



Characterization and Classification of the Soils of Buraka Micro-Watershed in Haryana for Integrated Development

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A detailed soil survey was undertaken to characterize and classify the soils of Buraka micro-watershed in Mewat region using remote sensing and GIS techniques. Based on interpretation of remote sensing image data and ground truth verification, seven physiographies viz., Aravalli hill tops, side slopes, inter-hill basin, upper piedmonts, middle piedmonts, lower piedmonts and stream terraces were identified. On the basis of field study and laboratory characterization, ten soils (Buraka A to Buraka J) were identified in the watershed area. They were classified as per soil taxonomy and categorized under different land capability and irrigability subclasses as per their limitations and potentials. The study showed that Buraka A, B, C, E, H and J soils belonged to Entisols covering 305.80 ha (56.4%) area, whereas Buraka D, F, G and I soils belonged to Inceptisols covering 206.70 ha (38.10%) area. Buraka C, E, H and J soils were loamy sand to sand in texture, very low in organic carbon (OC) content (0.4-1.8 g kg⁻¹) and very low in CEC [0.77-3.75 cmol(p⁺)kg⁻¹] and rated under land capability subclasses IIIse, IVes and irrigability subclasses 3st and 4st, respectively. Buraka D, F, G and I soils were sandy loam in texture, low to medium in OC content (1.9-5.7 g kg⁻¹) and low in CEC [3.05-6.18 cmol(p⁺)kg⁻¹] and rated as land capability subclasses IIIs, IIIes and irrigability subclasses 2s and 2st, respectively. Buraka A and B soils occurring on Aravalli hills were shallow in depth, loamy skeletal in texture with moderate to strong stoniness and rockiness and prone to severe erosion. They were rated under land capability subclasses VIes, VIIes and irrigability subclass 6st, respectively. The watershed area suffers from various constraints affecting crop productivity. Hence, proper soil and water conservation measures along with good agronomic practices may be adopted for enhancing productivity. The hilly areas may be brought under grasslands and forestry to protect from erosion and improve soil quality.

Key words: Buraka micro-watershed, Mewat region, physiography, Entisols, Inceptisols, land capability subclasses, land irrigability subclasses

Soil is the most precious natural resource as it produces food, fiber, fuel and fodder which are basic to our very existence. But indiscriminate use and over exploitation of soils leads to serious impact on the ecology (Gorai *et al.* 2013). For sustainable utilization of this indispensable resource, it is imperative to know the nature, characteristics, distribution along with their quality of soils, productive potential and suitability for optimum land use (Mahapatra *et al.* 2005). To achieve this goal, detailed information about the finite soil resource is prerequisite. Watershed management plays a vital role in the agriculture practices as it facilitates the controlled use of water for irrigation as

per crops requirement and it also provides water supply for a wide range of other uses. The watershed management is an important concept for sustainable development of an area. It is a practice of managing human activities on an area by understanding the inter-relationship among land use, soil and water as well as the linkage between varying landforms. Therefore, characterization of watershed is essential for its integrated development (Nagdev *et al.* 2017a,b). The use of remote sensing data and GIS techniques have found to be useful in delineation and characterization of any watershed. Buraka micro-watershed which falls in minor community dominated Mewat region of Haryana state, is facing hardship in agricultural activities and reduction in crop

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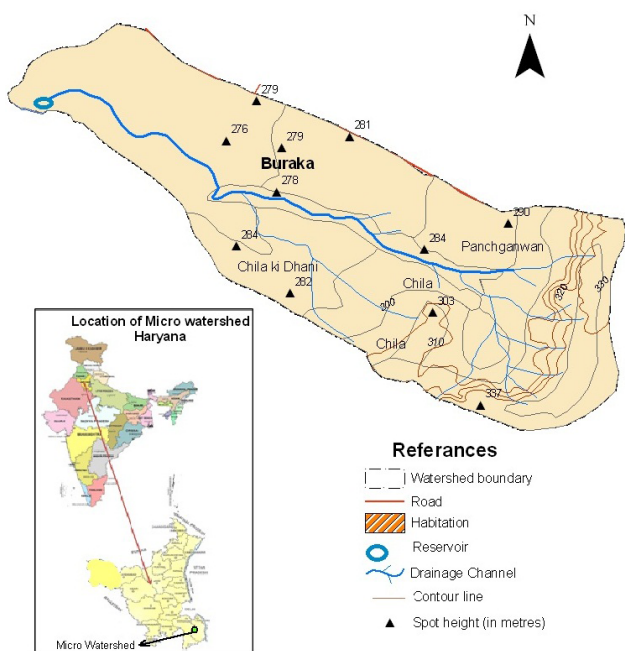


Fig. 1. Study area: Buraka micro-watershed, Mewat region, Haryana

productivity. Proper management of natural resources especially soil and water is thus very essential for development of this watershed area. Therefore, the present study was undertaken to characterize and classify the soils of Buraka micro-watershed for integrated development of the area.

Materials and Methods

Study area

The Buraka micro-watershed is situated at the foothills of Aravallis and belongs to block and tehsil Tauru, district Nuh (Mewat) in Haryana state (Fig. 1). It lies between $28^{\circ}10'$ to $28^{\circ}12'$ N latitudes and $76^{\circ}57'$ to $77^{\circ}00'$ E longitudes, belonging to agro-ecological sub-region No. 4.1. The area of the watershed is 542.4 ha comprising Buraka, Panchgaon and parts of Chila and Gwarka villages. It is located on the left side of the Tauru-Nuh road at a distance of about 500 m from Tauru town. The elevation ranges from 266–335 m above mean sea level. The geology is sandstone and quartzite. A spur of the Aravalli hills from Rajasthan enters Mewat region of Haryana between Nuh and Tauru towns on the south east border of watershed and expands into an elongated ridge of about 4–5 km broad running toward north east. The greater part of the Mewat consists of a mantle of alluvium which is an unconsolidated fluvial deposit with nodular calcium carbonate concretions at places.

The watershed forms only a small part of the area. The rockout crops on the Aravalli ridges consist of sandstone with inclusions of quartzite. The soils of the watershed are largely developed from local alluvium and colluvium and hilly soils in eastern part of the watershed from weathered sandstone, quartzite. Climate of the watershed is semi-arid with extreme summer and winter seasons. June is the hottest while January is the coldest month. The mean summer temperature is 33.0°C and mean winter temperature is 15.8°C . The mean annual temperature is 25.6°C . The mean annual rainfall is 461 mm. Nearly 84% of the rainfall is received during June to September months. The soil moisture control section (SMCS) remains partly or fully moist for 90–150 cumulative days in a year qualifying Ustic soil moisture regime. The mean annual summer temperature (MAST) ranges between 26 and 27°C and the differences between mean summer soil temperature (MSST) and mean winter soil temperature (MWST) is more than 6°C , thus qualifying the soil temperature regime as hyperthermic. Major crops grown in the area are bajra, wheat, jowar, mustard, pigeon pea and barley.

Image interpretation and ground truth verification

Geocoded IRS P6 LISS IV MSS data on 1:12,500 scale was interpreted to delineate landforms (physiography), slope and land use/land cover classes of the watershed. Geomorphic features were interpreted on the basis of key image elements such as shape, tone or colour, pattern, shadow, association and texture (Sahu *et al.* 2016). Ground truth verification was made by traversing the watershed area for confirmation of different landform units and slopes at random points in the field and base map was prepared for soil survey.

