Current and Potential Soil Suitability of Pearl Millet, Wheat and Mustard for Sustainable Production in Aravalli Foothills of Mewat Region of Haryana, India

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A B S T R A C T

Buraka micro-watershed was delineated into seven land management units (LMUs) to evaluate current and potential soil suitability of pearl millet, wheat and mustard crops for sustainable production. Current and potential soil suitability of pearl millet, wheat and mustard revealed that soils of LMU1 found to be permanently not suitable (N2) for cultivation of these crops due to severe soil constraints while soils of LMU5 due to less to very less constraints found to be highly suitable (S1) for pearl millet and mustard, and moderately suitable (S2) for wheat. Current soil suitability revealed that each pearl millet and mustard occupied 17 percent area under highly suitable class (S1) while no area qualified to be S1 for wheat cultivation. However, potential soil suitability registered significant increase in class S1 areas of pearl millet and mustard to 38.1 and 45.0%, respectively. Unlike pearl millet and mustard crops, wheat recorded improvement in area within class S2 to 69.7% due to removal of correctable limitations through scientific management and cultivation practices. Current and potential soil suitability evaluation of crops offer great choice to the farmers for crops cultivation in areas where soils are suitable besides, it also helps to suggest the management options for improving the soil related constraints. Thus, soil suitability evaluation helps in ensuring sustainable crop production and increased land use efficiency, and also enables the policy planners to develop suitable strategies for cultivation of particular crop in the particular areas.

Introduction

Land is one of the scarce natural resources essential for survival and growth of any civilization due to its role in food security and economic development. However, in the recent years land degradation perceived to be a major environmental threat globally, and in India alone it affects about 121 m ha land (Maji *et al.,* 2010). Soil degradation (Panagos *et al.,* 2015), waterlogging (Singh, 2016), salinization/alkalization (Velmurugan *et al.,* 2016), and contamination (Sam *et al.,* 2016; Chartzoulakis and Bertaki, 2015) are some of the serious environmental problems arise as a consequence of agricultural activities. Such degradations make it unsuitable for agricultural production (Verheye, 2008), and

if such deteriorating environment increases continuously, it may pose serious threat to food security (Gomiero, 2016; Abd-Elmabod, 2019). Increasing land degradation scenario calls for effective utilization of land resources *i.e.,* according to their suitability so as to achieve sustainable agricultural production (FAO 1976; Elaalem *et al.,* 2010). In this regard, land evaluation strategy seems to be the effective tool both for sustainable agriculture as well as sustainable land use planning (Shahbazi *et al.,* 2009; Perveen *et al.,* 2012). Its main objective is to improve and manage the land resources in a sustainable way so as to increase its potential for human uses (Rossiter 1996; FAO, 2007), and also helps in determining the potential of land for agricultural purposes (FAO 2007; Ananya-Romero *et al.,* 2015). It also provides information about major constraints and opportunities for a specific purpose and guides decision-makers for ensuring optimal land utilization.

Since, land suitability is a function of crop requirements and land characteristics, and a measure of how well the qualities of land unit match the requirements of a particular land use (FAO, 1976). Its assessment requires knowledge about nature of soils, their characteristics, and extent of distribution, qualities, productivity potential and suitability for optimum utilization. Its status is based on intrinsic properties of soils *viz.,* parent materials, soil texture and depth, and characteristics that can be altered by human management like drainage, salinity, nutrient concentration and vegetation cover (FAO, 1985; FAO, 1993). Moreover, agriculture land suitability evaluation predicts the potentials and limitations of land for crop production (Pan and Pan, 2012). Thus, to predict the potentials and limitations of land construction of matching tables or transfer functions are required to calculate the suitability class (FAO, 1976). However, in

most parts of the world crops are being grown irrespective of their suitability for a particular area therefore, it need to be evaluated for every parcel of land so as to ensure sustainable crop production, agriculture development and future planning. During this exercise lots of spatial information is generated that requires to be managed in more realistic way. Thus, in this context, use of sophisticated technologies such as Geographic Information Systems (GIS) holds great promise to enables decision makers to manage and understand the spatial data (Bagherzadeh and Mansouri Daneshvar, 2011).

Keeping land and soil related issues and crop production aspects at the centre soil suitability have been evaluated for cultivation in Buraka micro-watershed area, where cultivation is practiced without assessing soil suitability (based on soil/land qualities, characteristics and crop requirements), and also no scientific research carried out aiming usage of potential soil suitability to overcome these limitations. Pearl millet, wheat and mustard are the dominant crops in the micro-watershed, and holds paramount importance in food and livelihood security in the study area but faces lot of difficulties in meeting these targets due to their cultivation on moderately and marginally suitable areas, and under low to poor management conditions. Such constraints are responsible for low productivity of these crops compare to state as well as national average. In the study area, pearl millet and wheat are important for food and fodder security while mustard holds special significance as cooking oil and fuel in several rural households besides, being cash crop. Soil related constraints, delineation of suitable areas for cultivation, and low productivity are the biggest issues and challenges before scientific community. Therefore, it is imperative to evaluate the soil suitability of crops for sustainable crop

production, and to achieve the improved inputs and land use efficiencies. Besides, soil suitability estimates enables the decision makers and policy planners to formulate effective policies for holistic development of the area. The above facts indicates that soil suitability evaluation provides sound basis for agriculture development and future planning, and thus, holds prominence in managing the natural resources especially the land/soils for their sustainable utilization under changing land use scenario.

