial plain and recent flood plain based on Survey of India toposheet (1:50,000 scale) in conjunction with Resourcesat- 2, L4 FX data. Out of total 273 km^2 geographical area, alluvial plain occupied 193 km^2, recent flood plain 44 km^2, piedmont plain 31 km^2 and hill occupied 4.9 km^2 area. In general, the soils varied considerably in morphological, physical and chemical properties. The dominant hue was 10YR, value ranging from 2.5 to 7 and chroma of 1 to 6 in the study area. The soils were found to be strongly acidic in reaction. Sand, silt and clay content ranged from 7.3 to 71.5%, 12.9 to 50.4% and 12.5 to 53.3%, respectively. The organic carbon ranged from 6.1 to 24.0 g kg^{-1} in surface and 4.6 to 15.6 g kg^{-1} in subsurface horizon, cation exchange capacity from 4.7 to 11.8 cmol(p$^+$)kg^{-1} in surface and 4.8 to 12.2 cmol(p$^+$)kg^{-1} in sub-surface horizon and texture varied from sandy loam to clay throughout the horizons. The soils were low to medium in available N and P and medium to high in available K. Soils were classified as Fluvaquentic Dystrudepts (P1 and P9), Typic Dystrudepts (P2 and P3), Oxiaquic Dystrudepts (P4 and P6), Aquic Dystrudepts (P5 and P7) and Typic Endoaquents (P8) at subgroup level.

Key words: Watershed, remote sensing, GIS, soil classification

Sivasagar district of Assam state occupies an area of 2,66,800 hectare constituting 3.40% of the total geographical area. Dorika is one of the major rivers in Sivasagar district. Dorika watershed covers an area of 273 sq km. The river Dorika originates from the foothills areas of Assam bordering Nagaland flows through Sivsagar district, merge into the river Dikhow near Brahmaputra and finally, falls into the river Brahmaputra. Most of the cultivated areas under this watershed remain inundated for most part of the rainy season.

Rice is cultivated during the rainy season and thereafter most of the cultivable lands remain fallow. About 80% or more of the total annual rainfall in Assam is received during pre-monsoon and monsoon seasons causing occasional drought spell in different seasons of the year. As a result, the late *rabi* and early summer crops encounter mild to severe agricultural drought, which reduces their productivity and discourage the farmers opting second crop.

More than 90% people of the watershed are dependent on agriculture but have erratic land use due to poor management of soil as a whole that necessitates the study for scientific land use planning. Therefore, proper land use planning on the basis of land evaluation is of paramount importance for rational utilization of land resources. An understanding of types of soils and their distribution, constraints and potentials are important for proper management to increase productivity and crop yield (Niranjana *et al.* 2011). The modern remote sensing technologies using sensors in the visible, infrared, thermal and microwave regions of the electro-magnetic spectrum are of immense use in evaluation, monitoring and management of land, water and crop resources (Das *et al.* 2009). The potential utility of remote sensing data has been well recognized in mapping and assessing land attributes such as physiography, soils, land use/land cover, relief and soil erosion pattern (Potdar *et al.* 2003; Velmurugan and Carlos 2009; Patil *et al.* 2010). Study of soils within a watershed has increasingly been attempted as it offers diverse soils to form due to the topographic

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variation present in a watershed (Prabhavati *et al.* 2017). This watershed has a niche of different physiographic units and the soils have different inherent characteristics. However, no information is available on characterization and classification of the soils of Dorika watershed. In view of these, the proposed investigation was undertaken for characterization and classification of the soils of Dorika watershed of Sivsagar district in Assam using remote sensing and GIS techniques.

Materials and Methods

Site description

The Dorika watershed of Sivasagar district is a part of the Upper Brahmaputra Valley Zone of Assam. This watershed has an area of 273 km^2 comprising topography of hill slopes to alluvial plain. The drainage network of the watershed comprises Namsai Nai, Taola jan, Dorika River, Chataijan, Nimaijan, Nimonagarh, Timuk Nai and Dillih Nai. The climate of this area is humid subtropical with an average annual rainfall of 2334.1 mm. The mean annual temperature is 24 °C with mean summer and winter temperature of 31 °C and 15 °C. The soil moisture regime of this study area is udic and soil temperature regime is hyperthermic.

The watershed area represents the plains of the Brahmaputra valley. The alluvium deposited at the foothill slopes forming the piedmonts. Geology of the area is alluvium of Pleistocene (Wadia 1966) and recent periods in the plains and tertiary sedimentary rocks in the hill.

Delineation of watershed boundary and physiographic units

Remote sensing data was geo-referenced and digitized to delineate the watershed boundary based on drainage network, water flow path and ground truth verification. Finally watershed boundary area was extracted from the imagery with the help of GIS tools.

Digital data IRS Resourcesat- 2, L4 FX data in conjunction with Survey of India toposheet No. 83J/13, J/9 and 83I/12 (1:50,000 scale) was used to delineate and prepare the physiographic map of Dorika watershed. The geomorphic features were interpreted on the basis of key image elements such as slope, tone, pattern, shadow, association and texture. It was followed by ground truth study to verify the physiographic units.