Soil survey, mapping and classification

Detailed soil survey was carried out on 1:12,500 scale and soils of different landform units and parent materials were studied in the field in respect of their morphological properties by digging minipits and master profiles (Sehgal *et al.* 1987; Bhattacharya *et al.* 2009). Profile and random (auger bores) observations were taken in each interpreted physiographic units as per the heterogeneity of the terrain and the soil boundaries were delineated while traversing. The soil profiles representing different soils were studied and soil samples (horizon-wise) were collected, processed ($<2\text{ mm}$) and analyzed for important physical and chemical properties using standard procedures (Black 1965; Jackson 1966;

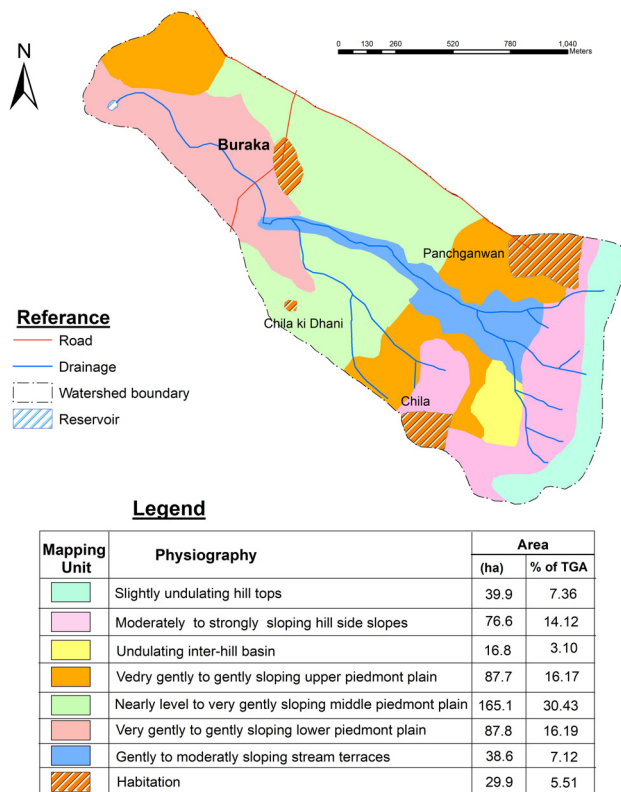


Fig. 2. Physiography of Buraka micro-watershed

Sharma *et al.* 1987). Soils were classified as per 'Keys to Soil Taxonomy' (Soil Survey Staff 2014) and the soil-physiography relationship was established. Based on field investigations, laboratory characterization and

correlation, soil map on 1:12,500 scale was prepared as phases of soil series. The land capability classes were determined on the basis of site characteristics (climate, landform, slope and erosion) and limitations of soils for plant growth based on soil depth, texture, stoniness, rockiness and permeability (Sys 1985; Sehgal 1996).

Results and Discussion

Physiography

On the basis of remote sensing data interpretation and field verification, seven physiographic units were identified in the watershed area *viz.*, (i) undulating hill tops, (ii) moderately to steeply sloping hill side slopes, (iii) undulating inter-hill basin, (iv) very gently to gently sloping upper piedmont plain, (v) nearly level to very gently sloping middle piedmont plain, (vi) very gently to gently sloping lower piedmont plain, and (vii) gently to moderately sloping stream terraces (Fig. 2). It was observed that middle piedmont plain covers major area occupying 165.1 ha (30.4%) followed by lower piedmont plain (87.8 ha, 16.2%), upper piedmont plain (87.7 ha, 16.2%), hill side slopes (76.6 ha, 14.2%), hill tops (39.9 ha, 7.4%), stream terraces (38.6 ha, 7.1%) and inter hill basin (16.8 ha, 3.10%). Soils were studied by taking minipits and master profiles in each physiography units. Soil-physiography relationship was established and depicted in fig. 3.

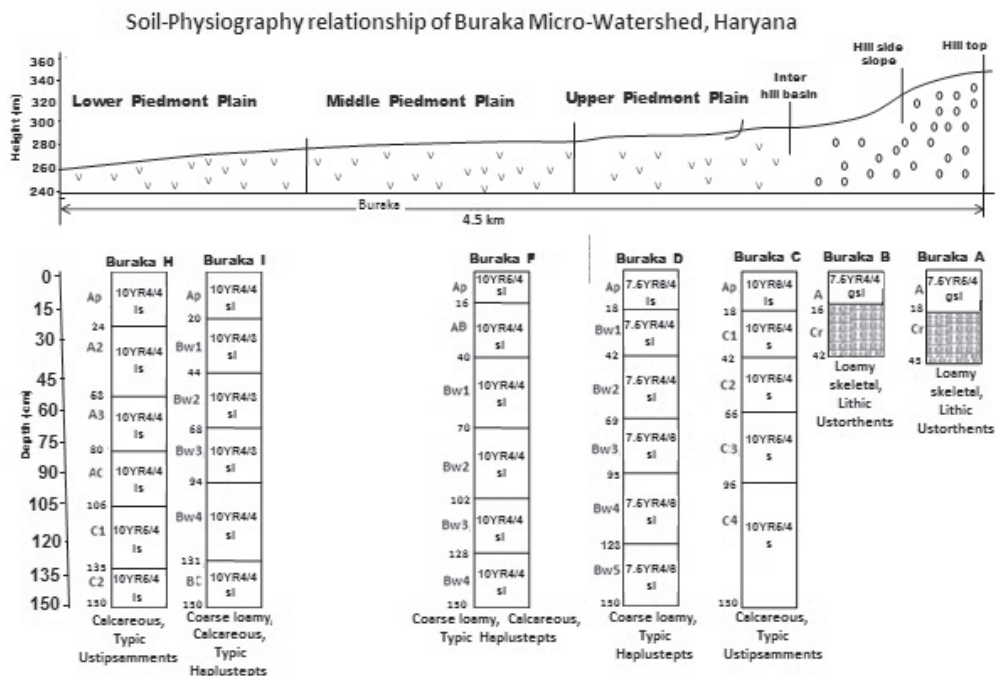


Fig. 3. Soil-physiography relationship of Buraka micro-watershed

Morphological characteristics of soils

On the basis of field study and laboratory characterization ten soils (Buraka A to Buraka J) were identified and mapped into 21 soil mapping units as phases of soil series. The morphological properties of the soils are presented in table 1. The soil map is depicted in fig. 4 and soil legends are presented in table 3. Buraka A soils were shallow in depth with only A and Cr horizons having clear smooth to abrupt smooth boundaries, excessively drained, brown in colour, sandy loam in texture having abundant gravels increasing downwards, massive, slightly hard, friable, non-sticky and non-plastic in consistence, underlain by indurated bedrock at 45 cm depth. Buraka B soils were shallow in depth with only A and Cr horizons having clear smooth to abrupt smooth boundaries, excessively drained, brown in colour, sandy loam in texture having abundant gravels increasing in Cr horizon, massive, slightly hard, friable, slightly sticky and slightly plastic in consistence, underlain by indurated bedrock at 42 cm depth. Buraka C soils were very deep, excessively drained and have Ap-C horizons with clear smooth, gradual and clear wavy boundaries. They were light yellowish brown to yellowish brown in colour, loamy sand to sand in texture, strongly calcareous, single grain in structure, loose, non-sticky and non-plastic in consistence. Buraka D soils were very deep and are comparatively developed having cambic (Bw) horizons. They were well drained, brown and strong brown in colour, and have Ap-Bw horizons with clear smooth and gradual

smooth boundaries. They were loamy sand to sandy loam in texture, single grain to fine, medium, weak subangular blocky in structure, loose to slightly hard, friable, non-sticky to slightly sticky and non-plastic to slightly plastic in consistence. Buraka E soils were very deep with A-AC-C horizons having clear smooth and gradual smooth boundaries. They were somewhat excessively drained, yellowish brown to dark yellowish brown in colour, loamy sand in texture, slightly calcareous, single grain in structure, loose, very friable, non-sticky and non-plastic in consistence.

