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Land suitability assessment for improved land use planning in selected watersheds of Haryana

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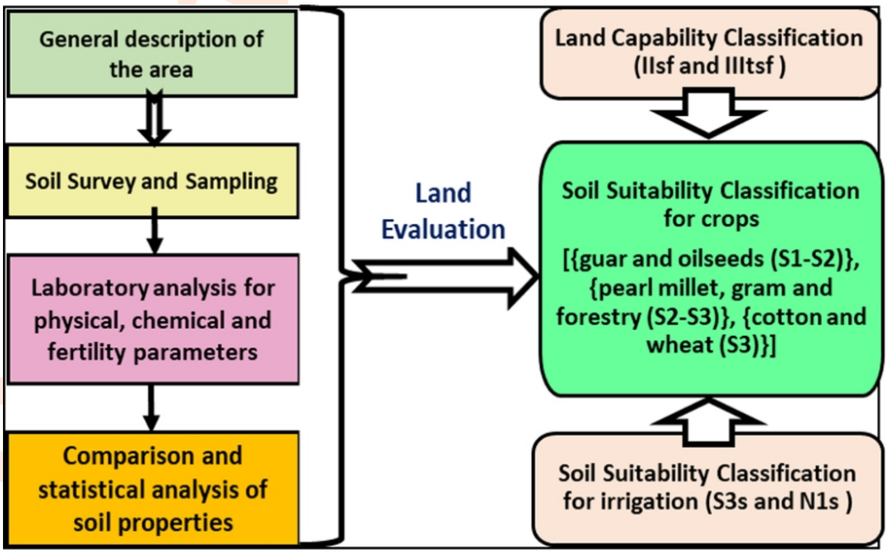
Abstract

Aim: The current study aimed to evaluate the capacity and suitability of land for semi-arid region of Haryana in selected watersheds to identify the major limitations of crop production.

Methodology: The study was carried out in Bhiwani district of Haryana in 2017 where eight typical pedons (P) representing four micro-watersheds viz., Motipura (P1 and P2), Sainiwas (P3 and P4), Jhumpa (P5 and P6), Budhsheli (P7 and P8) were studied.

Results: The studied pedons were neutral to alkaline in reaction (pH 6.87-9.10), non-saline (EC 0.02-0.21 dS m^{-1}) and low in organic carbon (OC) (0.06-0.27%). Available N, P, K and S were low (42.00-189.00 kg ha^{-1}), low to medium (4.20-17.10 kg ha^{-1}), low to high (62.20-326.50 kg ha^{-1}) and low (0.40-19.20 mg kg^{-1}) in the studied pedons, respectively. Soils were deficient in available Fe and Zn but marginal to sufficient in available Mn and Cu.



Interpretation: Soils were classified as IIsf and IIItsf and S3s and N1s according to LCC and irrigation suitability, respectively. The pedons were found suitable (S1) to moderately suitable (S2) for *guar* (cluster bean), oilseeds (mustard), moderately suitable (S2) to marginally suitable (S3) for pearl millet, gram and forestry, and marginally suitable (S3) for cotton and wheat.

Key words: Land suitability, Nutrients, Pedon, Semiarid, Watershed

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Introduction

Soil is an unreplaceable natural resource, thus, in the agrarian countries where population pressure is too high, prudent use of soil resource assumes greater importance for optimal and sustainable development with minimal environmental hazards. A comprehensive land use not only rationalizes the current use of land and soil, but also helps to preserve and maintain these resources for agricultural sustainability (Sahoo *et al.,* 2019). On account of meagre knowledge about soil characteristics, soils are easily degraded due to misuse and mismanagement. Therefore, the insight of soil involves marking their geographic location and extent besides discerning morphological, physico-chemical and fertility properties based on their geomorphic-soil relationship (Kharlyngdoh *et al.,* 2015). Watershed is a natural occurring hydrologic unit defined by natural boundaries, classified on the basis of geographical area, which carries runoff to a common point along a single waterway (Bhardwaj, 2020). A watershed is considered as a suitable entity for land and water resource conservation and management planning (Gajbhiye *et al.,* 2014).

Physiography, soil, geomorphology, drainage, land use/land cover are several parameters which play a major role in watershed planning (Javed *et al.,* 2011). To herald a generation of evergreen revolution, sustainable improvement of rainfed, degraded and wasteland areas to improve their productivity through effective planning and implementation of watershed management programs seems to be the guiding principle (Dass *et al.,* 2009). Land use planning is a systematic evaluation and appraisal of land and associated characteristics, thereby identifying the best land use options beneficial to landowners or managers/decision makers without degrading the land resources or environment (Sehgal, 1999). Land evaluation is the ranking of soil units on the basis of their capabilities, under certain management levels and socio-economic conditions, to assure optimum returns per unit area besides conserving the natural resources for future use. In essence, it is the process of predicting the potential of land for alternative kinds of use (Van-Wambeke and Rossiter, 1987). Land capability classification (LCC) is the field analysis of soil properties, degree of soil erosion, slope and shifting patterns of land use that constitutes the basis for future planning of soil and water conservation (Mondal and Mondal, 2015).

The assessment of land suitability for different crops is of utmost importance for proper land use planning (Sys *et al.,* 1991). Thus, the study of land suitability for crop production becomes a key aspect for enhancing agricultural production and productivity in regional settings. Consequently, there is an overwhelming need to manage and preserve the natural resource base by adopting appropriate technologies that are economically viable, socially acceptable and environmentally restoring in all its dimensions. This study was planned on watershed scale because the area surveyed is part of most productive region of the country. Therefore, realistic assessment of land suitability will help to develop effective management plan for strategic decision making in this area. Hence, an investigation was conducted in Bhiwani District's Jhumpa Kalan watershed to assess the suitability of soil for agriculture.