Collection of soil samples and laboratory analysis

Nine soil profiles representing different physiographic units were selected based on field study and variations in morphological and soil site characteristics. Horizon-wise soil samples were collected from each of the selected pedon following the procedure outlined by Soil Survey Division Staff (2000). Morphological features of each pedon were described with standard procedure (All India Soil and Land Use Survey Organization 1971). Soil samples were analyzed for pH, electrical conductivity (EC), texture (sand, silt, clay), organic carbon (OC), exchangeable cations, macro and micronutrients using standard analytical procedures (Bray and Kurtz 1945; Piper 1950; Subbiah and Asija 1956; McLean 1965; Jackson 1973; Lindsay and Norvell 1978).

Soils were classified on the basis of morphological and physicochemical properties following Keys to Soil Taxonomy (Soil Survey Staff 2014).

Results and Discussion

Physiography of the watershed

Four distinct physiographic units were identified within the watershed boundary *viz*., alluvial plain, recent flood plain, piedmont plain and hill slopes (Fig. 1). It was found that 193 km^2 area was occupied by alluvial plain followed by 44 km^2 by recent flood plain, 31 km^2 by piedmont plain and another 4.97 km^2 area by hill slopes, respectively.

Morphological characteristics

The morphological characteristics of the soils showed that most of the soils were deep to very deep in depth. The soils were light olive yellow to very dark brown in colour with hue of 10YR, value ranging from 2 to 7 and chroma of 1 to 6. Texture varied from sandy loam to silty clay loam in piedmont plain soil (P1), silty clay loam to silty clay in P2 and P4, clay to clay loam in P3, silty clay loam to clay loam in P5, silt loam to clay loam in P7 of alluvial plain soils. Generally, heavy texture in sub-surface horizon might be due to higher rate of weathering in subsurface horizons (Dutta 2009). Silty clay loam to clay loam or silty clay in texture was found in the soils of recent flood plain (P6, P8 and P9). The light texture of recent flood plain soil was influenced by frequent alluvium deposition of river Brahmaputra. Thus, wide textural variation was observed in the soils of Dorika watershed that varied from sandy loam to clay. In

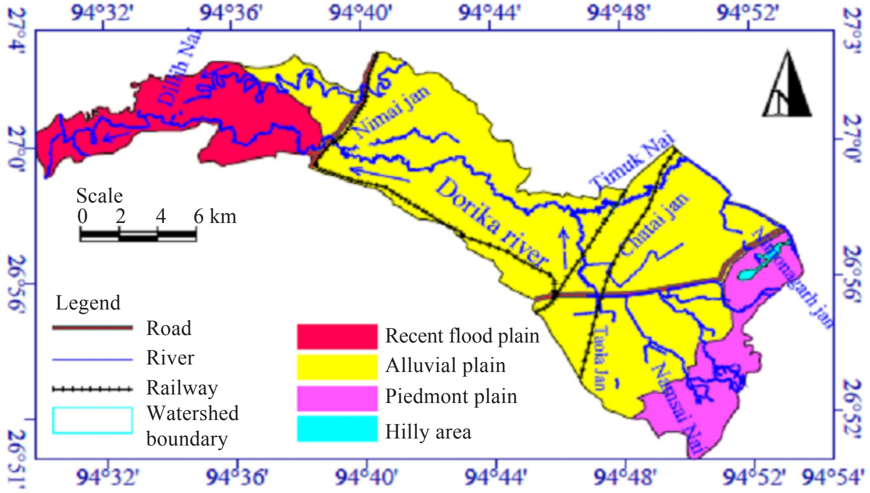

Fig. 1. Physiographic map of Dorika watershed

piedmont plain soil, sub-angular blocky structure with few, moderate, brown colour mottles were found in the surface horizon. Few to many, moderate, distinct mottles and sub-angular blocky structure were observed in the subsurface horizon. Sub-angular blocky structure was found in all the soils of alluvial plain and recent flood plain except pedon P3. Granular structure was observed in the pedon P3 (Table 1). Sub-angular blocky structure with common to medium distinct mottles was found in the surface horizon of P8 and P9 of recent flood plain. Coarse, prominent brown colour mottle was found in the surface horizon of P6. Das (1990) also observed sub-angular blocky structure for some typical rice growing soils of Assam.