Buraka F soils were very deep in depth with Ap-AB-Bw horizons having clear smooth and gradual smooth boundaries. They were well drained, yellowish brown to dark yellowish brown in colour, sandy loam in texture, slightly calcareous, massive to fine, medium, weak subangular blocky in structure, loose to slightly hard, loose to friable, non-sticky to slightly sticky and non-plastic to slightly plastic in consistence. Buraka G soils were very deep in depth having Ap-Bw horizons with clear smooth and gradual smooth boundaries. They were well drained, yellowish brown to dark yellowish brown in colour, sandy loam in texture, medium, weak and moderate subangular blocky in structure, slightly hard, friable, slightly sticky and slightly plastic in consistence. Buraka H soils were very deep with A-AC-C horizons having clear smooth, clear and gradual wavy boundaries. They were somewhat excessively drained, dark yellowish brown to yellowish brown in colour, loamy sand in texture, slightly calcareous, loose to soft, loose to very friable, non-sticky and non-plastic in consistence. Buraka I soils were very deep with Ap-Bw-BC horizons having clear smooth and gradual smooth boundaries, well drained, dark yellowish brown to brown in colour, sandy loam in texture, slightly calcareous, medium and fine, weak sub angular blocky in structure, slightly hard, friable, slightly sticky and slightly plastic in consistence. Buraka J soils were very deep in depth with Ap-AC-C horizons having clear smooth and diffuse irregular boundaries, excessively drained, light yellowish brown to yellowish brown in colour, sand in texture, strongly calcareous, single grain in structure, loose, non-sticky and non-plastic in consistence.

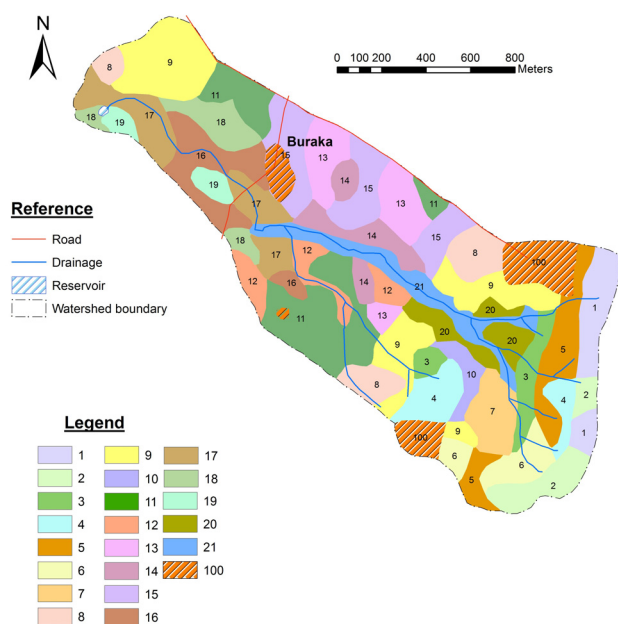


Fig. 4. Soils of Buraka micro-watershed

Physical and chemical properties of soil

The physical and chemical properties of the soils are presented in table 2. The soils of Buraka A were slightly acidic (pH 6.4) whereas soils of Buraka B were neutral (pH 7.1) in nature. Buraka C, H and J soils were slightly alkaline with pH ranging between

Table 1. Morphological characteristics of soils in Buraka micro-watershed

Soils	Horizon	Depth (cm)	Boundary	Colour (moist)	Texture	Structure*	Consistence**			Coarse gravels (%)	Effervescence
							d	m	w		
<i>Buraka A</i>	A	0-18	Clear, smooth	Brown (7.5YR 5/4)	Sandy loam	m	sh	fr	ss, ps	42	-
	Cr	18-45	Abrupt, smooth	Brown (7.5YR 5/4)	Coarse gravels and cobbles	-	-	-	-	70	-
	R	45+	Indurated bedrock	-	-	-	-	-	-	-	-
<i>Buraka B</i>	A	0-16	Clear, smooth	Brown (7.5YR 5/4)	Sandy loam	m	sh	fr	ss, ps	45	-
	Cr	16-42	Abrupt, smooth	Brown (7.5YR 5/4)	Sandy loam	-	-	-	-	82	-
<i>Buraka C</i>	R	42+	Indurated bedrock	-	-	-	-	-	-	-	-
	Ap	0-18	Clear, smooth	Light yellowish brown (10YR 6/4)	Loamy sand	sg	l	l	so, po	-	Slight
	C1	18-42	Gradual, wavy	Yellowish brown (10YR 5/4)	Sand	sg	l	l	so, po	-	Strong
	C2	42-66	Gradual, wavy	Yellowish brown (10YR 5/4)	Sand	sg	l	l	so, po	-	Strong
	C3	66-96	Clear, wavy	Yellowish brown (10YR 5/4)	Sand	sg	l	l	so, po	-	Strong
	C4	96-150+	-	Yellowish brown (10YR 5/4)	Sand	sg	l	l	so, po	-	Strong
<i>Buraka D</i>	Ap	0-18	Clear, smooth	Light brown (7.5YR 6/4)	Loamy sand	sg	l	l	so, po	-	-
	Bw1	18-42	Gradual, smooth	Brown	Sandy loam	m 1 sbk	sh	fr	ss, ps	-	-
	Bw2	42-69	Gradual, smooth	Brown (7.5YR 4/4)	Sandy loam	m 1 sbk	sh	fr	ss, ps	-	-
	Bw3	69-95	Gradual, smooth	Strong brown (7.5YR 4/6)	Sandy loam	m 1 sbk	sh	fr	ss, po	-	-
	Bw4	95-123	Gradual, smooth	Strong brown (7.5YR 4/6)	Sandy loam	f 1 sbk	sh	fr	ss, po	-	-
	Bw5	123-150+	-	Strong brown (7.5YR 4/6)	Sandy loam	f 1 sbk	sh	vfr	ss, po	-	-
<i>Buraka E</i>	Ap	0-18	Clear, smooth	Yellowish brown (10YR 5/4)	Loamy sand	sg	l	l	so, po	-	Slight
	A2	18-40	Gradual, smooth	Dark yellowish brown (10YR 4/5)	Loamy sand	sg	l	l	so, po	-	Slight
	A3	40-67	Gradual, smooth	Dark yellowish brown (10YR 4/6)	Loamy sand	sg	l	l	so, po	-	Slight
	A4	67-96	Gradual, smooth	Dark yellowish brown (10YR 4/6)	Loamy sand	sg	l	l	so, po	-	Slight
	AC	96-127	Gradual, smooth	Dark yellowish brown (10YR 4/6)	Loamy sand	sg	l	l	so, po	-	Slight
	C	127-156+	-	Dark yellowish brown (10YR 4/6)	Loamy sand	sg	l	l	so, po	-	Slight