Materials and Methods

Study area: The study was carried out in Bhiwani district of Haryana in 2017-18 covering 3000 ha comprising four micro watersheds, viz. Motipura, Sainiwas, Jhumpa and Budhsheli (28° 46' to 28° 49' N latitudes and 75° 31' N to 75° 34' E longitudes; elevation of 225 m above Mean Sea Level). Fig. 1 shows the location map of the study site. Broadly, the study area is sandy, undulating plain dotted with sand dunes of varying shapes and dimensions occurring in multi-directional dispositions. The area has mostly soil types of orthids and psamments. Climate is semi-arid subtropical with hot summers and cold winters. In this region, the mean annual soil temperature and average rainfall are 25°C and 360.8 mm, respectively. The weekly weather data of the study area is presented in Fig. 2. Tropical dry deciduous forest is found in the area and Kikar (*Acacia nilotica*), Neem (*Azadirachta indica*), Shisham (*Dalbergia sissoo*), Khejri (*Prosopis cineraria*), Eucalyptus (*Eucalyptus globulus*) and Kair (*Capparis decidua*) are the main trees. The main kharif crops include bajra (*Pennisetum glaucum*), cotton (*Gossypium spp.*), while the minor crops include sugarcane (*Saccharum officinarum*), jowar (*Sorghum bicolor*), chillies (*Capsicum frutescens*), moong and vegetables. The main rabi crops include wheat (*Triticum aestivum*), gram (*Cicer arietinum*) and oilseeds. Barley (*Hordeum vulgare*), rabi pulses and vegetables are minor ones.

Soil sampling and analysis: For detailed soil survey, the topographic maps of India (1:50000) and aerial photographs were used for site selection and profile excavation. Based on geomorphic-soil relationship, eight profiles were exposed and studied. The pedons were numbered from P1 to P8. Morphological characteristics, such as different horizons, depth, soil colour, texture were demarcated in each pedon in the field, and soil profile description was done in compliance with guidelines given by FAO (1993). Horizon-wise sampling was done and in total 39 samples were collected from different horizons of 8 pedons. The collected samples were dried, ground, sieved and analysed by standard procedures. Particle size distribution, particle density (PD) and bulk density (BD) of the soils were determined by the International Pipette method (Piper, 1950), pycnometer method (Means and Parcher, 1963) and core method (Blake 1965), respectively. Porosity was calculated from particle density and bulk density by the following equation:

$$\text{Porosity} = 1 - \left(\frac{\text{Bulk density}}{\text{Particle density}}\right)$$

Moisture retention capacity of soils at 0.03 and 1.5 Mpa was determined with Richard's pressure plate apparatus (Bruce and Luxmoore, 1986). Soil pH was measured with glass electrode using soil suspension of 1:2 (soil: water) and electrical conductivity (ECe) in same supernatant. Cation exchange capacity (CEC) was determined by neutral normal ammonium acetate extraction (Jackson, 1973). Organic carbon (OC), available N, P, K and S were determined by wet-oxidation method of Walkley and Black (1934), alkaline permanganate method (Subaiah and Asija, 1956), using 0.5M $NaHCO_3$ (Olsen *et al.,* 1954), flame photometer (Jackson, 1973) and 0.15% $CaCl_2$ method (Black, 1965), respectively. Calcium carbonate in soil samples was estimated by rapid titration method (Puri, 1949). Exchangeable Ca and Mg were also determined in neutral normal ammonium acetate extract by Versanate titration method (Cheng and Bray, 1951). Ten gram of soil (2 mm sieved) was used for extracting Zn, Cu, Mn and Fe with 20 ml of diethylenetriamine pentaacetic acid (DTPA) extractant