Materials and Methods

Study locale

The study was carried out during 2017 and 2018 for sustainable agricultural land use planning in the economically backward Buraka micro-watershed area, located in the ecologically sensitive Aravalli foothills of Mewat Region of Haryana, India (Fig.1). The micro-watershed with its total area of 542.4 ha situated between $28^o10'00''$ to $28^o11'56''$ N latitudes and $76^o57'15''$ to $76^o59'30''$ E longitudes. Climate is semiarid, continental and monsoon type. Mean minimum and maximum temperature is 18.7^oC and 32.2^oC, respectively, and mean annual rainfall is 574 mm. Micro-watershed is drained by a *nalah* (network of seasonal streams) originated from the adjoining Aravalli hill outcrops. Elevation ranges from 259 to 340 m above mean sea level with slope direction from south-east towards north-west. The soils developed from local alluvium and colluvium parent materials while some hilly soils in the eastern parts developed from weathered quartzite/ sandstone. The area falls under agro-ecological sub-regions 4.1, characterized by hot semi-arid climate with 90-120 days length of growing period (LGP). However, micro-watershed has assured irrigation with good quality underground water due to being located adjacent to foothills of Aravalli

ranges. Pearl millet-wheat and pearl millet-mustard cropping systems are dominant systems whereas other crops including vegetables also cultivated in the micro-watershed.

Delineation of LMUs

LMUs were delineated based on dominant soil features (depth, slope, textural class, coarse fragments, rockiness/stoniness, erosion, drainage, soil pH, soil organic carbon and available water capacity), land use/land cover (LULC), and production systems. LMU is homogeneous area for effective management of natural resources particularly the soil and land resources with particular set of treatment/management under particular condition.

Soil suitability evaluation

Soil suitability has been evaluated considering soil and site characteristic mainly rainfall and temperature. Climatic data collected from *Krishi Vigyan Kendra*, Babal, Haryana, India, and average of 5 years data (2013-14 to 2017-18) have been considered for suitability evaluation due to their important role in crop growth and development (Fig. 2). Suitability had been assessed following matching crop requirement criteria scheme proposed by Sys (1993) and modified by Naidu *et al.* (2006). Soil suitability groupings at various levels *viz.,* order *i.e.,* S (suitable) and N (not suitable), reflecting the kind of suitability followed FAO framework for land evaluation (1976). Order S was divided into 3 classes *viz.,* S1 (highly suitable), S2 (moderately suitable) and S3 (marginally suitable) while order N into 2 classes *viz.,* N1 (presently not suitable) and N2 (permanently not suitable), reflecting the degree of suitability within the order. Current soil suitability also known as actual soil suitability evaluated to know the actual area available in a particular class for

cultivating a crop under the existing soil-site regime while, potential suitability estimate the potential land availability for crop production, assuming that the existing limitations be rectified through improved land use and management practices in due course of time. Current and potential soil suitability evaluated following earlier approaches (Sys, 1991a; Sys, 1991b; Sabalia and Gundalia, 2010; Meena *et al.,* 2017).

Thematic map generation

Thematic maps were generated under Geographical Information System (GIS) environment using Arc GIS 10.3.1 to represent the area under a particular class in the entire micro-watershed however, soils suitability have been evaluated for each LMU.

Results and Discussion

Land management units (LMUs)

Buraka micro-watershed area was delineated into seven LMUs for sustainable agriculture land use planning (Fig. 3). Result revealed that LMU2, LMU3, LMU4, LMU5 and LMU6 belonged to irrigated ecosystem, and supported agriculture and allied activities while, LMU1 and LMU7 falls under rainfed ecosystems, and not suited for agricultural purpose. LMUs of irrigated ecosystem having very deep soils, nearly level to gently sloping, loamy sand to sandy loam, somewhat excessively well drained to well drained soils with slight to moderate erosion, and under the double and triple crops land use land cover. LMUs of irrigated ecosystem supported agricultural, agri-horticulture and livestock based production systems while LMUs of rainfed ecosystem mainly supported silviculture and silvi-pastoral systems (Table1). Differences in suitability of soils for various kinds of land uses mainly ascribed to soil and land related constraints. LMU5, for

example found to be suitable for agricultural and many other land uses including horticulture due to low to very low level of soil related constraints while non-suitability of LMU1 and LMU7 for agricultural purpose mainly attributed to severe soils and land related constraints. Soils related constraints in LMU1 includes very shallow, gravelly sandy loam soils, moderate stony and rockiness with coarse fragment (43.5%) and severely eroded soils, gently to strongly sloping, excessively drained nature, which mainly attributed to geology and parent material as well as variations in physiographic features *i.e.,* soils of LMU1 belongs to Aravalli hill tops. Constraints of LMU7 include its location near stream terraces, severe erosion and somewhat excessively drained soils. Our research findings are in close agreement with land and soil suitability evaluation study carried out for land unit maps (LUM) considering similar factors (Girmay *et al.,* 2018).

Parameters considered for soil suitability evaluation

Soil suitability evaluation involves soil-site characteristics and climatic parameters as important criteria to meet the requirements of crops. Thus, it is essential to consider soil physico-chemical properties such as soil texture, depth, pH, drainage, slope, organic matter content, salinity (EC) and sodicity (ESP) and many other parameters, and climatic factors particularly rainfall and temperature while evaluating the soil suitability for crops. Results revealed that soil texture ranges from gravelly sandy loam (LMU1) to sandy loam (LMU 3, LMU5 and LMU6) to loamy sand (LMU2, LMU4 and LMU7). Soils of LMU1 had slightly acidic pH (6.8) while, alkaline soil reaction in case of soils of LMU2 (soil pH 7.8) and LMU7 (soil pH 7.8). Soil fertility in terms of organic carbon was low in most of the LMUs, and it ranges from as low as 0.03% in LMU7 to as

high as 0.41% in case of LMU1. Soil salinity (expressed as EC status) was found to be within safe limit for most of the crops while, soil sodicity (ESP) was high in LMU2 (24.4%) and LMU7 (31.4%). Base saturation was high under soils of LMU4 (82.6%) while lowest in LMU5 (68.9%). Calcium carbonate was nil in case of LMU1 and LMU3 while, LMU2 and LMU7 recorded higher values compared to LMU4, LMU5 and LMU6 (Table 2). Rainfall and temperature data (average of 5 years *i.e.,* 2013-14 to 2017-18) revealed that minimum and maximum annual average temperature was $16.97^{o}C$ and $31.64^{o}C$, respectively while annual average rainfall was 637.15 mm. Gravelly sandy loam texture of soils of LMU1 could be attributed to hilly terrains of Aravalli ranges. Low salinity of the soils and water was also ascribed to the location of the micro-watershed adjacent to Aravalli foothills. Slightly acidic soil pH might be due to leaching of bases from hill tops. Alkaline pH of soils of LMU2 and LMU7 could be due to presence of $CaCO_3$.