<i>Buraka F</i>	Ap	0-16	Clear, smooth	Yellowish brown (10YR 5/4)	Sandy loam	m	sh	vfr	ss, ps	-	Slight
	AB	16-40	Gradual, smooth	Dark yellowish brown (10YR 4/4)	Sandy loam	f 1 sbk	sh	fr	ss, ps	-	Slight
	Bw1	40-70	Gradual, smooth	Dark yellowish brown (10YR 4/4)	Sandy loam	m 1 sbk	sh	fr	ss, ps	-	Slight
	Bw2	70-102	Gradual, smooth	Dark yellowish brown (10YR 4/4)	Sandy loam	m 1 sbk	sh	fr	ss, ps	-	Slight
	Bw3	102-128	Gradual, smooth	Dark yellowish brown (10YR 4/4)	Sandy loam	m 1 sbk	sh	fr	ss, ps	-	Slight
	Bw4	128-150+	-	Dark yellowish brown (10YR 4/4)	Sandy loam	m 1 sbk	sh	fr	ss, ps	-	Slight
<i>Buraka G</i>	Ap	0-17	Clear, smooth	Yellowish brown (10YR 5/4)	Sandy loam	m 1 sbk	sh	vfr	ss, ps	-	-
	Bw1	17-45	Gradual, smooth	Dark yellowish brown (10YR 3/4)	Sandy loam	m 1 sbk	sh	fr	ss, ps	-	-
	Bw2	45-72	Gradual, smooth	Dark yellowish brown (10YR 3/4)	Sandy loam	m 1 sbk	sh	fr	ss, ps	-	-
	Bw3	72-100	Gradual, smooth	Dark yellowish brown (10YR 3/4)	Sandy loam	m 2 sbk	sh	fr	ss, ps	-	-
	Bw4	100-127	Gradual, smooth	Dark yellowish brown (10YR 3/4)	Sandy loam	m 2 sbk	sh	fr	ss, ps	-	-
	Bw5	127-150+	-	Dark yellowish brown (10YR 3/4)	Sandy loam	m 1 sbk	sh	vfr	ss, ps	-	-
<i>Buraka H</i>	Ap	0-24	Clear, smooth	Dark yellowish brown (10YR 4/4)	Loamy sand	sg	l	l	ss, po	-	Slight
	A2	24-53	Gradual, smooth	Dark yellowish brown (10YR 4/4)	Loamy sand	sg	l	l	ss, po	-	Slight
	A3	53-80	Gradual, smooth	Dark yellowish brown (10YR 4/4)	Loamy sand	m	sh	vfr	ss, po	-	Slight
	AC	80-106	Clear, wavy	Dark yellowish brown (10YR 4/4)	Loamy sand	sg	l	l	so, po	-	Slight
	C1	106-135	Gradual, wavy	Yellowish brown (10YR 5/4)	Loamy sand	sg	l	l	so, po	-	Strong
	C2	135-154+	-	Yellowish brown (10YR 5/4)	Loamy sand	sg	l	l	so, po	-	Strong
<i>Buraka I</i>	Ap	0-20	Clear, smooth	Yellowish brown (10YR 4/4)	Sandy loam	m	sh	fr	ss, ps	-	Slight
	Bw1	20-44	Gradual, smooth	Brown (7.5YR 4/4)	Sandy loam	m 1 sbk	sh	fr	ss, ps	-	Slight
	Bw2	44-68	Gradual, smooth	Brown (7.5YR 4/4)	Sandy loam	m 1 sbk	sh	fr	ss, ps	-	Slight
	Bw3	68-94	Gradual, smooth	Brown (7.5YR 4/4)	Sandy loam	m 1 sbk	sh	fr	ss, ps	-	Slight
	Bw4	94-131	Gradual, smooth	Dark yellowish brown (10YR 4/5)	Sandy loam	f 1 sbk	sh	vfr	ss, ps	-	Slight
	BC	131-156+	-	Dark yellowish brown (10YR 4/6)	Sandy loam	m	sh	vfr	ss, ps	-	Slight

<i>Buraka J</i>	Ap	0-18	Clear, smooth	Yellowish brown (10YR 5/4)	Loamy sand	sg	l	vfr	so, po	-	Strong
	A2	18-45	Diffused, irregular	Light Yellowish brown (10YR 6/4)	Sand	sg	l	l	so, po	-	Strong
	A3	45-72	Diffused, irregular	Light Yellowish brown (10YR 6/4)	Sand	sg	l	l	so, po	-	Strong
	AC	72-111	Diffused, irregular	Yellowish brown (10YR 5/4)	Sand	sg	l	l	so, po	-	Strong
	C1	111-125	Diffused, irregular	Yellowish brown (10YR 5/4)	Sand	sg	l	l	so, po	-	Strong
	C2	125-160+	-	Yellowish brown (10YR 5/4)	Sand	sg	l	l	so, po	-	Strong

*m: massive; sg: *single grain*; m1sbk: *medium weak subangular blocky*; m2sbk: *medium moderate subangular blocky*; f1sbk: *fine weak subangular blocky*

**sh: *slightly hard*; l: *loose*; fr: *friable*; vfr: *very friable*; so: *non-sticky*; ss: *slightly sticky*; po: *non plastic*; ps: *slightly plastic*

Table 2. Physical and chemical properties of soils

Soils	Horizon	Depth (cm)	pH (1:2.5)	E.C (dS m ⁻¹)	Org. C (g kg ⁻¹)	Sand	Silt (%)	Clay	CaCO ₃ (%)	CEC [cmol (p ⁺)kg ⁻¹]	CEC/ Clay (%)	Base Saturation (%)
<i>Buraka A</i>	A	0-18	6.4	0.39	4.1	58.0	25.1	17.0	-	6.49	38.2	76.8
<i>Buraka B</i>	A	0-16	7.1	0.24	4.0	54.8	31.7	13.5	-	4.68	34.7	79.8
<i>Buraka C</i>	Ap	0-18	7.5	0.25	0.8	88.0	8.5	3.5	0.50	1.20	34.2	77.5
	C1	18-42	7.9	0.34	0.6	93.9	3.7	2.5	0.72	0.77	30.8	84.8
	C2	42-66	8.2	0.34	0.4	90.0	7.6	2.5	1.10	0.94	37.6	81.3
	C3	66-96	8.3	0.30	0.4	88.3	9.2	2.5	1.20	0.94	37.5	80.6
	C4	96-150	8.4	0.32	0.2	91.3	6.5	2.3	1.22	0.86	38.3	80.6
<i>Buraka D</i>	Ap	0-18	7.6	0.48	4.2	80.4	11.5	8.2	-	3.05	37.5	78.8
	Bw1	18-42	7.8	0.25	4.0	71.2	15.9	13.0	-	4.68	36.0	78.8
	Bw2	42-69	7.7	0.25	3.9	67.3	15.2	17.5	-	6.05	34.6	78.2
	Bw3	66-95	7.8	0.19	3.7	72.6	14.9	12.5	-	4.39	35.1	81.0
	Bw4	95-123	7.8	0.19	3.6	69.9	17.7	12.5	-	4.41	35.3	79.7
	Bw5	123-150	7.8	0.27	2.3	71.0	17.0	12.0	-	4.30	35.8	80.5
<i>Buraka E</i>	Ap	0-18	7.5	0.51	1.8	81.7	10.8	7.5	0.32	2.78	37.1	83.3
	A12	18-40	7.7	0.39	1.3	82.0	10.0	8.0	0.47	2.73	34.7	80.8
	A13	40-67	7.8	0.37	0.8	85.1	7.4	7.5	0.25	2.26	30.2	81.4
	A14	67-96	7.7	0.22	0.7	87.0	5.8	7.3	0.27	2.34	32.3	80.9
	AC	96-127	7.7	0.17	0.5	89.0	7.5	3.5	0.29	1.26	36.1	77.8
	C	127-156	7.8	0.20	0.5	89.1	7.0	4.0	0.24	1.40	35.0	81.0
<i>Buraka F</i>	Ap	0-16	7.4	0.57	2.3	75.1	12.4	12.5	0.81	4.49	37.4	65.1
	Bw1	16-40	7.5	0.48	1.2	71.1	13.9	15.0	1.17	5.11	34.1	77.7
	Bw2	40-70	7.7	0.38	1.0	67.3	15.8	17.0	1.25	6.16	34.2	80.2
	Bw3	70-102	7.5	0.41	0.9	65.9	16.6	17.5	1.44	6.09	32.9	79.1
	Bw4	102-128	7.8	0.45	0.9	64.6	18.5	17.0	1.58	6.08	33.8	80.3
	Bw5	128-150+	7.8	0.43	0.3	66.1	16.5	17.5	1.50	6.18	33.4	80.4
<i>Buraka G</i>	Ap	0-17	8.0	0.38	3.1	73.1	15.9	11.0	-	4.21	38.3	83.9
	Bw1	17-45	7.8	0.33	1.9	70.4	17.2	12.5	-	4.27	34.2	83.5
	Bw2	45-72	7.8	0.33	1.9	70.4	16.1	13.5	-	4.47	33.1	86.5
	Bw3	72-100	7.4	0.17	1.9	66.2	17.3	16.5	-	5.28	32.0	79.1
	Bw4	100-127	7.2	0.19	1.4	67.3	17.8	15.0	-	5.52	36.8	79.7
	Bw5	127-150	7.2	0.24	1.4	66.3	18.7	15.0	-	5.49	36.6	79.8
<i>Buraka H</i>	Ap	0-24	7.6	0.31	0.5	85.0	11.5	3.5	0.27	1.33	38.1	81.5
	A21	24-53	7.8	0.23	1.3	77.5	14.3	8.2	0.32	3.15	38.4	82.7
	A22	53-80	8.0	0.22	0.7	77.0	14.5	8.5	0.41	3.10	36.5	83.3
	AC	80-106	8.0	0.23	0.5	79.5	13.0	7.5	0.50	2.53	33.8	87.4
	C1	106-135	8.1	0.21	0.5	81.8	11.5	6.8	7.74	2.17	32.1	84.7