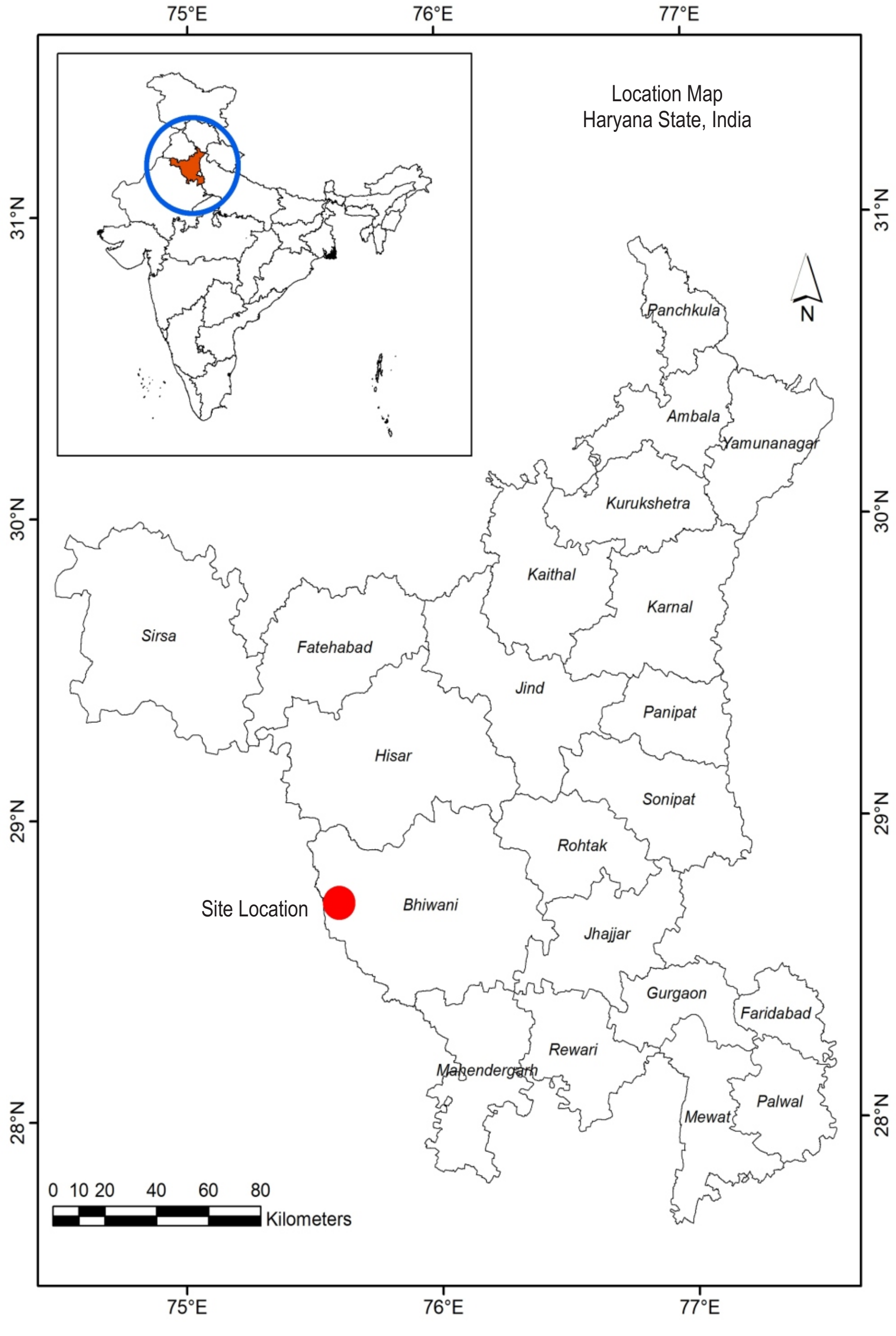

Fig. 1: Location map of the study area.

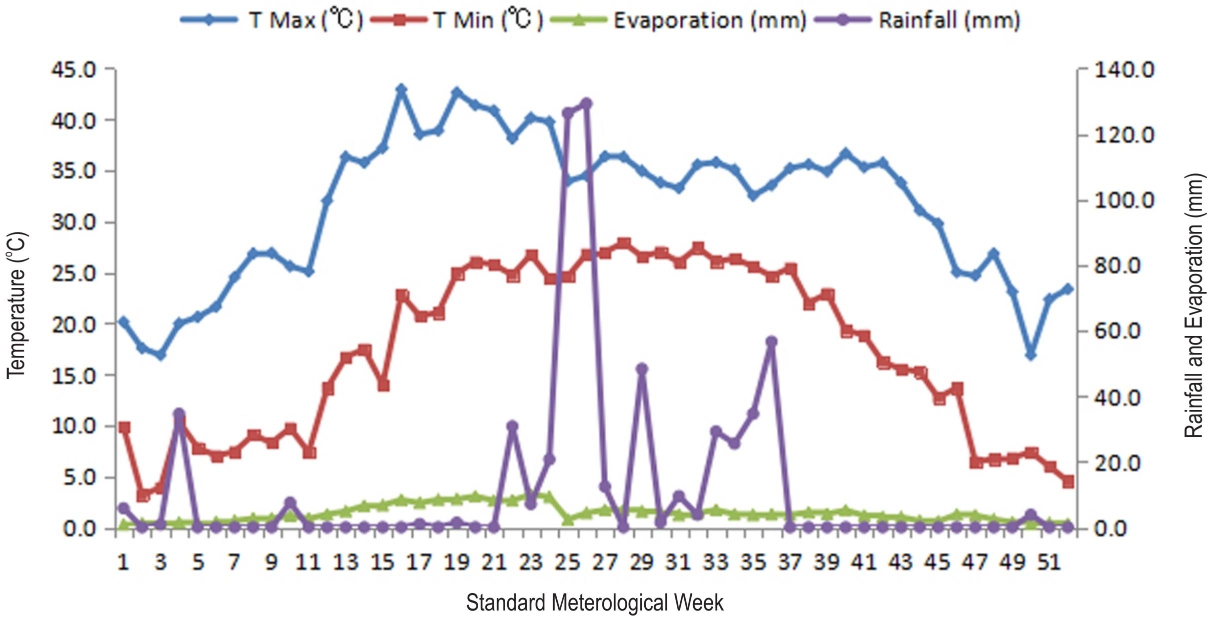

Fig. 2: Weekly weather data of the study area (2017).

(0.005M DTPA + 0.01 M $CaCl_2$ + 0.1 M triethanolamine, adjusted to pH 7.3) using atomic absorption spectrometer (Lindsay and Norvell, 1978). The weighed means were computed to match the data for each geomorphic unit by the following formula:

$$\text{Weighted mean (wm)} = \frac{\text{Concentration of each horizon} \times \text{Depth of each horizon}}{\text{Total depth of the profile}}$$

Land capability classification (LCC), irrigability classification and soil suitability evaluation for growing crops were carried out following the guidelines given by Framework of Land Evaluation (FAO, 1993; Sehgal, 1999). The criteria followed for sub classes were based on limitation operating on the land such as risk of erosion and runoff (e), wetness (w), slope (l), landform/ topography (t), physical characteristics (s) and chemical characteristics and fertility status (f). Irrigability classification is useful in grouping soils according to their suitability for sustained use of irrigation. In terms of degree of soil limitations, the classes were defined. Soil suitability classification for crops refers to the fitness of a given type of soil for different type of crops (Table 1). For this, the soils were evaluated for different agricultural crops, vegetable crops, forest and horticultural plantation. The criteria of land use requirement for different agricultural crops were used considering the various soil parameters, *i.e.,* texture, drainage, slope, available water holding capacity, salinity and alkalinity, erosion and soil fertility etc.