Low organic carbon content in LMU2 and LMU7 attributed to fast decomposition and their dispersal under coarse textured soils (loamy sand). Low CEC of soils of LMU2 and LMU7 ascribed to coarser soil texture (low clay content), and thus low CEC lead to low nutrient retention capacity (low fertility of soils). However, high CEC of soils of LMU5 could be due to relatively improved textural class compared to other LMUs, and these soils have more nutrient retention capacity. Nutrient retention capacity is controlled by several factors *viz.,* organic matter and type of clay minerals (Sawhney *et al.,* 1996; Gorai *et al.,* 2013). Perveen *et al.* (2007) used soil texture, soil moisture, soil consistency, pH, organic matter content and soil drainage for agricultural land suitability analysis while, Zengin and Yilmaz (2008) used soil depth, erosion, slope, aspect, rainfall and temperature for soil suitability evaluation.

Current and potential soil suitability for sustainable crop production

Soil suitability of pearl millet

Current and potential soil suitability evaluation revealed that soils of LMU5 found to be S1for pearl millet cultivation while soils of LMU1 evaluated to be N2. Current soil suitability revealed that soils of LMU7 found to be N1 while potential suitability revealed that soils found to be class S3 (Table 3). Further, current soil suitability map revealed that class S3 occupied highest area (171.2 ha) followed by class S2 (114.5 ha) and least under class S1 (92.2 ha), which respectively constituted 31.6, 21.1 and 17.0% area of the entire micro-watershed (Fig. 4). Potential soil suitability evaluation revealed significant increase in class S1 area to 206.7 ha, which constituted 38.1% area of the micro-watershed (Fig. 5). Current soil suitability evaluation revealed that area under class N1 and N2 also occupied significant portion of the micro-watershed while, potential soil suitability evaluation indicated that class N1 areas improvised to cultivated classes due to rectification of correctable limitations. Increase in class S1area may be attributed to decline in class S3 areas and bringing into cultivation class N1 land with the improved management and scientific cultivation practices *i.e.,* by removing the correctable limitations. Girmay *et al.*, (2018) also suggested management option and the conservation measure to improve the suitability of class S3 and class N1 land units. Severe soil related constraints *viz.,* soil erosion, soil texture, stoniness and rockiness attributed to class N2 and relatively less serious limitations to class N1. Class S3 rating attributed to relatively less serious problems *i.e.,* soil erosion, drainage and fertility status besides soil texture, compared

to class N1. Contrary to this, class S1 rating for crop production may be ascribed to favourable soil physico-chemical properties such as soil texture, drainage and erosion soil pH, EC and ESP. Organic carbon was major limitation for pearl millet in most of the LMUs except soils of LMU1, LMU3 and LMU5. Major limitations in the soils of LMU1 were depth, texture, erosion and drainage as well as permeability while organic carbon and erosion in soils of LMU7. Therefore, appropriate interventions *viz.,* soil and water conservation, integrated soil fertility management, moisture conservation and water harvesting, and agronomic practices need to be adopted to enhance the current land suitability of the micro-watershed for sustainable crop production. Similar interventions were suggested in several studies from areas where this kind of limitations exists for crop production (Alemu *et al.,* 2013; Girmay *et al.,* 2018). In this study specific soil and climate requirements for pearl millet were determined based on Naidu *et al.* (2006), modification over Sys *et al.* (1993). Current (actual) and potential soil suitability closely follows the previous research studies (Sabalia and Gundalia, 2010; Meena *et al.,* 2017; Girmay *et al.,* 2018). The spatial information of suitable and not-suitable areas were depicted with the suitable thematic maps under GIS environment for easy understanding of the spatial information as well as to enable the decision makers for effective policy planning and management for such areas. Bagherzadeh and Mansouri Daneshvar (2011) also used thematic maps in their study to depict the spatial information for similar reasons.

Soil suitability of wheat

Results revealed that soils of LMU3, LMU5 and LMU6 found to be class S2 for wheat cultivation while soils of LMU1 belongs to class N2 when evaluated for their current and potential soil suitability. However, soils of LMU2 and LMU4 rated as class S3 under current soil suitability evaluation, and class S2 when evaluated in terms of potential soil suitability (Table 4). Further, area under particular class revealed that class S2 occupied highest area (206.7 ha) followed by class S3 (171.2 ha) when evaluated in terms of their current soil suitability, and this area respectively constituted to 38.1 and 31.6% area of the entire micro-watershed (Fig. 6). However, significant increase was registered under class S2 area (377.9 ha) while evaluated to their potential soil suitability as compared to their current acreage (206.7 ha), and this area (potential suitability) under class S2 constituted to 69.7% of the micro-watershed (Fig. 7). Area under class N1 and N2, respectively estimated to 18.1 ha (3.3%) and 116.5 ha (21.5%) in terms of current soil suitability while, potential soil suitability indicated an improvement in class N1 areas due to rectification of existing correctable limitations with scientific management practices and resultant to this, the same could be brought to cultivation.