<i>Buraka I</i>	C2	135-154+	8.3	0.23	0.4	82.0	12.0	6.0	11.07	1.99	33.1	85.3
	Ap	0-20	7.3	0.51	1.9	76.3	13.8	10.0	0.18	3.30	33.0	80.0
	Bw1	20-44	7.5	0.34	1.3	68.2	19.3	12.5	0.27	4.07	32.6	76.5
	Bw2	44-68	7.7	0.35	0.9	72.0	15.5	12.5	0.32	4.09	32.7	79.0
	Bw3	68-94	7.6	0.38	0.6	69.2	15.9	15.0	0.32	4.71	31.4	77.9
	Bw4	94-131	7.7	0.38	0.6	76.1	13.9	10.0	0.36	3.34	33.4	84.6
<i>Buraka J</i>	BC	131-156+	7.7	0.31	0.6	77.5	11.1	11.5	0.45	3.52	30.6	82.7
	A11	0-18	7.9	0.32	0.6	85.2	8.9	6.0	7.11	2.15	35.8	80.5
	A12	18-45	8.1	0.28	0.4	92.1	2.9	5.0	6.75	1.80	36.1	80.2
	A13	45-72	8.1	0.25	0.2	92.5	5.0	2.5	5.45	0.97	38.8	81.9
	AC	72-111	8.2	0.24	0.2	93.3	4.3	2.5	5.94	0.97	38.9	81.9
	C1	111-125	8.2	0.26	0.2	91.4	5.0	3.6	6.30	1.20	33.4	80.3
	C2	125-160+	8.3	0.26	0.1	92.8	4.2	3.1	7.15	1.12	36.8	84.6

7.5 and 8.4 whereas soils of Buraka D, E, F, G and I were neutral to very slightly alkaline with pH varying from 7.2 to 7.8. The acidic nature of Buraka A soils and neutral nature of Buraka B soils are due to the reasons that bases were leached from the hill tops (Buraka A) to hill side slopes (Buraka B). The neutral to slightly alkaline nature of Buraka D to G and I soils is due to fluvial deposits of bases as well as presence of CaCO₃ in pedons. The alkaline nature of Buraka C, H and J soils was due to presence of abundant CaCO₃ in these soils.

The electrical conductivity (EC) of the soils was low (0.17-0.57 dS m⁻¹) which is due to the reasons that soils occur on sloppy landscape of hills, foot hills and piedmonts and the salts have been removed from these soils with runoff water during heavy rains.

Organic carbon (OC) content of the soils (except Buraka C and J) was low to medium (2.0-5.7 g kg⁻¹) in surface horizons and very low to low (0.4-2.0 g kg⁻¹) in subsurface horizons because of more biomass input in surface layers. However, in Buraka H soils the OC content of second horizon (A2) was higher (1.3 g kg⁻¹) in comparison to surface layer *i.e.*, Ap (0.5 g kg⁻¹) which is due to leaching of decomposed organic matter in the coarse (loamy sand) textured soils. Besides, it is noticed that the OC content decreased with depth in all the soils, as also observed by earlier researchers in various types of soils (Mahapatra *et al.* 2000, 2005; Nagdev *et al.* 2017c).

Buraka C, E, H and J soils were coarse textured having loamy sand to sand and clay content ranging from 2.50-8.50% only. The coarser texture of these soils are due to quartzitic parent material of Aravalli hills. Buraka D, F, G and I soils were sandy loam in texture with clay content varying from 8.15-17.50%. Comparatively higher clay content of these soils are due to the reason that these soils occur on relatively lower elevations and leached clay particles from higher elevations are deposited in these soils.

Nutrient retention capacity of Buraka C, E, H and J soils were very low as evident from low cation exchange capacity (CEC) ranging from 0.77-3.75 cmol(p⁺)kg⁻¹. This is due to coarser soil texture having very low clay content in these soils. Whereas, soils of Buraka D, E, F, G and I had low nutrient retention capacity as revealed from their CEC values which ranged from 3.05-6.18 cmol(p⁺)kg⁻¹. The CEC values of these soils are comparatively high as they are sandy loam in texture having comparatively more clay content than Buraka C, E, H and J soils. The values of nutrient retention capacity are governed by clay content, organic matter and type of clay minerals (Sawhney *et al.* 1996; Gorai *et al.* 2013; Nagdev *et al.* 2017c).

Soil classification

The temperature and moisture regimes of the watershed area are hyperthermic and ustic, respectively. The mineralogy of all the soils was mixed type as revealed from their CEC:clay ratio which ranged from 30.2-38.9 (Smith 1986). Sachdev *et al.* (1995) also reported mixed mineralogy in the soils of this region.

Buraka A soils were shallow, sandy loam in texture having clay content up to 17%. They were undeveloped having only A-Cr horizons and indurated bedrock at 45 cm depth and belonged to Entisols. The soils contained more than 35% coarse gravels throughout the profile and thus belonged to loamy skeletal family textural class and classified as loamy skeletal, mixed, hyperthermic, Lithic Ustorthents. Buraka B soils were shallow in depth, sandy loam in texture with more than 35% coarse fragments throughout the profile and clay content upto 13.5%. These soils were also undeveloped having only A-Cr horizons and indurated bedrock at 42 cm depth and hence belonged to Entisols and were classified as loamy skeletal, mixed, hyperthermic, Lithic