Statistical analysis: The PCA of data was carried by SPSS version 17.0 software (SSPS Inc., Chicago, IL, USA).

Results and Discussion

Soil-site characteristics: The description of study area with respect to location, physiography, geology, relief, climate, drainage and present land use have a great significance in any pedogenic investigation not only from categorization point of view but also for the interpretation of observed data. The general characteristics of studied pedons are presented in Table 2. Pedon P1, P2, P6, P7 and P8 were gently undulating aeolian plains with moderate to imperfect drainage. Pedon P3 and P4 were stabilized sand dune with slight to moderate erosion, moderate drainage and less profile development, while pedon P5 was nearly levelled plain with slight erosion and moderately well drained.

Physical properties: The physical properties of soil of studied pedons are presented in Table 3. The results revealed that when all the pedons were considered, sand content varied from 81.10-97.05% with lowest wm (86.22%) in P2 and highest (96.02%) in P4. Silt content ranged from 0.35-14.45% with lowest wm (1.83%) in P4 and highest (7.59%) in P3. The clay content varied from 1.05-10.50% with lowest wm (2.02%) in P6 and highest (6.49%) in P2. Sand constituted the majority of mechanical fractions that could be attributed to dominance of physical weathering and siliceous nature of parent material. The subsurface horizons of pedons generally held more clay and silt than the surface horizons due to their translocation and accumulation. Tripathi *et al.* (2006) observed sub-surface horizons showing a greater clay content than surface horizons, illuviation occurring during soil development could be responsible for that. Compared to sand fractions, the low silt and clay content in these areas was due to aeolian activity owing to their location near Rajasthan desert

Table 1: Land suitability categories (Olaniyi *et al.,* 2015)

Code	Class	Description
S1	Highly suitable	Land having no significant limitation for agricultural productivity
S2	Moderately suitable	Land having some limitations that are severe for sustained productivity
S3	Marginally suitable	Land with major limitations for sustained agricultural productivity
N	Unsuitable	Land with extreme limitations for sustained agricultural productivity

Table 2: General soil-site characteristics

Soil- site characteristics	P1	P2	P3	P4	P5	P6	P7	P8
Physiography	Aeolian Plain	Aeolian Plain	Sand dune stabilized	Sand dune stabilized	Nearly Level Plain	Sand dune stabilized	Gently Undulating Plain	Sand dune stabilized
Drainage	Well	Well	Mod	Mod. well	Mod. well	Mod. well	Imperfect	Well
Erosion	e2	e2	e1	e2	e1	e2	e2	e1
Parent Material	Aeolian	Aeolian	Aeolian	Aeolian	Fluvio Aeolian	Aeolian	Fluvio Aeolian	Aeolian
Slope (%)	1-3	1-3	0-1	1-3	0-1	1-3	1-3	1-3
Slope Direction	E-W	E-W	E-W	E-W	N-S	N-S	N-S	N-S

Erosion (No erosion-e0, Slight-e1, Moderate-e2, Severe-e3, V. severe-e4); Slope Direction (E-east, W-west, N-north, S-south)

Table 3: Range and weighted mean of physical properties

Pedon	Statistical parameter	Sand	Silt	Clay	BD	PD	Pore space	Moisture retention		AW
								0.3bar	15 bar	
P1	Range	88.80-92.15	1.85-8.80	2.40-7.90	1.34-1.54	2.54-2.61	39.37-47.96	11.60-12.99	6.20-6.60	5.40-6.39
	Wm	89.96	4.62	5.42	1.47	2.56	42.67	12.20	6.39	5.81
P2	Range	81.10-93.90	3.80-10.40	2.30-10.50	1.40-1.59	2.56-2.62	38.37-46.56	14.61-16.58	6.20-6.95	8.38-9.87
	Wm	86.22	7.29	6.49	1.52	2.58	40.95	16.10	6.57	9.35
P3	Range	82.55-93.85	0.35-13.35	4.10-6.15	1.40-1.58	2.47-2.60	36.29-46.15	8.80-13.64	4.07-4.53	4.62-9.51
	Wm	86.86	7.59	5.55	1.48	2.53	41.41	12.34	4.24	8.10
P4	Range	92.70-97.05	1.05-3.70	1.90-3.60	1.51-1.62	2.54-2.59	36.22-41.86	6.29-6.78	3.11-3.67	2.68-3.20
	Wm	96.02	1.83	2.15	1.56	2.57	39.18	6.40	3.57	2.83
P5	Range	81.65-94.20	1.90-14.45	2.00-3.90	1.41-1.57	2.49-2.64	36.95-46.59	9.32-12.71	3.61-9.11	2.68-9.10
	Wm	87.21	9.98	2.81	1.51	2.53	40.28	11.98	5.57	6.41
P6	Range	93.25-94.55	3.25-5.65	1.05-2.90	1.38-1.60	2.49-2.59	35.74-46.72	5.79-7.56	3.70-5.41	2.04-3.45
	Wm	93.90	4.09	2.02	1.53	2.55	39.96	6.99	4.81	2.18
P7	Range	89.90-93.20	4.90-6.30	1.60-5.20	1.44-1.54	2.47-2.63	37.65-44.11	7.91-8.24	3.93-4.57	3.61-4.12
	Wm	90.90	5.78	3.31	1.49	2.51	40.63	8.15	4.23	3.91
P8	Range	81.80-95.04	1.80-8.70	3.16-9.50	1.38-1.61	2.45-2.61	34.29-46.97	14.70-18.80	3.90-7.84	8.67-13.78
	Wm	88.93	5.06	6.01	1.50	2.52	40.35	16.76	5.71	11.05