Increase in class S2 area may be attributed to decline in class S3 areas besides improved rating of class N1 areas to suitable class for cultivation. Girmay *et al.* (2018) also suggested management option and the conservation measure to improve the suitability of class S3 and class N1 land units. Severe soil related constraints *viz.,* soil erosion, soil texture, stoniness and rockiness attributed to class N2 and relatively less serious limitations to class N1. Contrary to this, class S1 rating for crop production may be ascribed to favourable soil physico-chemical properties such as soil texture, drainage and erosion soil pH, EC and ESP. Area under class S3 could be due to problems of soil erosion, drainage and fertility status besides soil texture. Organic carbon was major limitation for wheat in the soils of all LMUs except soils of LMU1. Major limitations in the soils of LMU1 were depth,

texture, erosion and drainage as well as permeability while organic carbon, slope and erosion in soils of LMU7. Therefore, appropriate interventions *viz.,* soil and water conservation, integrated soil fertility management, moisture conservation and water harvesting, and agronomic practices need to be adopted to enhance the current land suitability of the micro-watershed for sustainable crop production. Similar interventions were suggested in several studies from areas where this kind of limitations exists for crop production (Alemu *et al.,* 2013; Girmay *et al.,* 2018). In this study specific soil and climate requirements

for wheat were determined based on Naidu *et al.* (2006), modification over Sys *et al.* (1993). Current (actual) and potential soil suitability closely follows the previous research studies (Sabalia and Gundalia, 2010; Meena *et al.,* 2017; Girmay *et al.,* 2018). Thematic maps using sophisticated techniques like GIS were prepared to depict the spatial information about suitable and not-suitable areas for easy understanding and decision making regarding policy planning and management of these areas. Our findings were in close agreement to Bagherzadeh and Mansouri Daneshvar (2011).

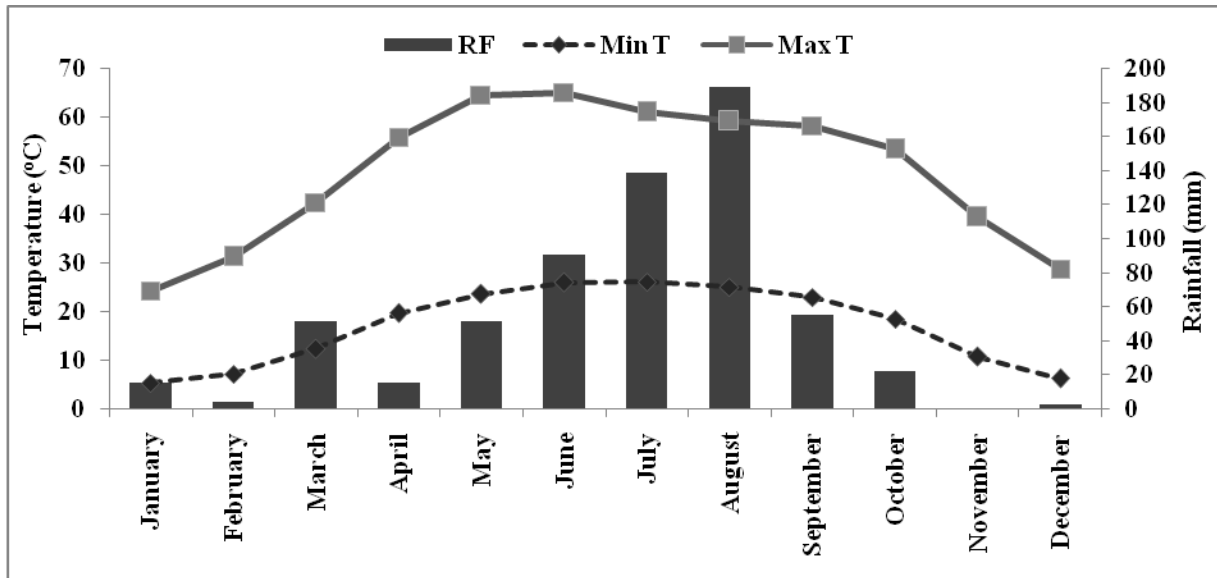**Fig. 1** Location map of Buraka micro-watershed in Mewat Region of Haryana (India)
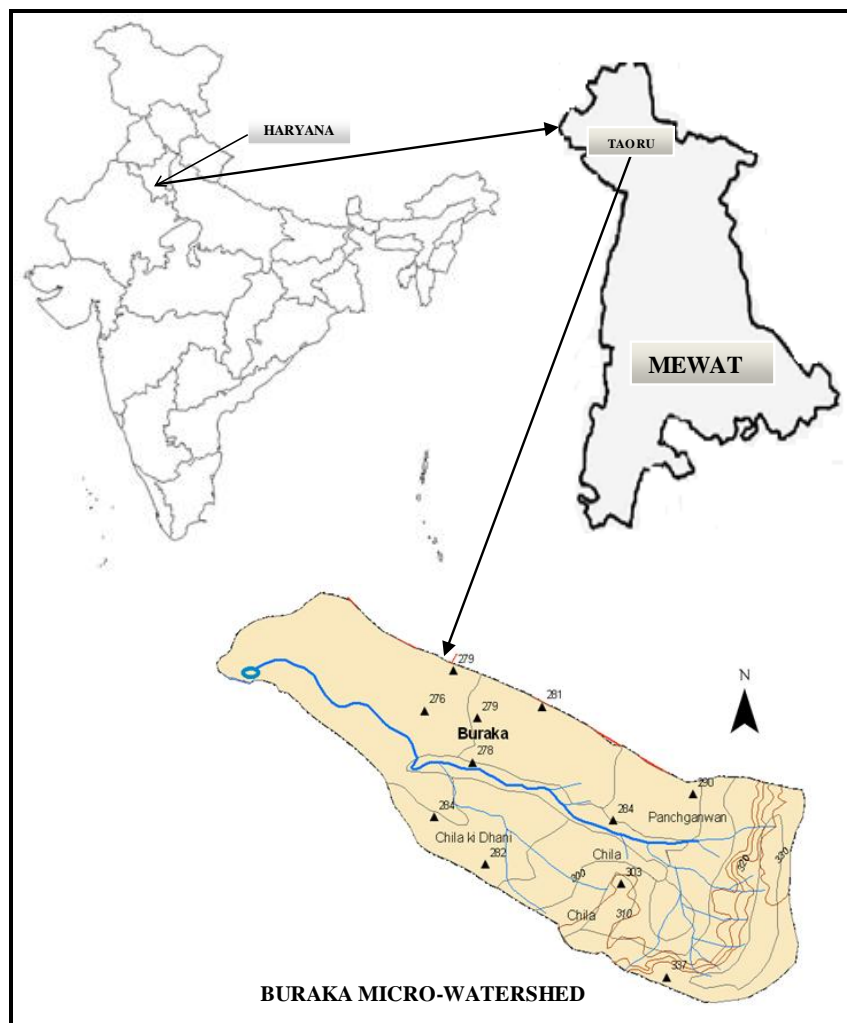
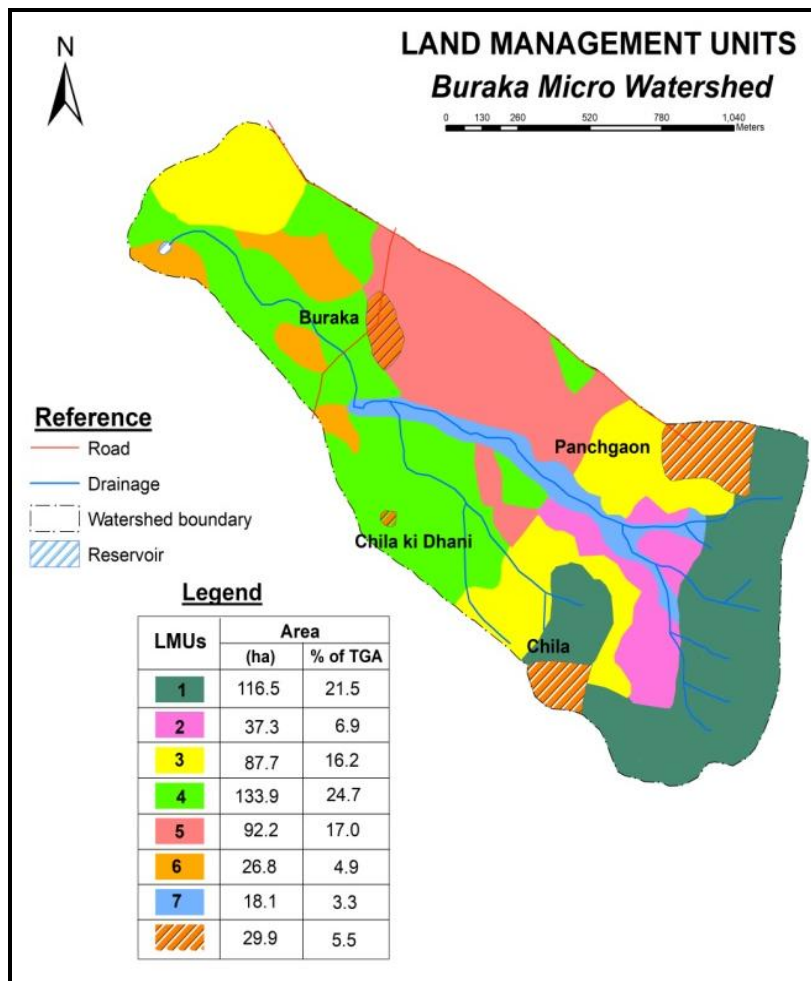**Fig.2** Climatic profile of the study area (Average of 5 years data)