Physicochemical properties of soil

The particle size distribution data (Table 2) showed that the sand content in piedmont plain soils (P1) ranged from 32.5 to 71.5% within the profile. It was higher at surface horizon as compared to subsurface horizon. Silt content values varied from 12.9 to 29.8% and it showed irregular distribution pattern with depth. The percent of clay content varied from 15.6 to 39.4 and increased with depth reaching maximum value at Bw4 horizon and thereafter showed a declining trend. Such type of distribution is the characteristics of fairly well developed soil (Barshad 1964). The surface soil (0-30 cm) contained higher amount of sand, lower amount of silt and clay as compared to subsurface horizon of piedmont plain soil. Presence of more sand in piedmont plain soil might be due to transportation of fine particles from upper slopes under high rainfall condition. Sand content in alluvial plain soils (P2, P3, P4, P5 and P7) varied from 7.3 to 43.5%, silt 21.5 to 50.4% and clay 12.5 to 53.3%, respectively. In surface horizon of alluvial plain soil, sand content varied from 26.5 to 40.2%, silt content varied from 24.2 to 48.5%, and clay content varied from 25.2 to 47.5% whereas 7.3 to 43.5% sand, 21.5 to 50.4% silt, and 12.5 to 53.3% clay were found in sub-surface horizon (Table 2). Data further revealed that clay content increased with increasing depth in P2 and P4, whereas in P5 it increased with depth up to Bw3 (67-85 cm) and thereafter it decreased. But in the pedon P3 and P7, irregular distribution of clay was observed. In recent flood plain soils (P6, P8 and P9), the sand content varied from 16.2 to 45.3%, silt content varied from 22.5 to 47.6% and clay content varied from 25.7 to 47.7% within the profile. The sand content in recent flood plain soils (P6, P8 and P9) varied from 25.9 to 41.9%, silt content varied from 27.5 to 46.4% and clay content varied from 25.7 to 42.7% in the surface horizon whereas 16.2 to 45.3% sand, 22.5 to 47.6% silt, and 26.4 to 47.7% clay were found in subsurface horizons (Table 2). The clay content increased with depth in P6 and P8 and irregular trend was observed in P9 soil of recent flood plain. Higher content of sand was observed in surface horizon as compared to sub-surface horizon of P8 soil of recent flood plain. Presence of more sand on surface horizon in recent flood plain soil (P8) might be due to intermittent erosion and or clay translocation. Piedmont plain soil contained more sand as compared to alluvial plain and recent flood plain soil. It might be due to the fact that during high rainfall, sand is deposited from upper slope and fine particles are removed towards lower elevations *i.e.* alluvial and flood plains. The soil of

Table 1. Morphological characteristics of soils