areas (Ahuja *et al.,* 1997). The BD of the studied pedons ranged from 1.34 – 1.62 mg m^{-3} with lowest wm (1.47 mg m^{-3}) in P1 and highest (1.56 mg m^{-3}) in P4 and exhibited increasing trend with depth. This might be attributed to progressive compaction due to aluvial material filling, lower organic matter (OM) and less aggregation (Kharlyngdoh *et al.,* 2015; Mustafa *et al.,* 2016). Dinesh *et al.* (2017) also reported that an increase in BD down the profile is because of low OM and compaction of soil aggregates. The PD and total porosity ranged from 2.45-2.64 mg m^{-3} and 34.29-47.96%, respectively and showed no specific trend with depth. Water retention at field capacity (0.3 bar) and permanent wilting point (15 bar) across all the pedons varied from 5.79-18.80% and 3.11-9.11%, respectively. As the study area is broadly sandy in texture the available water (AW) content was low ranging between 2.04-13.78% with lowest wm (2.18%) in P6 and highest (11.05%) in P8 because water is retained in the soil by capillary and adsorptive forces which is mainly a function of clay and mineralogy (Dinesh *et al.,* 2017).

Chemical properties: The chemical properties of studied pedons are presented in Table 4. The soils of the studied pedons were neutral to alkaline (pH 6.87-9.10) in reaction. The highest

Table 4: Range and weighted mean of chemical properties

Pedon	Statistical parameter	EC	pH	$CaCO_3$	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	CEC	BSP	ESP
P1	Range	0.03-0.24	6.87-7.28	0.00-0.00	2.19-3.00	1.69-1.94	0.25-0.43	0.24-0.42	4.89-6.09	91.34-94.41	5.11-7.53
	Wm	0.1	7.11	0	2.64	1.79	0.32	0.36	5.52	92.53	5.71
P2	Range	0.04-0.05	7.50-7.78	0.00-1.93	3.20-5.10	0.60-1.72	0.37-0.57	0.18-0.33	4.81-7.85	92.31-95.27	5.51-11.18
	Wm	0.04	7.62	0.29	4.03	1.11	0.46	0.26	6.22	94.11	7.71
P3	Range	0.04-0.09	7.49-7.73	0.00-7.60	3.10-3.90	0.50-1.04	0.35-0.57	0.16-0.23	5.31-5.72	90.26-96.97	6.15-10.73
	Wm	0.06	7.59	1.3	3.72	0.86	0.42	0.21	5.61	92.74	7.48
P4	Range	0.02-0.05	7.33-7.61	0.00-0.00	2.90-3.70	0.20-0.50	0.24-0.39	0.16-0.19	3.82-4.86	93.98-98.57	6.17-8.54
	Wm	0.02	7.45	0	3.15	0.3	0.3	0.17	4.03	97.52	7.44
P5	Range	0.03-0.61	8.40-9.10	0.23-7.53	1.10-1.70	1.90-2.90	0.23-0.61	0.11-0.25	3.89-5.09	87.36-95.15	5.91-11.98
	Wm	0.26	8.82	4.7	1.48	2.27	0.37	0.16	4.69	91.5	7.83
P6	Range	0.05-0.20	7.50-8.70	0.00-0.45	1.10-2.70	0.50-1.10	0.19-0.45	0.08-0.21	2.21-4.10	92.20-97.55	4.88-11.48
	Wm	0.1	8.2	0.05	2.27	0.78	0.34	0.13	3.7	94.97	9.14
P7	Range	0.02-0.03	7.30-7.80	0.00-0.00	2.90-4.30	0.20-0.60	0.23-0.45	0.09-0.14	3.84-5.56	90.61-97.62	5.99-8.09
	Wm	0.02	7.42	0	3.73	0.44	0.33	0.1	4.82	95.53	6.73
P8	Range	0.06-0.21	7.80-8.50	0.00-11.73	2.90-4.70	0.60-2.00	0.12-0.31	0.08-0.34	4.79-7.32	89.84-98.08	2.17-6.47
	Wm	0.17	8.36	6.12	3.92	1.39	0.22	0.12	5.95	94.87	3.89