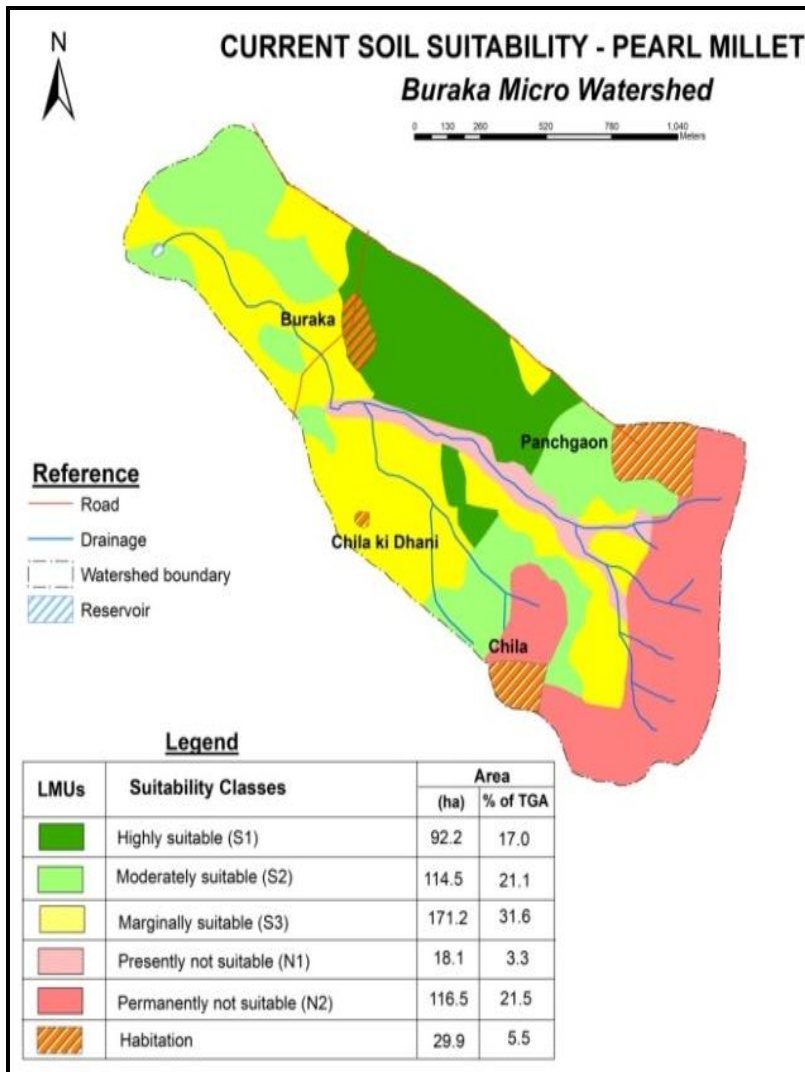**Fig.3** Land management units of Buraka micro-watershed