Pedon	Horizon	Depth (cm)	Colour (moist)	Structure*	Texture*	Mottles***
Piedmont plain soil						
P1 (Santak)	Ap	0-15	Gray (10 YR 5/1)	sbk	sl	f1f
	Bw1	15-30	Gray (10 YR 5/1)	sbk	l	f1f
	Bw2	30-45	Gray (10 YR 5/1)	sbk	cl	f2d
	Bw3	45-70	Light brownish gray (10 YR 6/2)	sbk	cl	f2d
	Bw4	70-100	Light brownish gray (10 YR 6/2)	sbk	sicl	f2d
	Bw5	100-140	Light brownish gray (10 YR 6/2)	sbk	sicl	m2d
	Bw6	140-180	Light brownish gray (10 YR 6/2)	sbk	sicl	m2d
	Bw7	180-200	Light brownish gray (10 YR 6/2)	sbk	sicl	m2d
Alluvial plain soil						
P2 (Gormur)	Ap	0-22	Brown (10 YR 5/3)	sbk	sicl	f1f
	Bw1	22-43	Brown (10 YR 4/3)	sbk	sic	f1f
	Bw2	43-65	Dark brown (10 YR 4/3)	sbk	sic	c1f
	Bw3	65-85	Dark yellowish brown (10 YR 4/4)	sbk	sic	c1f
	Bw4	85-110	Dark yellowish brown (10 YR 4/4)	sbk	sic	c1d
	Bw5	110-125	Yellowish brown (10 YR 5/4)	sbk	sic	m2d
	Bw6	125-150	Yellowish brown (10 YR 5/4)	sbk	sic	m2d
P3 (Rajabari)	Ap	0-15	Black (10 YR 2.5/1)	gn	c	f1f
	Bw1	15-48	Black (10 YR 2.5/1)	gn	sicl	f1f
	Bw2	48-70	Black (10 YR 2.5/1)	gn	sicl	f1f
	Bw3	70-85	Black (10 YR 2.5/1)	gn	cl	f1f
	Bw4	85-110	Dark yellowish brown (10 YR 4/4)	gn	cl	f1f
	Bw5	110-165	Dark yellowish brown (10 YR 4/4)	gn	cl	f1f
P4 (Moran gaon)	Ap	0-25	Dark brown (10 YR 3/3)	sbk	sicl	c2d
	Bw1	25-47	Dark brown (10 YR 3/3)	sbk	sicl	c2d
	Bw2	47-85	Dark brown (10 YR 3/3)	sbk	cl	c2d
	Bw3	85-110	Dark brown (10 YR 3/3)	sbk	cl	c2d
	Bw4	110-150	Dark brown (10 YR 3/3)	sbk	sic	c2d
P5 (Luthurichetia gaon)	Ap	0-25	Gray (10 YR 5/1)	sbk	sicl	c2d
	Bw1	25-45	Gray (10 YR 5/1)	sbk	sicl	c2d
	Bw2	45-67	Gray (10 YR 5/1)	sbk	sic	c2d
	Bw3	67-85	Dark grayish brown (10 YR 4/2)	sbk	sic	c2d
	Bg1	85-105	Dark grayish brown (10 YR 4/2)	sbk	cl	m3p
	Bg2	105-150	Dark grayish brown (10 YR 4/2)	sbk	cl	m3p
P7 (Banmukh)	Ap	0-22	Grayish brown (2.5 Y 5/2)	sbk	sil	c2d
	Bw1	22-46	Grayish brown (2.5 Y 5/2)	sbk	sil	c2d
	Bw2	46-85	Olive yellow (2.5 Y 6/8)	sbk	sil	m3p
	Bw3	85-120	Olive yellow (2.5 Y 6/8)	sbk	cl	m3p
	Bw4	120-150	Olive yellow (2.5 Y 6/8)	sbk	cl	m3p
Recent flood plain soil						
P6 (Dorikaghat)	Ap	0-28	Brown (10 YR 5/3)	sbk	sicl	m3p
	Bw1	28-60	Brown (10 YR 5/3)	sbk	sicl	m3p
	Bw2	60-85	Yellow (10 YR 7/6)	sbk	cl	c2p
	Bw3	85-140+	Yellow (10 YR 7/6)	sbk	cl	c2p
P8 (Chutia gaon)	Ap	0-18	Gray (10 YR 5/1)	sbk	sicl	c2d
	AC	18-33	Gray (10 YR 5/1)	sbk	sicl	c2d
	C1	33-55	Dark brown (10 YR 4/3)	sbk	sicl	c2d
	C2	55-90	Dark brown (10 YR 4/3)	sbk	sicl	c2d
	C3	90-140	Dark brown (10 YR 4/3)	sbk	sic	m3p
P9 (Mogona gaon, Panbecha)	Ap	0-18	Dark gray (10 YR 4/1)	sbk	sic	c2d
	Bw1	18-45	Dark greyish brown (10 YR 4/2)	sbk	sic	c2d
	Bw2	45-70	Dark greyish brown (10 YR 4/2)	sbk	sic	c3d
	Bw3	70-90	Dark greyish brown (10 YR 4/2)	sbk	sicl	c3d
	Bw4	90-120	Dark greyish brown (10 YR 4/2)	sbk	cl	c3d
	Bw5	120-150	Dark greyish brown (10 YR 4/2)	sbk	cl	c3d