Table 3. Description and extent of soil mapping units

Mapping Unit No.	Mapping Unit Code	Description	Area (ha)	% of surveyed area
(1). A Soils: Very shallow, excessively drained, brown, very gravelly sandy loam soils on undulating hill tops (Loamy skeletal, Lithic Ustorthents).			39.9	7.36
1	AcC3SR	A very gravelly sandy loam, gently sloping with severe erosion, moderately stony and moderately rocky.	21.2	3.91
2	AcC3SR	A very gravelly sandy loam, gently sloping with severe erosion, moderately stony and severely rocky.	18.7	3.45
(2). B Soils: Very shallow, excessively drained, brown to dark yellowish brown, very gravelly to extremely gravelly sandy loam soils on moderately to moderately steeply sloping hill side slopes (Loamy skeletal, Lithic Ustorthents).			76.6	14.12
3	BcD3SR	B very gravelly to extremely gravelly sandy loam, moderately sloping with severe erosion, moderately stony and rocky.	12.5	2.30
4	BcD3SR	B very gravelly to extremely gravelly sandy loam, moderately sloping with severe erosion, moderately stony and severely rocky.	19.9	3.67
5	BcE3SR	B very gravelly to extremely gravelly sandy loam, strongly sloping with severe erosion, moderately stony and severely rocky.	27.4	5.05
6	BcE3SR	B very gravelly to extremely gravelly sandy loam, strongly sloping with severe erosion, severely stony and rocky.	16.8	3.10
(3). C Soils: Very deep, somewhat excessively drained, yellowish brown to dark yellowish brown, loamy sand soils on undulating inter-hill basin (Calcareous, Typic Ustipsamments).			16.8	3.10
7	CbC2	C loamy sand, gently sloping with moderate erosion.	16.8	3.10
(4). D Soils: Very deep, well drained, brown to dark yellowish brown, sandy loam soils on nearly level to gently sloping upper piedmont plain (Coarse loamy, Typic Haplustepts).			87.7	16.17
8	DbA1	D loamy sand, nearly level sloping with slight erosion.	23.0	4.24
9	DbB1	D loamy sand, very gently sloping with slight erosion.	59.1	10.90
10	DbC2	D loamy sand, gently sloping with moderate erosion.	5.6	1.03
(5). E Soils: Very deep, somewhat excessively drained, yellowish brown to dark yellowish brown, loamy sand to sandy loam soils on very gentle to gently sloping middle piedmont plain (Calcareous, Typic Ustipsamments).			72.9	13.44
11	EbB ₁	E loamy sand, very gently sloping with slight erosion.	54.8	10.10
12	EbC2	E loamy sand, gently sloping with moderate erosion.	18.1	3.34
(6). F Soils: Very deep, Well drained, yellowish brown to dark yellowish brown, sandy loam soils on nearly level to very gently sloping middle plain piedmont [Coarse loamy (Calc.), Typic Haplustepts].			54.8	10.10
13	FcA1	F sandy loam, nearly level sloping with slight erosion.	30.5	5.62
14	FcB1	F sandy loam, very gently sloping with slight erosion.	24.3	4.48
(7). G Soils: Very deep, Well drained, dark yellowish brown, sandy loam soils on nearly level to very gently sloping middle piedmont plain (Coarse loamy, Typic Haplustepts).			37.4	6.89
15	GcA1	G sandy loam, nearly level sloping with slight erosion.	37.4	6.89
(8). H Soils: Very deep, somewhat excessively drained, yellowish brown to dark yellowish brown, loamy sand to sandy loam soils on very gently to gently sloping lower piedmont plain (Calcareous, Typic Ustipsamments).			61.0	11.25
16	HbB1	H loamy sand, very gently sloping with slight erosion.	29.3	5.40
17	HbC2	H loamy sand, gently sloping with moderate erosion.	31.7	5.85
(9). I Soils: Very deep, Well drained, dark yellowish brown, sandy loam soils on nearly level to very gently sloping lower piedmont plain [Coarse loamy (Calc.), Typic Haplustepts].			26.8	4.94
18	IcB1	I sandy loam, very gently sloping with slight erosion.	18.1	3.34
19	IcC2	I loamy sand, gently sloping with moderate erosion.	8.7	1.60
(10). J Soils: Very deep, somewhat excessively drained, yellowish brown to dark yellowish brown, sand to loamy sand soils on gently to moderately sloping stream terraces (Calcareous, Typic Ustipsamments).			38.6	7.12
20	JbC2	J loamy sand, gently sloping with moderate erosion.	20.5	3.78
21	JbD3	J loamy sand, moderately sloping with severe erosion.	18.1	3.34
Total			512.5	94.49
Habitation			29.9	5.51
Grand Total			542.4	100.0

Ustorthents. Buraka C soils were very deep, sandy in texture and have only A-C horizons. Hence, they belonged to Entisols and classified as mixed, hyperthermic, Typic Ustipsamments. Buraka D soils were very deep, sandy loam in texture and calcareous (CaCO_3 up to 1.2%) in nature. These soils were comparatively well developed having cambic (Bw) subsurface diagnostic horizon and hence belonged to Inceptisols. They had sandy loam texture with <18% clay content and hence belonged to coarse loamy family textural class and classified as coarse loamy, calcareous, mixed, hyperthermic, Typic Haplustepts. Buraka E soils were very deep, loamy sand in texture, calcareous in nature (CaCO_3 up to 0.29%) and having A-AC-C horizons. They were undeveloped/partially developed and belonged to Entisols. They were classified as mixed, calcareous, hyperthermic, Typic Ustipsamments at family level.

Buraka F soils were very deep, sandy loam in texture with clay content up to 17.5% and calcareous (CaCO_3 up to 1.58%) in nature. They were at initial stage of development having cambic sub-surface diagnostic horizons and hence belonged to Inceptisols. They had coarse loamy family textural class and classified as coarse loamy, mixed, calcareous, hyperthermic, Typic Haplustepts. Buraka G soils were very deep, sandy loam in texture with clay content upto 16.5%. They exhibited A-Bw horizons and belonged to Inceptisols and were classified as coarse loamy, mixed, hyperthermic Typic Haplustepts. Buraka H soils were very deep, loamy sand in texture, strongly calcareous (CaCO_3 up to 11.07%) and having A-AC-C horizons. They belonged to Entisols and were classified as mixed, calcareous, hyperthermic, Typic Ustipsamments. Buraka I soils were very deep, sandy loam in texture with clay content upto 15.0% and had A-Bw-BC horizons. These soils belonged to Inceptisols with coarse loamy textural class and were classified as coarse loamy, mixed, hyperthermic, Typic Haplustepts. Buraka J soils were very deep, sandy in texture, calcareous (CaCO_3 up to 7.15%) with only A-C horizons. They belonged to Entisols and were classified as mixed, calcareous, hyperthermic, Typic Ustipsamments. Thus, the study reveals that major soils belonged to Entisols (56.4%) followed by Inceptisols (38.1%). Among Entisols, Ustipsamments cover 34.9% followed by Ustorthents (21.5%) whereas in Inceptisols, coarse loamy Typic Haplustepts covered 23.1% followed by coarse loamy, calcareous, Typic Haplustepts occupying 15.0%.

Soil mapping units

On the basis of soil depth, drainage, colour, texture, calcareousness, slope, landform surface texture, erosion and taxonomy, 21 soil mapping units were prepared following the procedure of Soil Survey Manual (IARI 1970). Legends used for the soils were A, B, C, D, E, F, G, H and I instead of Buraka A, Buraka B *etc.* The soil map has been depicted in Fig 4 and description of the 21 mapping units as shown in the soil map has been described in table 3. The soil mapping units were mapped as phases of soil series. They were composed of respective series name (A, B, C, D, E, F, G, H, I and J) followed by surface texture, slope class, erosion class, stoniness and rockiness (if any). In the same series, mapping units were different due to differences in one or more above parameters. On the basis of these parameters, 10 soils of the micro-watershed were mapped into 21 soil mapping units. Buraka A soils have 2 mapping units due to variation in rockiness, whereas B soils have 4 units due to differences in slope, stoniness and rockiness. The C soils have only one unit whereas, D soils have 3 units due to variation in slope and erosion classes. The E and F soils have 2 units each due to variation in slope and erosion classes, while G soils have only one unit and H soils have 2 units due to variation in slope and erosion classes. Both I and J soils have 2 units each due to variation in surface texture, slope and erosion classes.

Land capability and irrigability classification

The soils of the watershed were categorized into four land capability and irrigability classes and six land capability and five irrigability subclasses based on their site characteristics, limitations and potentials (Table 4). The extent and distribution of different land capability subclasses and land irrigability subclasses are presented in fig. 5 and 6, respectively.

Land capability subclass IIIs and irrigability subclass 2s: Soils under these subclasses covered 90.90 ha (16.8%) area. It comprised soil units DbA1, FcA1 and GcA1 and were moderately good lands, with moderate limitations of soils (coarse texture; sandy loam with 8.15-17.5% clay content). The water holding capacity, nutrient retention capacity and productivity potential were low having CEC ranging from 3.05-6.16 $\text{cmol}(\text{p}^+)\text{kg}^{-1}$. Selected crops can be grown under proper management practices such as addition of organic manures, green manuring and adequate/judicious use of fertilizers (Sys *et al.* 1991; Singh *et al.* 2004).