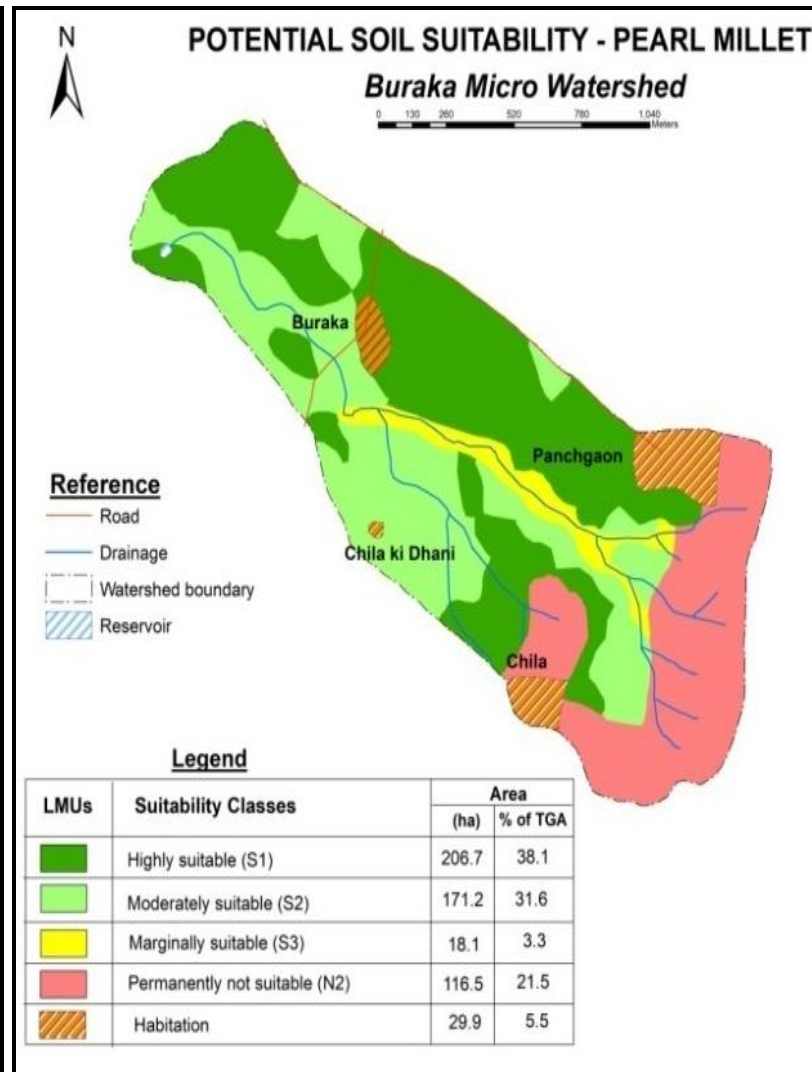**Fig.4** current soil suitability of pearl millet crop in Buraka micro-watershed