Table 5: Range and weighted mean of fertility parameters

Pedon	Statistical parameter	OC	N	P	K	S	Fe	Mn	Cu	Zn
P1	Range	0.08-0.22	102.00-154.00	4.20-12.01	191.00-326.50	5.60-13.40	4.28-6.70	2.29-4.72	0.51-0.72	0.41-0.92
	Wm	0.14	127.71	8.28	280.91	8.18	5.20	3.67	0.57	0.67
P2	Range	0.10-0.27	77.00-189.00	6.80-14.40	138.50-258.50	4.10-11.50	1.59-6.49	2.68-4.99	0.27-0.57	0.24-0.65
	Wm	0.16	114.61	10.44	201.56	7.01	3.14	3.38	0.43	0.41
P3	Range	0.12-0.27	93.00-157.00	9.20-17.10	125.50-177.50	1.10-7.80	0.87-1.08	1.35-2.84	0.23-0.58	0.30-0.44
	Wm	0.21	131.42	13.70	163.58	3.32	0.94	2.42	0.33	0.35
P4	Range	0.10-0.27	87.00-148.00	9.40-15.00	125.50-151.50	2.10-13.40	1.19-1.40	1.98-2.77	0.16-0.29	0.21-0.37
	Wm	0.19	116.44	12.61	134.26	7.46	1.32	2.29	0.24	0.29
P5	Range	0.08-0.21	82.00-151.00	6.10-16.20	86.30-192.50	1.20-11.20	0.94-1.96	1.59-2.62	0.21-0.28	0.18-0.40
	Wm	0.13	102.64	10.68	126.17	4.15	1.21	2.29	0.24	0.31
P6	Range	0.06-0.27	88.00-156.00	7.40-16.50	62.20-167.50	5.50-19.20	1.14-1.86	1.50-2.76	0.13-0.24	0.15-0.35
	Wm	0.14	108.41	11.22	99.95	9.17	1.52	2.07	0.16	0.26
P7	Range	0.10-0.22	80.00-126.00	7.18-14.70	68.70-110.90	3.60-9.60	0.97-1.14	1.03-2.06	0.13-0.20	0.16-0.27
	Wm	0.15	95.59	9.67	80.99	6.08	1.03	1.38	0.18	0.24
P8	Range	0.06-0.19	42.00-112.00	5.70-16.20	62.50-261.30	0.40-7.80	0.91-1.43	1.20-2.00	0.13-0.47	0.15-0.28
	Wm	0.1	66.60	9.30	92.75	1.98	1.21	1.63	0.27	0.21

wm of pH was recorded in P5 and lowest in P1. The higher pH values could be attributed to high base saturation and exchangeable sodium percentage (ESP) (Mustafa *et al.,* 2016). EC revealed that all the soils were low in soluble salt content (0.02-0.21dS m^{-1}) which might be due to light texture of soils (Sahoo *et al.,* 2019). Calcium carbonate varied from traces to 11.73% across all the pedons. Concretions of $CaCO_3$ were absent in pedons P1, P4 and P8 but increased patterns with depth were observed in pedons P2, P3, P5, P6 and P7. Calcium carbonate may be formed *in situ* due to the calcification process under aridic climatic conditions (Sahoo *et al.,* 2019). In sand dunal toposequences of Haryana, Ahuja *et al.* (1997) also reported in situ formation of $CaCO_3$. Calcium (Ca^{2+}) was dominant cation in all pedons and varied from 1.10-5.10 cmol (p^+) kg^{-1} followed by Mg^{2+} 0.20-2.90 cmol (p^+) kg^{-1}, Na^+ 0.12-0.57 cmol (p^+) kg^{-1} and K^+ 0.08-0.42 cmol (p^+) kg^{-1}. The CEC was low and ranged from 2.21-7.85 cmol (p^+) kg^{-1} across all the pedons, which could be ascribed to the sandy texture and low OC content. Base saturation percentage (BSP) varied from 87.36-98.57% suggesting that bases overwhelmed the exchangeable complex. Exchangeable sodium percentage (ESP) varied from 2.17-11.98 indicating that soils were non-sodic (ESP<15) in nature.

Fertility status: The fertility parameters of soil of the studied pedons are presented in Table 5. Soils were low in OC content and varied from 0.06-0.27%, which might be assigned, to aridic

Table 6: Land capability classification and Soil suitability classification for irrigation

Pedon	Land form/ topography (t)		Wetness (w)	Physical characteristics (s)			Chemical characteristics and fertility status (f)				LCC	Suitability for irrigation
	Slope	Erosion	Drainage	Texture	PD	Depth	EC	OC	CEC	BS		
P1	II	III	I	III	III	I	I	V	IV	II	IIItsf	S3s
P2	II	III	I	III	III	I	I	V	IV	II	IIItsf	S3s
P3	I	II	II	III	III	I	I	V	IV	II	IIsf	S3s
P4	II	III	II	III	III	I	I	V	IV	II	IIItsf	N1s
P5	I	II	II	III	III	I	I	V	IV	II	IIsf	S3s
P6	II	III	II	III	III	I	I	V	IV	II	IIItsf	N1s
P7	II	III	III	III	IV	I	I	V	IV	II	IIItsf	S3s
P8	II	IV	I	III	III	I	I	V	IV	II	IIItsf	N1s

Note: PD (Profile development)

Table 7: Soil suitability classification for crops

Soil units	Soil Suitability Classes							
	Cotton	Wheat	*Guar*	Pearl millet	Gram	Oilseed (Raya)	Vegetable	Forestry
P1	S3	S3	S1/S2	S2/S3	S2/S3	S1/S2	N	S2/S3
P2	S3	S3	S1/S2	S2/S3	S2/S3	S1/S2	N	S2/S3
P3	S3	S3	S1	S1/S2	S1/S2	S1	N	S2/S3
P4	S3	S3	S1/S2	S2	S2	S1/S2	N	S2/S3
P5	S3	S1/S3	S1/S2	S1/S2	S1/S2	S1/S2	N	S2/S3
P6	S3	S3	S1/S2	S1/S2	S1/S2	S1/S2	N	S2/S3
P7	S3	S3	S1/S2	S2/S3	S2/S3	S1/S2	N	S2/S3
P8	N	S3	S1/S2	S2/S3	S2/S3	S1/S2	N	S2/S3

moisture regime, hyperthermic temperature regime, low precipitation and poor vegetation. Dinesh *et al.* (2017) also reported low OC content in soils on different geomorphic units of north-eastern Haryana. Available N was low, ranged from 42.00-189.00 kg ha^{-1} with highest wm in P1, and lowest in P8. However, available N content was higher in surface horizon and decreased gradually down the profile that might be due to prevailing high temperature and decreasing trend of OC with depth (Dinesh *et al.,* 2020). Available P was low to medium across all the pedons and varied between 4.20-17.10 kg ha^{-1}.