Table 4. Land capability and irrigability classification and management recommendations

Land capability subclass	Land Irrigability subclass	Soil units	Potentials /limitations	Management recommendations	Area	
					(ha)	(%)
III _s	2 _s	DbA1, FcA1, GcA1	Moderately good lands, moderate limitation of soils	Need proper management practices, cultivation of climatically adapted crops	90.90	16.8
III _{es}	2 _{st}	DbB1, DbC2, FcB1, IcB1, IcC2	Moderately good lands, moderate limitation of erosion and soils	Need leveling of lands and proper management practices, cultivation of climatically adapted crops	115.80	21.3
III _{se}	3 _{st}	EbB1, EbC2, HbB1, HbC2	Fairly good lands, moderate limitation of soils, erosion and droughtiness	Sufficient and timely irrigations (preferably sprinkle), recommended doses of organic and inorganic fertilizers, selection of crops adapted to limitation of soils and climate	133.90	24.7
IV _{es}	4 _{st}	CbC2, JbC2, JbD3	Fair lands with moderate to severe limitation of erosion, soils and droughtiness	Needs land leveling, sufficient and timely irrigations (preferably sprinkle), INM practices involving recommended doses of organic and inorganic fertilizers, selection of crops adapted to limitation of soils and climate	55.40	10.2
VI _{es}	6 _{st}	AcC3SR, AcC3SR	Rocky lands, severe limitation of erosion, soil depth, stoniness and rockiness	Establishment of vegetative cover like pasture, forestry <i>etc.</i> and construction of engineering structures to check soil erosion; development of infrastructures like warehouses, recreation, <i>etc.</i>	39.90	7.4
VII _{es}	6 _{st}	BcD3SR, BcD3SR, BcE3SR, BcE3SR	Rocky lands, severe limitation of erosion, soil depth, stoniness and rockiness	Adoption of silvi-pasture with suitable forestry management practices including engineering structures to prevent soil erosion; development of infrastructures like warehouses, recreation, <i>etc.</i>	76.60	14.1

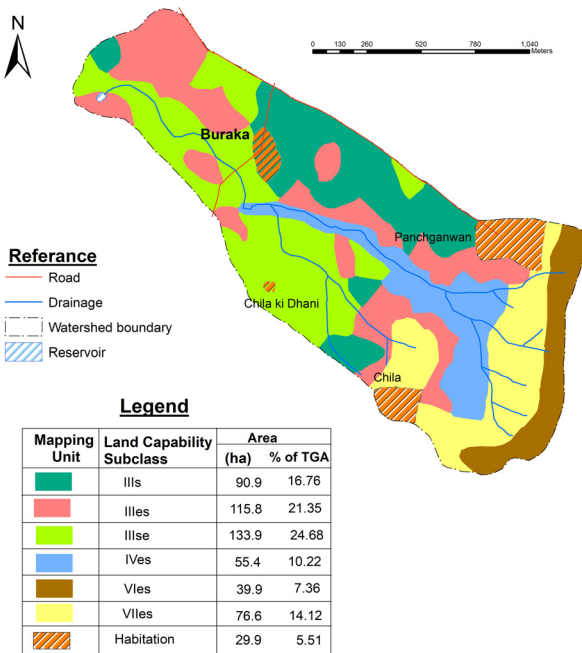


Fig. 5. Land capability subclass, Buraka micro-watershed

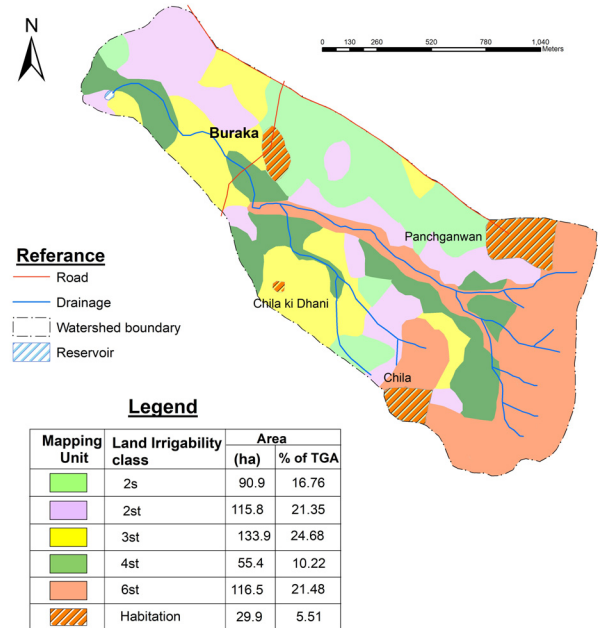


Fig. 6. Land irrigability subclasses, Buraka micro-watershed

Land capability subclass IIIes and irrigability subclass 2st: These subclasses comprised of soil units DbB1, DbC2, FcB1, IcB1 and IcC2 covering 115.8 ha (21.3%) area. They are moderately good lands with moderate limitations of erosion and soils (sandy loam texture with 8.15-17.50% clay). The water holding capacity, nutrient retention capacity and productivity potential of these soils were low with CEC ranging from 3.05-6.16 $\text{cmol}(\text{p}^+)\text{kg}^{-1}$. Proper management practices such as leveling of lands, application of organic manures including green manuring may be adopted along with recommended dose of fertilizers (Sys *et al.* 1991; Singh *et al.* 2004).

Land capability subclass IIIse and irrigability subclass 3st: These subclasses covered major area of the watershed comprising soil units EbB1, EbC2, HbB1, HbC2 and occupying 133.90 ha (24.7%) area. They are fairly good lands with moderate limitations of soils (loamy sand texture), erosion and droughtiness. The water holding capacity, nutrient retention capacity and productivity potential were very low to low with CEC ranging from 1.26-3.15 $\text{cmol}(\text{p}^+)\text{kg}^{-1}$. Proper management practices may be adopted for enhancing productivity such as leveling of lands, sufficient and timely irrigation (preferably sprinkle), integrated nutrient management (INM) involving recommended doses of organic and inorganic manures and fertilizers, selection of crops adapted to limitations of soils and climate.

Land capability subclass IVes and irrigability subclass 4st: These subclasses covered about 55.40 ha (10.2%) area comprising soil units CbC2, JbC2 and JbD3. They are fairly good lands with moderate limitation of erosion, soils (loamy sand texture) and droughtiness. The water holding capacity, nutrient retention capacity and productivity potential were very low having CEC ranging from 1.40-3.15 $\text{cmol}(\text{p}^+)\text{kg}^{-1}$. Proper soil and water conservation measures like land leveling, application of INM practices involving green manuring, FYM, vermicompost along with recommended dose of inorganic fertilizers, selection of crops adapted to limitation of soils and climate may be adopted in these lands.

Land capability subclass VIes and irrigability subclass 6st: These subclasses covered 39.90 ha (7.36%) area in Aravalli hills comprising soil units AcC3SR and AcC3SR. The major limitations were severe erosion, limited soil depth (<50 cm), moderate stoniness and rockiness. These soils are not suitable for common cultivated crops but could be utilized for pasture and forestry with establishment of good vegetative cover and construction of engineering

structures to check the soil erosion (Dhyani *et al.* 2005; Prasad and Dhyani 2010). Development of infrastructures like warehouses, recreation, *etc.* can be encouraged for better utilization of these lands.