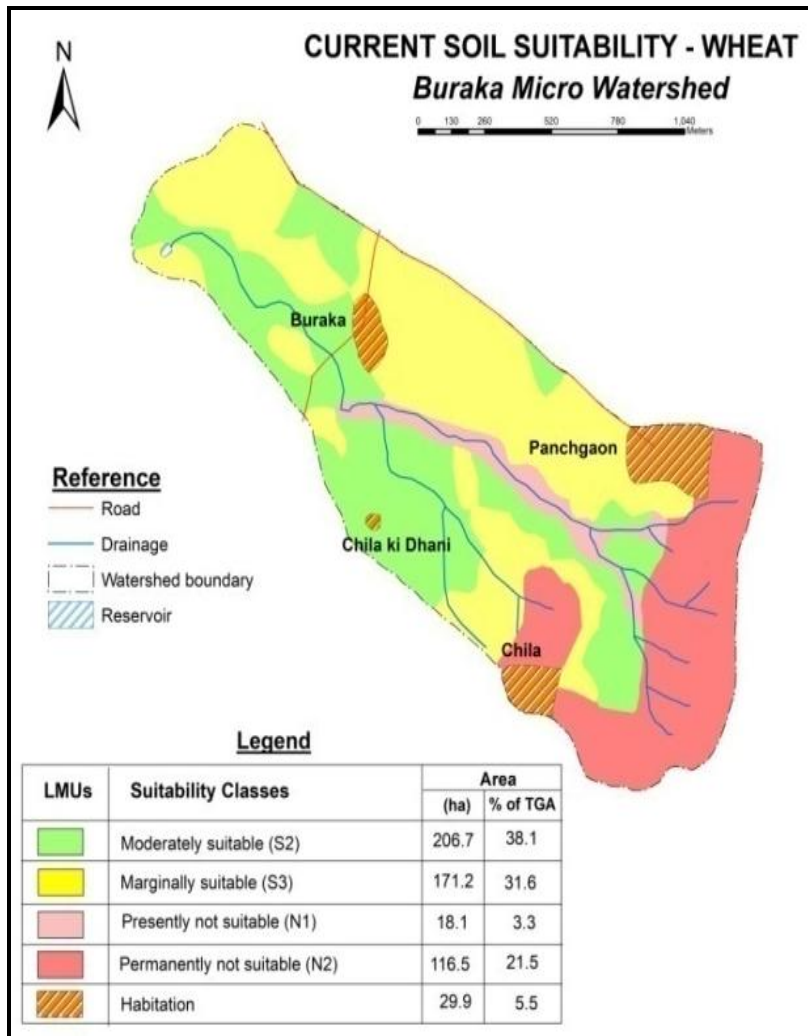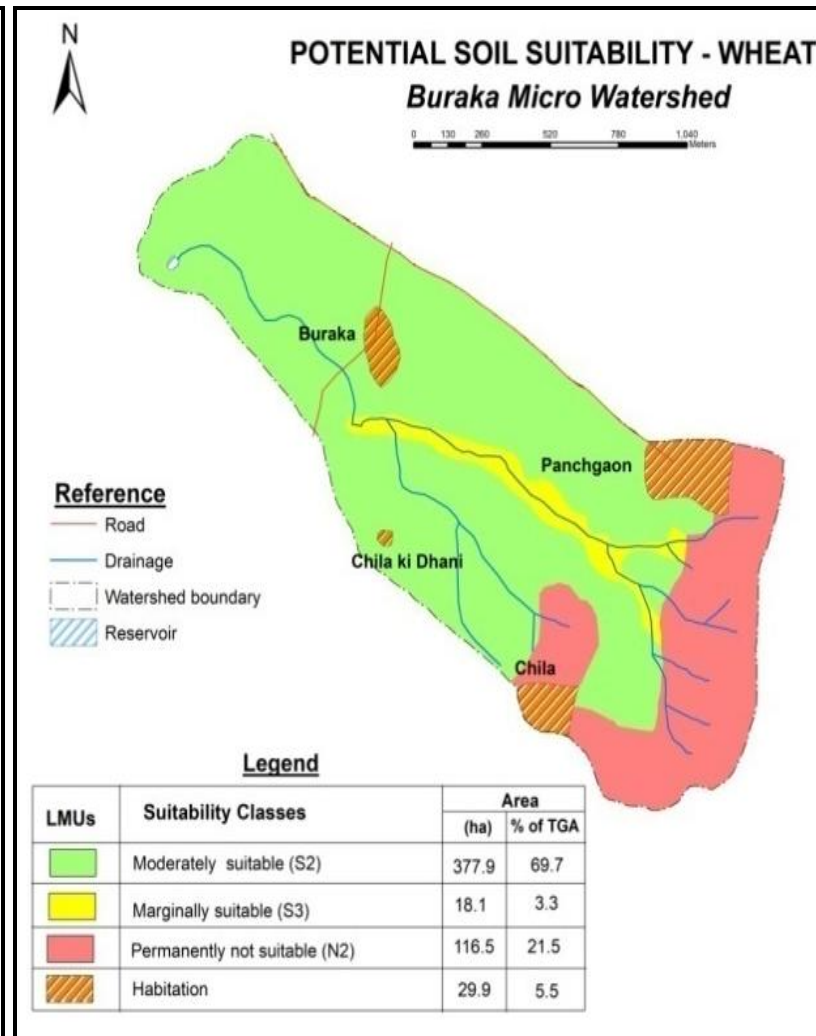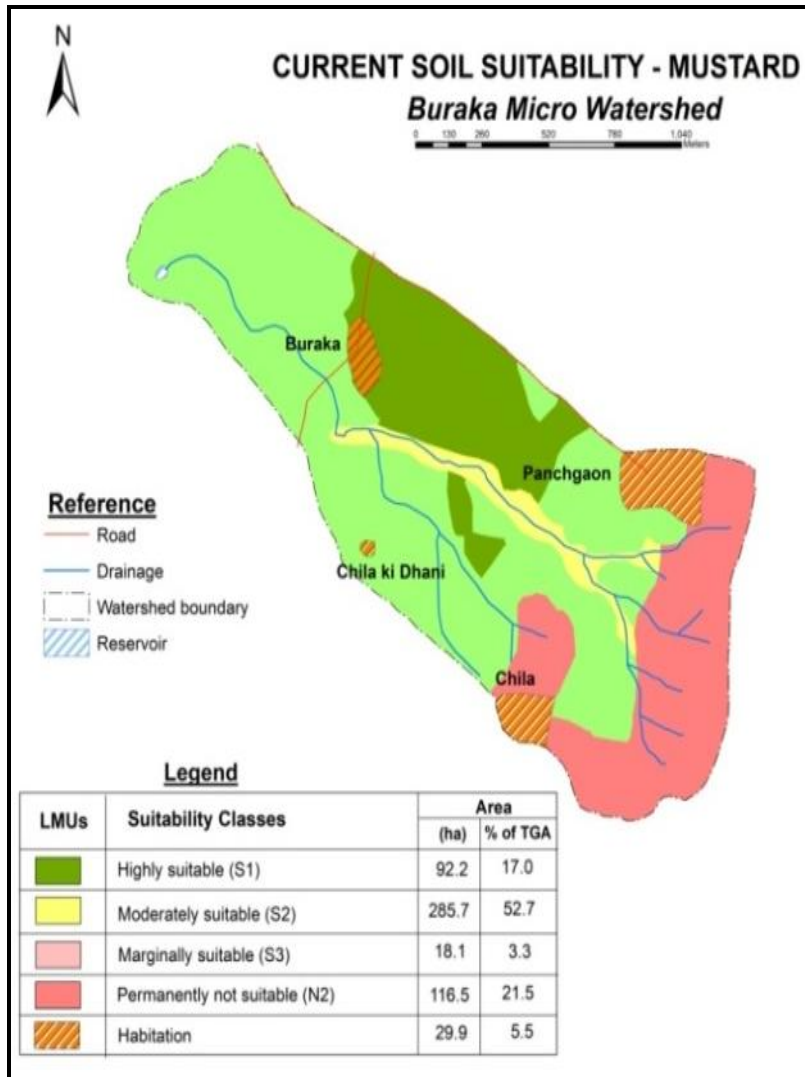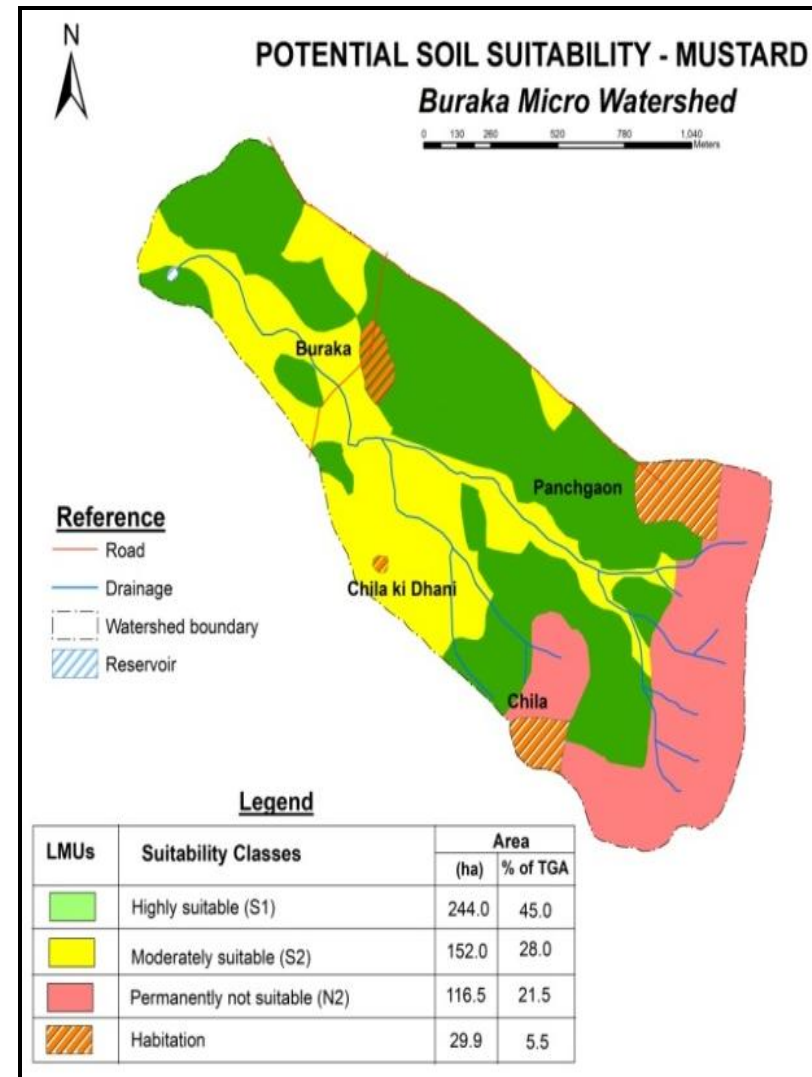**Fig.5** Potential soil suitability of pearl millet crop in Buraka micro-watershed