*sbk = subangular blocky, gn = granular

**sl = sandy loam, l = loam, sicl = silt clay loam, c = clay, cl= clay loam, sic = silty clay, sil = silt loam

*** = f = few, c = common, m = many; 1 = fine, 2 = medium, 3 = coarse; d = distinct, f = faint, p = prominent

Table 2. Physical and chemical characteristics of soils

Horizon depth (cm)	Sand (%)	Silt (%)	Clay (%)	pH (1:2.5 soil solution)	EC (dS m^{-1})	OC (%)	Exchangeable acidity [cmol(p$^+$)kg^{-1}]		Exchangeable cations [cmol(p$^+$)kg^{-1}]				CEC [cmol(p$^+$)kg^{-1}]	BS (%)	Av. N (kg ha^{-1})	Av. P (kg ha^{-1})	Av. K (kg ha^{-1})
							H$^+$	Al^{3+}	Ca^{2+}	Mg^{2+}	Na$^+$	K$^+$					
Piedmont plain soil																	
Piedmont plain (P1)																	
0-15	71.45	12.92	15.63	6.04	0.02	0.69	0.25	0.78	2.02	0.54	0.09	0.11	4.7	58.72	250.8	15.6	332.4
15-30	61.17	22.76	16.07	6.12	0.02	0.66	0.25	0.75	2.04	0.67	0.12	0.15	4.8	62.08	225.4	16.1	290.1
30-45	40.27	22.95	36.78	6.36	0.03	0.78	0.23	0.73	2.21	0.98	0.12	0.14	6.1	56.55	200.5	17.7	231.6
45-70	37.97	23.85	38.98	6.41	0.05	0.71	0.22	0.72	2.24	1.45	0.11	0.12	6.8	57.64	188.1	20.3	246.5
70-100	32.48	28.09	39.43	6.55	0.05	0.63	0.21	0.71	2.29	1.46	0.11	0.11	6.6	60.15	166.4	23.2	245.1
100-140	38.72	26.72	34.56	6.63	0.05	0.50	0.19	0.70	2.04	1.52	0.10	0.09	5.4	69.44	125.4	29.8	201.3
140-180	38.81	28.05	33.14	6.78	0.06	0.42	0.18	0.70	2.08	1.73	0.10	0.08	5.2	76.73	85.6	26.1	104.1
180-200	37.34	29.77	32.89	7.25	0.07	0.31	0.15	0.70	2.18	1.73	0.10	0.08	5.1	80.19	57.3	24.5	64.5
Alluvial plain soil																	
Alluvial plain (P2)																	
0-22	34.17	27.66	38.17	5.31	0.03	0.84	0.29	1.00	1.65	1.08	0.25	0.19	8.6	36.86	76.3	16.8	331.5
22-43	25.64	29.76	44.60	5.39	0.03	0.79	0.27	0.96	1.76	1.13	0.23	0.20	9.1	36.48	313.6	17.2	220.8
43-65	21.88	32.54	45.58	5.43	0.03	0.75	0.26	0.94	2.21	1.17	0.23	0.21	9.6	39.79	246.5	18.1	99.4
65-85	17.66	35.42	46.92	5.56	0.04	0.71	0.24	0.89	2.19	1.19	0.17	0.15	10.2	36.27	188.1	20.4	164.1
85-110	10.91	38.75	50.34	5.63	0.05	0.69	0.22	0.85	2.38	1.22	0.17	0.15	10.6	36.98	125.4	21.7	156.6
110-125	9.44	38.11	52.45	5.64	0.06	0.61	0.20	0.80	2.75	1.42	0.15	0.14	11.2	39.82	87.6	22.1	87.6
125-150	7.27	39.44	53.29	5.75	0.06	0.58	0.20	0.76	3.37	1.64	0.12	0.14	11.6	45.43	62.7	24.7	42.3
Alluvial plain (P3)																	
0-15	28.25	24.23	47.52	5.43	0.03	2.40	0.29	0.89	3.22	1.03	0.15	0.22	11.8	51.44	439.0	25.5	256.5
15-48	32.79	27.85	39.36	5.46	0.04	1.56	0.28	0.86	3.10	1.54	0.13	0.22	11.1	50.81	376.3	22.3	280.4
48-70	33.51	28.11	38.38	5.49	0.04	0.75	0.27	0.85	2.95	1.68	0.13	0.23	10.6	49.62	250.8	19.6	308.6
70-85	36.98	23.90	39.12	5.49	0.04	0.61	0.25	0.79	2.52	1.95	0.12	0.16	10.4	43.07	188.1	18.1	220.1
85-110	36.99	23.42	39.59	5.49	0.04	0.57	0.25	0.75	2.40	2.19	0.12	0.12	9.5	44.00	125.4	14.4	158.3
110-165	39.94	22.19	37.87	5.49	0.04	0.55	0.25	0.75	2.16	2.48	0.11	0.10	7.9	43.03	95.4	10.1	101.3
Alluvial plain (P4)																	
0-25	38.42	26.93	34.65	4.84	0.01	0.61	0.32	1.12	1.77	0.78	0.18	0.19	7.8	37.43	125.4	12.1	199.1
25-47	35.44	27.85	36.71	5.16	0.01	0.53	0.30	1.08	1.82	0.84	0.17	0.18	7.9	38.10	125.4	24.6	176.3
47-85	38.13	23.45	38.42	5.25	0.02	0.50	0.28	1.05	1.88	1.07	0.16	0.17	8.6	38.13	106.5	28.8	155.6
85-110	38.60	22.31	39.09	5.27	0.02	0.47	0.27	0.96	2.16	1.26	0.16	0.15	9.1	40.98	92.7	33.4	120.2
110-150	26.31	28.26	45.43	5.45	0.03	0.46	0.26	0.94	2.85	1.68	0.16	0.15	11.2	43.21	81.1	40.5	101.1
Alluvial plain (P5)																	
0-25	40.24	26.15	33.61	5.15	0.01	0.78	0.32	1.06	2.51	0.82	0.32	0.14	8.8	43.06	250.8	16.7	169.1
25-45	35.67	28.46	35.87	5.25	0.02	0.78	0.30	0.97	2.78	1.07	0.28	0.13	9.1	46.81	250.8	21.4	160.3
45-67	28.26	29.41	42.33	5.29	0.02	0.75	0.28	0.94	2.95	1.26	0.21	0.13	9.6	47.39	250.8	26.8	112.2
67-85	25.77	30.25	43.98	5.36	0.03	0.72	0.26	0.87	3.38	1.46	0.20	0.17	10.4	50.09	188.1	38.3	106.1
85-105	40.71	22.54	36.75	5.42	0.04	0.68	0.24	0.84	2.77	1.02	0.16	0.19	9.7	42.68	125.4	35.6	98.7
105-150	43.45	21.45	35.10	5.45	0.05	0.65	0.24	0.78	2.74	0.81	0.15	0.18	9.1	42.63	101.5	32.9	80.2