Higher content was found in the surface horizons and decreased periodically with depth which could be due to the anion replacement of $H_2PO_4^-$ on adsorption sites of organic matter thereby increasing the mineralization of organic P to inorganic P (Bhat *et al.,* 2017) besides the confinement of crop cultivation to the rhizosphere and supplementation of depleted P through external sources, *i.e.,* fertilizers (Sharma *et al.,* 2008). Available K was low to high and varied between 62.20-326.50 kg ha^{-1}. Irregular trend down the profile was observed in the K content across all the pedons due to the presence of K bearing minerals like feldspars, illite, mica in clay and silt fractions (Reza *et al.,* 2014) and also due to upward translocation of K from lower depths along with the capillary rise of groundwater, release of labile K from organic residues, more intense weathering and application of K-fertilizers. Available S was low to high and ranged from 0.40-19.20 kg ha^{-1} across all the pedons. Sulphur exhibited a decreasing trend down the profile, which could be adduced to higher organic carbon content in surface horizons (Paul and Mukhopadhyay, 2015). The DTPA extractable Fe, Zn, Mn and Cu contents across all the pedons varied from 0.87-6.70, 0.15-0.92, 1.03-4.99 and 0.13-0.72 mg kg^{-1}, respectively. Sahoo *et al.* (2020) discussed the detailed information on the distribution of micronutrients. Considering the critical limits for DTPA extractable micronutrients, it could be inferred that soils of the study area are, by and large, deficient in Fe and Zn, marginal to sufficient in Mn and sufficient in Cu. No consistent distribution pattern was observed down the profile in all the pedons.

Land evaluation: Land evaluation is a multi-disciplinary approach. Land suitability is assessed and classified with respect to the specified type of use during land evaluation. The suitable qualitative land evaluation procedures for the conservation of land resources include LCC, Soil Suitability Classification for irrigation and crops.

Land Capability Classification: The results (Table 6) indicated that the soils were classified as IIsf and IIItsf according to LCC due to limitations. Soils of pedons P1, P2, P4, P6, P7 and P8 were kept under LCC subclass IIItsf due to erosion problems, less profile development, limitations of texture, OC, base saturation,

Table 8: Principal component analysis of soil parameters

Parameter		PC1	PC2	PC3	PC4	PC5	Pc6
Sand		0.177	-0.115	-0.574	-0.75	0.1	-0.082
Silt		-0.115	-0.015	0.176	0.914	-0.021	0.076
Clay		-0.175	0.247	0.859	0.092	0.033	0.046
Bulk density		-0.867	-0.129	-0.025	-0.004	-0.18	0.257
Particle density		0.785	0.24	-0.015	-0.25	0.116	0.06
Pore space		0.921	0.179	0.016	-0.075	0.173	-0.181
Percent moisture retention	0.3 bar	-0.064	0.12	0.799	0.273	0.302	-0.138
	15 bar	0.1	0.41	0.473	-0.208	0.564	0.191
Available water		-0.12	-0.019	0.766	0.409	0.14	-0.25
EC		-0.314	-0.129	-0.178	0.509	0.497	-0.419
pH		-0.23	-0.658	0.002	0.023	0.614	0.074
$CaCO_3$		-0.402	-0.308	0.237	0.408	0.198	-0.39
OC		0.889	0.073	-0.196	-0.035	-0.266	-0.045
N		0.764	0.314	-0.304	-0.003	-0.086	0.197
P		0.828	-0.271	-0.191	-0.07	-0.149	0.138
K		0.379	0.801	0.057	0.105	0.032	0.005
Ca^{2+}		-0.249	-0.038	0.738	-0.213	-0.553	-0.104
Mg^{2+}		0.079	0.24	0.242	0.328	0.769	0.007
Na^{+}		-0.149	0.065	0.125	0.169	0.056	0.918
K^{+}		0.379	0.801	0.057	0.105	0.032	0.005
CEC		-0.174	0.233	0.905	0.14	0.044	0.029
BSP		0.057	-0.193	-0.09	-0.707	-0.269	-0.141
ESP		-0.038	-0.129	-0.426	0.051	0.064	0.84
S		0.695	0.277	-0.438	-0.219	-0.028	-0.041
Fe		0.121	0.853	-0.056	-0.053	0.192	-0.103
Mn		0.009	0.794	0.1	0.284	-0.02	0.108
Cu		-0.022	0.776	0.285	-0.136	0.092	-0.168
Zn		-0.028	0.721	0.216	-0.027	0.005	0.183
Eigenvalues		7.684	6.513	2.803	2.635	1.897	1.596
Variance (%)		27.444	23.26	10.012	9.411	6.775	5.701
Cumulative variance (%)		27.444	50.704	60.716	70.128	76.902	82.603

CEC and low fertility status. Soils of pedons P3 and P5 were placed in LCC subclass IIsf due to major limitations of texture, organic carbon, base saturation, CEC and overall low soil fertility. Proper soil management and diversification of crops can decrease the risk of crop failures caused by such limitations. Devi and Naidu (2016) classified the sugarcane soils of Chittoor, A.P. into land capability sub-class IVs due to major limitations of texture, OC, base saturation and CEC; IVes having limitations of slope erosion, texture, base saturation, and OC; Vs because of the limitations of texture, CEC, base saturation and OC and VIes which had limitations of slope, erosion, shallow depth, coarse texture, CEC and OC.