Land capability subclass VIIes and irrigability subclass 6st: These subclasses covered 76.60 ha (14.1%) area in Aravalli hill slopes comprising soil units BcD3SR, BcD3SR, BcE3SR and BcE3SR. Severe erosion, shallow soil depth, severe stoniness and rockiness were the major constraints in these lands. They are not suitable for cultivation and should be kept under silvi-pasture by adopting suitable forestry management practices and construction of engineering structures to prevent soil erosion (Dhyani *et al.* 2005; Prasad and Dhyani 2010). Development of infrastructures like warehouses, recreation, *etc.* can be implemented for sustainable land use purposes.

The watershed area suffers from different constraints affecting the crop productivity such as undulating topography, inherent soil characteristics and depleting ground water table. These problems are enhanced by human intervention, deforestation to meet the fuel demand and economic benefits and overgrazing for fodder purposes. Besides, stone quarrying for construction purposes have destructed the hills (Mahapatra *et al.* 2002; Nagdev *et al.* 2017d). Therefore, suitable conservation measures must be undertaken to overcome these problems and protect the precious natural resources specially soils. Afforestation may be encouraged to check soil erosion in hilly areas. Besides, grasses and shrubs may be grown which will provide sufficient vegetative cover to protect the areas from degradations and improve the soil quality (Dhyani *et al.* 2005; Prasad and Dhyani 2010). In cultivated areas, proper soil and water conservation measures along with good agronomic practices like green manuring, balanced dose of fertilizers, sprinkler irrigation, *etc.* may be adopted for enhancing crop productivity and integrated development of the watershed area.

Conclusions

Detailed soil survey was conducted in the Buraka micro-watershed in Mewat region of Haryana and 10 soils were identified covering various physiographies *viz.*, Aravalli ridges, side slopes, upper, middle and lower piedmonts. Major soils (56.4%) belonged to Entisols followed by Inceptisols (38.1%). Soils were mostly loamy sand to sandy loam in texture (except in hilly area where it was gravelly sandy loam), very low to medium in OC content (0.4-5.7 g kg^{-1}) and very low to low in nutrient holding

capacity (CEC 0.77-6.18 cmol(p⁺)kg⁻¹). In the arable area, soils were categorised under land capability classes III and IV whereas in hilly area they were rated under VI and VII classes. Availability of irrigation water was the major problem in the watershed area associated with soil constraints and hence proper soil and water conservation measures as well as good agronomic practices may be adopted to enhance productivity.

References

- Bhattacharya, T., Sarkar, Dipak and Pal, D.K. (Eds.) (2009) *Soil Survey Manual*. NBSS&LUP, Publication No. 146, 1-400.
- Black, C.A. (Ed.) (1965) *Methods of Soil Analysis*, Part I. American Society of Agronomy, Madison, Wisconsin, USA.
- Dhyani, S.K., Sharda, V.N. and Samra, J.S. (2005) Agroforestry for sustainable management for soil, water and environment quality: looking back to think ahead. *Range Management and Agroforestry* **26**, 71-83.
- Gorai, T., Ahmed, N., Mahapatra, S.K., Datta, S.C., Singh, R.D. and Sharma, R.K. (2013) Effect of topography and vegetation on soil development in Kumaon hills of North Western Himalayas. *Journal of Soil and Water Conservation* **12**, 269-276.
- IARI (1970) *Soil Survey Manual*. All India Soil and Land Use Survey, Indian Agricultural Research Institute, New Delhi
- Jackson, M.L. (1966) *Soil Chemicals Analysis*. Prentice Hall of India (Pvt.) Ltd., New Delhi.
- Mahapatra, S.K., Ram, J. and Singh, S.P. (2002) An inventory of the soils of Almora district for sustainable agriculture. In *Extended Summary of International Conference on Managing Natural Resources*, pp. 55-57.
- Mahapatra, S.K., Walia, C.S., Sidhu, G.S., Rana, K.P.C. and Tarsem Lal (2000) Characterization and classification of the soils of different physiographic units in the sub humid eco-system of Kashmir region. *Journal of the Indian Society of Soil Science* **48**, 572-577.
- Mahapatra, S.K., Jagat Ram, Singh, S.P. and Dhankar, R.P. (2005) Soil resource inventory of warm humid Kumaon Himalayas for sustainable land use. *Journal of the Indian Society of Soil Science* **53**, 390-393.
- Nagdev, Ritu, Mahapatra, S.K., Yadav, R.P. and Singh, S.K. (2017a) Delineation and characterization of Purvi Nayar River watershed in Mid-Himalayan region of India using remote sensing and GIS techniques. *International Journal of Current Microbiology and Applied Science* **6**, 2047-2062.
- Nagdev, Ritu, Mahapatra, S.K. and Yadav, R.P. (2017b) Assessment of agri-environment in Garhwal Himalayas of India for sustainable productivity. *International Journal of Ecology and Environmental Sciences* **43**, 295-307.
- Nagdev, Ritu, Mahapatra, S.K., Yadav, R.P. and Singh, S.K. (2017c) Assessment of soil resource potential of warm humid Kumaon Himalayas for sustainable productivity. *Journal of the Indian Society of Soil Science* **65**, 138-147.
- Nagdev, Ritu, Mahapatra, S.K., Yadav, R.P. and Singh, S.K. (2017d) Land capability classification and management needs in Aravalli fringes of southern Haryana for sustainable land use planning. *Journal of Soil and Water Conservation* **16**, 117-125.
- Prasad, R. and Dhyani, S.K. (2010) Review of agroforestry contributions and problems in arid ecosystem for livelihood support in India. *Journal of Soil and Water Conservation* **9**, 277-287.
- Sachdev C.B., Lal, Tarsem, Rana, K.P.C and Sehgal, J. (1995) *Soils of Haryana for Optimising Land Use*. NBSS Publication 46, NBSS&LUP, Nagpur, pp. 1-59.
- Sahu, Nisha, Singh, S.K., Obi Reddy, G.P., Nirmal Kumar, Nagraju, M.S.S. and Srivastava, Rajeev (2016) Large scale soil resource mapping using IRS P6 LISS IV and Cartosat-1 DEM in Basaltic Terrain of Central India. *Journal of Indian Society of Remote Sensing* **44**, 811-819.
- Sawhney, J.S., Deka, B., Sharma, B.D. and Sidhu, P.S. (1996) Magnitude of soil variability in morphological and other properties across different landscape in the Siwalik hills of Punjab. *Journal of the Indian Society of Soil Science* **44**, 465-469.
- Sehgal, J.L., Saxena, R.K. and Vadivelu, S. (1987) *Field Manual; Soil Resource Mapping of Different States*. Bulletin **13**, NBSS&LUP, Nagpur.
- Sehgal, J. (1996) *Pedology-concepts and applications*. First Edition, Kalyani publishers, New Delhi.
- Sharma, V.A.K., Krishnan, P. and Budhial, S.L. (1987) *Laboratory Methods: Soil Resource, Mapping of Different States in India*. Bulletin **14**, NBSS&LUP, Nagpur.
- Singh, Chhida, Singh, Prem and Singh, Rajbir (2004) *Modern techniques of raising field crops*. Oxford and IBH Publishing Co. Pvt. Ltd., New Delhi, pp. 1-583.

- Smith, G.D. (1986) The Guy D Smith Interviews: Rationales for concept in Soil Taxonomy. (SMSS Technical Monograph 11 (SMSS, SCS, USDA).
- Soil Survey Staff (2014) *Keys to Soil Taxonomy*, 12th Edition, United States Department of Agriculture, Natural Resource Conservation Service, Washington, D.C., USA.
- Sys, C. (1985) *Land Evaluation*, Part II. Agriclas, Publ.7, Ghent, Belgium, pp. 143-157.
- Sys, C., E-van, R. and Debaveye, J. (1991) *Land evaluation*. Part II. *Principles in land evaluation and crop production calculations*. International Training Centre for Post-Graduate Soil Scientists, University of Ghent.

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