Horizon depth (cm)	Sand (%)	Silt (%)	Clay (%)	pH (1:2.5 soil solution)	EC (dS m^{-1})	OC (%)	Exchangeable acidity H^+ [cmol(p^+)kg^{-1}]	Exchangeable acidity Al^{3+} [cmol(p^+)kg^{-1}]	Exchangeable cations Ca^{2+} [cmol(p^+)kg^{-1}]	Exchangeable cations Mg^{2+} [cmol(p^+)kg^{-1}]	Exchangeable cations Na^+ [cmol(p^+)kg^{-1}]	Exchangeable cations K^+ [cmol(p^+)kg^{-1}]	CEC [cmol(p^+)kg^{-1}]	BS (%)	Av. N (kg ha^{-1})	Av. P (kg ha^{-1})	Av. K (kg ha^{-1})
Alluvial plain (P7)																	
0-22	26.35	48.45	25.20	5.25	0.02	0.89	0.40	1.10	1.95	0.94	0.16	0.14	8.5	37.52	313.6	14.2	199.3
22-46	38.63	48.91	12.46	5.34	0.02	0.74	0.37	1.08	1.92	1.12	0.15	0.15	8.2	40.73	250.8	16.6	150.5
46-85	32.10	50.35	17.55	5.47	0.03	0.59	0.35	1.06	1.91	1.48	0.09	0.13	8.0	45.12	188.1	19.7	130.1
85-120	42.09	24.76	33.15	5.58	0.04	0.57	0.32	1.03	2.53	1.28	0.08	0.12	9.4	42.65	125.4	21.8	92.3
120-150	42.82	22.78	34.40	5.61	0.05	0.54	0.29	0.90	3.50	1.15	0.07	0.11	9.8	49.28	101.4	22.4	54.2
Recent flood plain soil																	
Recent flood plain (P6)																	
0-28	27.92	46.42	25.66	5.28	0.02	0.92	0.33	0.82	2.03	0.67	0.23	0.16	8.1	38.14	313.6	24.8	201.6
28-60	26.05	47.57	26.38	5.31	0.03	0.72	0.31	0.79	2.65	0.98	0.21	0.15	11.4	35.00	188.1	28.3	162.8
60-85	45.26	24.58	30.16	5.42	0.04	0.71	0.27	0.77	2.78	1.14	0.22	0.15	11.5	37.30	137.4	34.6	123.1
85-140+	40.11	23.17	36.72	5.59	0.05	0.61	0.25	0.74	3.30	1.26	0.15	0.13	12.2	39.67	105.6	36.3	79.7
Recent flood plain (P8)																	
0-18	41.94	27.51	30.55	5.26	0.02	0.76	0.37	0.86	1.21	2.06	0.23	0.12	8.2	44.14	125.4	18.1	305.4
18-33	35.90	30.45	33.65	5.34	0.03	0.66	0.35	0.83	1.29	2.18	0.22	0.19	8.7	44.59	125.4	24.6	250.6
33-55	30.32	32.79	36.89	5.39	0.03	0.62	0.32	0.80	1.32	2.95	0.20	0.21	9.2	50.86	112.8	30.6	262.1
55-90	26.69	35.10	38.21	5.46	0.04	0.57	0.28	0.74	1.56	3.17	0.19	0.18	9.8	52.04	99.3	32.7	194.5
90- 140	18.81	38.42	42.77	5.62	0.05	0.55	0.26	0.72	1.73	3.26	0.15	0.16	10.1	52.47	85.4	34.7	134.2
Recent flood plain (P9)																	
0-18	25.91	31.44	42.65	5.31	0.03	0.81	0.32	0.86	2.50	0.92	0.29	0.15	10.4	37.11	250.8	22.4	198.9
18-45	21.01	33.51	45.48	5.38	0.03	0.66	0.28	0.83	2.84	0.97	0.25	0.14	10.6	39.62	201.8	21.7	167.4
45-70	16.16	36.17	47.67	5.47	0.04	0.72	0.27	0.79	3.38	1.18	0.26	0.18	11.2	44.64	188.1	20.4	171.5
70-90	19.01	42.45	38.54	5.52	0.05	0.61	0.25	0.77	3.01	1.04	0.24	0.15	9.6	46.25	158.1	20.3	150.2
90-120	39.28	24.56	36.16	5.59	0.06	0.57	0.24	0.74	2.22	1.02	0.20	0.14	7.9	45.31	116.5	19.4	119.6
120-150	41.97	22.48	35.55	5.65	0.06	0.51	0.23	0.73	2.17	1.10	0.13	0.14	7.8	45.33	93.8	18.9	93.2

piedmont plain (P1) was slightly acidic to neutral in reaction and pH values ranged from 6.04 to 7.25 within the profile. The pH of alluvial plain soils (P2, P3, P4, P5 and P7) ranged from 4.84 to 5.43 in surface horizon and 5.16 to 5.75 in sub-surface horizon. In recent flood plain soils (P6, P8 and P9), the pH ranged from 5.28 to 5.31 in the surface and 5.31 to 5.65 in sub-surface horizons. It was observed that the pH value increased with increasing soil depth within the profile in all the three physiographic units. Low pH in the surface horizon might be due to higher biochemical weathering that leads to accumulation of H^+ and Al^{3+} in these horizons or it might be due to leaching of exchangeable bases under high rainfall condition. A regular increase of pH down the profile indicated deposition of bases leached out from the upper reaches (Sen *et al*. 1997). Similar findings for alluvium derived soils of Assam were reported by Deka *et al*. (2009).

The EC ranged from 0.02 to 0.07 dS m^{-1} in piedmont plain soils, 0.01 to 0.06 dS m^{-1} in alluvial plain soils and 0.02 to 0.06 dS m^{-1} in recent flood plain soils. The OC content varied from 3.1 to 7.8 g kg^{-1} within the profile in piedmont plain soil (P1) whereas in alluvial plain soils (P2, P3, P4, P5 and P7) it ranged from 6.1 to 24.0 g kg^{-1} in surface horizon and 4.6 to 15.6 g kg^{-1} in sub-surface horizons. The highest OC content (24 g kg^{-1}) was observed in the pedon P3 which could be due to low removal or depletion of OC from the surface soil. High OC in the surface horizon could be due to slow microbial activity and continuously under cropping and seasonal addition of plant biomass. The decrease in OC with depth is due to degradation of organic matter occurring at a faster rate coupled with low vegetative cover (Rao *et al*. 2008). In recent flood plain soils (P6, P8 and P9), the OC content varied from 7.6 to 9.2 g kg^{-1} in surface horizon and 5.1 to 7.2 g kg^{-1} in subsurface horizon. It was observed that the amount of organic matter content was higher in surface horizons of all the pedons and it decreased regularly with soil depth except the pedons P1 and P9. The distribution pattern of organic matter in the alluvium derived soils of Assam showed a gradual decrease with depth (Chakravarty 1978), while in the flood plain soils of the northern Brahmaputra valley, it was irregular with depth (Karmakar and Rao 1999). Irregular distribution of OC content was observed in P9 pedon which might be due to fluventic nature.