Soil suitability classification for Irrigation: Assessment of irrigability potential of an area is the basic need for watershed management. The results presented in Table 6 inferred that pedons P1, P2, P3, P5 and P7 were marginally suitable for surface irrigations having limitations of soils while that of pedons P4, P6, P8 were unsuitable under flood irrigation due to light texture and undulating topography and are best suited for sprinkler irrigation. The results are in conformity with those of Nagaraju *et al.* (2014) who classified the soils of Ahmednagar Command area into 2d, 3st and 4st land irrigability sub-classes.

Soil suitability classification for crops: The soil suitability classes for different crops are presented in Table 7. Soils of pedons P1 and P2 were suitable for cluster bean (*guar*), oilseed (raya) and moderately to marginally suitable for gram, pearl millet, cotton and forestry. The soils of pedons P3 and P4 were placed in suitable class for cluster bean (*guar*), oilseeds, gram and moderately to marginally suitable for pearl millet, cotton and wheat. The soils of pedons P5 and P7 were also found suitable to moderately suitable for cluster bean (*guar*), oilseeds and pearl millet and marginally suitable for cotton cultivation. Soils of pedons P6 and P8 were put in suitable to moderately suitable category for cluster bean (*guar*) and oilseeds crops whereas, marginally suitable for gram, pearl millet and wheat. However, low fertility status along with landform and physical characteristics were main limitations that make these soils unsuitable (N) for vegetable crops. Nasre *et al.* (2013) evaluated the soils at series level and observed that the soils in the upper physiographic units were extremely poor to poor in soil productivity with marginal to moderate suitability for major crops while as, soils of plains were good in productivity and moderately to highly suitable for major crops.

Principal component analysis: The PCA limits the variables and extracts smaller number of independent factors (principal components) for predicting the association among observed variables. PCA was done using varimax rotation with Kaiser Normalization as orthogonal rotation minimizes the number of variables with a high loading on each component facilitating the interpretation of PCA results. The principal components with eigenvalues greater than 1, which explained at least 5% of total variance, were retained for interpretation.

Six principal components (PC1, PC2, PC3, PC4, PC5 and PC6) with eigenvalues greater than 1 were extracted (Table 8). PCA led to reduction of initial dimension of the dataset to six components, which explains 82.6% of the total dataset variance. PC1 is the most important component and explains 27.4% of total variance having a strong positive loading of particle density, pore space, organic carbon, N, P and S whereas negative loading of bulk density thereby can be defined as the organic matter component because most of these properties are influenced by OC. This implies that increase in organic matter will have positive impact on these properties. PC2 has positive loading of K, K^+, Fe, Mn, Cu and Zn and accounts for 23.3% of the total variance thereby represents lithogenic factor indicating that these parameters are governed by parent material. PC3 exhibited positive loadings of clay, moisture retention at 0.3 bar, available water, Ca^{2+} and CEC, and explained 10% of the total variance. This component seems to be influenced by clay content because water retention characteristics and cation exchange capacity are strongly linked with clay content (Dinesh *et al.,* 2017).

The positive loading of Ca^{2+} and CEC might be ascribed to the fact that Ca^{2+} is derived from the parent material (Khaledian *et al.,* 2016), therefore, it is presumed that Ca^{2+} will dominate cation exchange sites (Murphy, 2014). The PC4 showed positive loading for silt, EC and $CaCO_3$ and negative loading of sand and base saturation which could be due to geochemical weathering. This component accounted for 9.4% of the total variance. The PC5 exhibited positive loadings of moisture retention at 15 bar, pH and Mg^{2+} and explained 6.8% of total variance. The positive loading of Mg^{2+} and pH could be adduced to the drier climate, which prevents leaching of Mg^{2+} and increases its availability in the soil. PC6 showed positive loading Na^+ and ESP and explained 5.7% of total variance. This component can be described as sodicity factor since high pH is associated with high exchangeable sodium percentage levels. It also indicates the translocation of Na^+ in the pedons. Principal component loadings describe the amount of variance of a given variable accounted by principal components (Lattin *et al.,* 2003; Dinesh *et al.,* 2020).

Even though these PC factors did not describe the total variation of the whole set of the variables but is considered as realistic dimension reduction method as PC factors can be properly construed. The results of physico-chemical properties of the studied pedons revealed that the soils were very deep, well to imperfectly drained due to topographic variation, neutral to alkaline in soil reaction and non-saline as well as low in organic matter content. The soils were low in available N, low to medium in available P, low to high in available K and low in available S. In addition, these soils were deficient in extractable Fe and Zn but marginal to sufficient in Mn and Cu content. Soil suitability for various crops revealed that soils were suitable (S1) to moderately suitable (S2) for *guar*, oilseed (*raya*), moderately (S2) to marginally suitable (S3) for pearl millet, gram, forestry and marginally suitable (S3) for cotton and wheat. However, these soils were not suitable for vegetables because of the various edaphic constraints. Erosion concerns, less profile development, texture, OC, base saturation, CEC and overall low soil fertility are the main limiting factors as evident from soil and landform suitability assessment. Applicable measures such as soil and water conservation, integrated nutrient management, use of micro irrigation methods and improved agricultural practices may improve the contemporary soil suitability issues of the study area. PCA reduced eighteen variables into six principal components and described 82.6% of the original variance.

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Add-on Information

Authors' contribution: J. Sahoo: Conducting study, data collection, analyses; **Dinesh:** Planning and guidance in research; **A. Dass:** Writing and editing of manuscript; **M.A. Bhat:** Data tabulation, literature collection; **H.S. Gouda:** Preparing figures and tables for manuscript; **Anurag:** Identification of data points using remote sensing, preparing map.

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