A perusal on data of exchangeable acidity showed that exchangeable Al^{3+} was dominant cation over exchangeable H^+ in all the three physiographic units. In piedmont plain soil, the amount of exchangeable Al^{3+} and exchangeable H^+ were found 0.70 to 0.78 and 0.15 to 0.25 cmol(p^+)kg^{-1}, respectively. In alluvial plain soils the amounts of exchangeable Al^{3+} and H^+ were found to vary from 0.75 to 1.12 and 0.20 to 0.40 cmol(p^+)kg^{-1}. In recent flood plain soil, Al^{3+} and H^+ were found to be varying from 0.73 to 0.86 and 0.23 to 0.37 cmol(p^+) kg^{-1}, respectively. In general, exchangeable Al^{3+} and H^+ decreased with increasing depth. The distribution of exchangeable Ca^{2+}, Mg^{2+}, K^+ and Na^+ in piedmont plain soil, ranged from 2.02 to 2.29, 0.54 to 1.73, 0.08 to 0.15 and 0.09 to 0.12 mg kg^{-1}, respectively. In alluvial plain, exchangeable Ca^{2+}, Mg^{2+}, K^+ and Na^+ ranged from 1.65 to 3.50; 0.78 to 2.48; 0.10 to 0.23 and 0.07 to 0.32 cmol(p^+)kg^{-1}, respectively. In recent flood plain soil, the exchangeable Ca^{2+} , Mg^{2+}, K^+ and Na^+ ranged from 1.21 to 3.38; 0.67 to 3.26; 0.12 to 0.21 and 0.13 to 0.29 cmol(p^+)kg^{-1}, respectively. Irrespective of physiographic unit, Ca^{2+} was the dominant exchangeable cation followed by Mg^{2+}, K^+ and Na^+. The dominance of exchangeable Ca^{2+} in the alluvium derived soils were agreement with the findings of earlier workers on soils of N.E region (Karmakar and Rao 1999). In general, the distribution of exchangeable Na^+ and K^+ decreased with increasing depth. Low amounts of exchangeable K^+ and Na^+ in these soils might be due to preferential losses of monovalent cations over divalent cations in leaching under high rainfall condition (Jenny 1931).

The CEC of piedmont plain soils ranged from 4.7 to 6.8 cmol(p^+)kg^{-1}. The CEC of soils ranged from 7.8 to 11.8 cmol(p^+)kg^{-1} in the pedon of alluvial plain soil and 7.8 to12.2 in recent flood plain soil. Relatively low CEC of these soils might be due to dominance of clay minerals with low CEC and presence of hydrous oxide of iron and aluminium in these soils (Sarkar *et al*. 2002). The base saturation in piedmont plain ranged from 56.6 to 80.2% within the profile. It was observed that with increasing pH the base saturation also increased. The base saturation in the alluvial plain and recent flood plain soils ranged from 36.5 to 51.4 and 35.0 to 52.5%, respectively. Low base saturation in the surface horizon may be due to dominance of exchangeable Al^{3+} on exchange complex.

Fertility status

Data in table 1 indicated that the amount of available nitrogen (N) in piedmont plain (P1) soil varied from 57.3 to 250.8 kg ha^{-1} which showed a decreasing trend within the profile (Table 2). The available phosphorus (P) content ranged from 15.6 to 29.8 kg ha^{-1} and available potassium (K) was 64.5 to 332.5 kg ha^{-1}, respectively. The distribution of available N and K decreased with increasing depth. The distribution pattern of P was not regular within the profile. Lower amount of N content in piedmont plain soil might be due to low OC content (Rao *et al*. 2008). However, more amount of K content could be ascribed to frequent deposition of colloidal material containing K. In alluvial plain soils (P2, P3, P4, P5 and P7), the status of available N, P and K content in surface horizons varied from low to medium (76.3 to 439.0 kg ha^{-1}), medium to marginally high (12.1 to 25.5 kg ha^{-1}) and medium to high (169.1 to 331.5 kg ha^{-1}), respectively. The available N, P and K of subsurface horizons were rated low to medium (62.7 to 376.3 kg ha^{-1}), low to high (10.1 to 40.5 kg ha^{-1}) and low to high (42.3 to 308.6 kg ha^{-1}), respectively. The lower available N and P content in alluvial soil could be result of continuous cropping which might have depleted the available nutrients. Moreover, low amount of available P might be due to fixation of P by free oxides and exchangeable Al^{3+}. Similar findings were also reported by Sahoo *et al*. (2010) for Langol Hill soils of Manipur region. The amount of available K in the alluvial soils was higher in the surface horizon as compared to the sub surface horizon. This may be due to the fact that surface soils were subjected to intense weathering in upper horizons which might have resulted increase in K content (Chaudhury 2007). In addition, frequent deposition of colloidal material from adjoining upper slopes of catchment areas might also have contributed in increasing available K content in the surface horizon.

In recent flood plain soils (P6, P8 and P9), the amount of available NPK varied from 125.4 to 313.6, 18.1 to 24.8 and 198.9 to 305.4 kg ha^{-1}, respectively in surface horizon which showed a decreasing trend within the profile. But in sub-surface horizon available N in recent flood plain soil varied from 85.4 to 201.8 kg ha^{-1}, P varied from 18.9 to 36.3 kg ha^{-1} and K varied from 79.7 to 262.1 kg ha^{-1}, respectively. Higher amount of available N and K were observed in surface horizon as compared to subsurface horizon. The distribution pattern of available P within a profile was not regular.

Classification of soils

The pedons (P1 to P7 and P9) of the watershed were classified as Inceptisols because of presence of cambic horizon (Table 3). The temperature regime was hyperthermic and soil moisture regime was udic. So these soils were classified as Udepts at suborder level and Dystrudepts at great group level as it was characterized by absence of sulphuric horizon, fragipan, duripan and free carbonates and the soils had a base saturation less than 60% in one or more horizons at a depth between 25 and 75 cm. An irregular decrease in organic-carbon content was found in P1 (Santak) and P9 (Mogona gaon, Panbecha) pedons between a depth of 25 cm and either a depth of 125 cm below the mineral soil surface. So, this pedon was qualified as Fluvaquentic Dystrudepts at subgroup level and fine loamy, mixed hyperthermic at family level.

Pedon P2 (Gormur) and P3 (Rajabari) represented central concept of subgroup. So these soils were placed at Typic Dystrudepts at sub group level. P5 (Luthurichetia gaon), and Banmukh (P7) was classified as Aquic Dystrudepts as it has one or more horizons within 60 cm of the mineral soil surface with low chroma (1-2) accompanied by mottles and also aquic conditions for some time in normal years

Table 3. Classification of soils

Pedon	Classification				
	Order	Suborder	Great group	Subgroup	Family
P1	Inceptisols	Udepts	Dystrudepts	Fluvaquentic	Fine loamy, mixed Dystrudepts hyperthermic
P2	Inceptisols	Udepts	Dystrudepts	Typic Dystrudepts	Fine, mixed hyperthermic
P3	Inceptisols	Udepts	Dystrudepts	Typic Dystrudepts	Fine, mixed hyperthermic
P4	Inceptisols	Udepts	Dystrudepts	Oxiaquic Dystrudepts	Fine, mixed hyperthermic
P5	Inceptisols	Aquepts	Endoaquepts	Typic Endoaquepts	Fine, mixed hyperthermic
P6	Inceptisols	Udepts	Dystrudepts	Oxiaquic Dystrudepts	Fine loamy, mixed hyperthermic
P7	Inceptisols	Udepts	Dystrudepts	Aquic Dystrudepts	Fine loamy, mixed hyperthermic
P8	Entisols	Aquents	Endoaquents	TypicEndoaquents	Fine loamy, mixed hyperthermic
P9	Inceptisols	Udepts	Dystrudepts	Fluvaquentic	Fine, mixed Dystrudepts hyperthermic

(or artificial drainage). Moran gaon (P4), Dorikaghat (P6) were classified as Oxyaquic Dystrudepts; it has subsurface horizons which were saturated with water in one or more layers within 100 cm of the mineral soil surface for 20 or more consecutive days; or 30 or more cumulative days in a year. Hence, P4 and P6 were classified as Oxyaquic Dystrudepts at subgroup level. The soils of P8 (Chutia gaon) belonged to Entisols as these soils did not have any diagnostic horizon other than ochric. These soils were saturated with water during some parts of the year and had low chroma (1-2) accompanied by mottles. These soils were classified as Aquents at suborder and Endoaquents at great group level. Further, the soil represented the central concept of subgroup. So, these soils were placed in Typic Endoaquents at subgroup level.

Conclusions

Based on the present study, it can be concluded that the soils of Dorika watershed were strongly acidic with medium to high organic carbon content, low in CEC, medium to high base saturation and fine to coarse textured. Soils were classified as Fluvaquentic Dystrudepts (P1 and P9), Typic Dystrudepts (P2 and P3), Oxiaquic Dystrudepts (P4 and P6), Aquic Dystrudepts (P5 and P7) and Typic Endoaquents (P8). The fertility status of the study area is low to medium in available N and P and medium to high in available K. The acidity and fertility limitation could be improved by using appropriate amendments like lime, organic manure, green manure, *etc*. The area experiences sufficient rainfall with length of growing period of 290 days and optimum temperatures suitable for a number of crops. Most soils of recent flood plain and piedmont plain could be utilized for at least two crops during *rabi* and post *rabi* seasons.

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