Fig.6 current soil suitability of wheat crop in Buraka micro-watershed

Fig.7 Potential soil suitability of wheat crop in Buraka micro-watershed

Fig.8 current soil suitability of mustard crop in Buraka micro-watershed

Fig.9 Potential soil suitability of mustard crop in Buraka micro-watershed

Table.1 Characteristics of LMUs *vis-à-vis* soils of Buraka micro-watershed area in Mewat Region of Haryana

LMUs	Characteristic features
LMU1	Wastelands, on very shallow, gravelly sandy loam soils, moderate stony and rockiness with coarse fragment (43.5%) and severely eroded soils, gently to strongly sloping, excessively drained and comes under rainfed ecosystem. Soils belonged to weak fine granular and sub-angular blocky structure. Available water capacity of the soils were 48.3 mm. This LMU falls under rainfed ecosystem.
LMU2	Irrigated, agriculture and livestock based production system on very deep, loamy sand soils, gently sloping, moderately eroded and somewhat excessively drained. Soils belonged to single grain structure. Available water capacity of the soils were 22.7 mm. It comes under double crop LULC category.
LMU3	Irrigated, agriculture and livestock based production system on very deep, sandy loam soils, nearly level to gently sloping, slight to moderately erosion, and well drained. Soils belonged to weak fine granular, weak fine to medium sub-angular blocky structure. Available water capacity of the soils was 58.3 mm. It comes under double crop LULC category.
LMU4	Irrigated, agriculture and livestock based production system on very deep, loamy sand to sandy loam soils, very gently to gently sloping, slight to moderate erosion, somewhat excessively drained. Soils structure was single grain and massive. Available water capacity of the soils was 65.6 mm. It comes under double crop LULC category.
LMU5	Irrigated, agriculture, horticulture and livestock based production system on very deep, sandy loam soils, nearly level to very gently sloping, slightly eroded, well drained soils. Soils had weak fine to medium sub-angular blocky structure. Available water capacity of the soils was 77.2 mm. It comes under triple crop LULC category.
LMU6	Irrigated, agriculture and livestock based production system on very deep, sandy loam soils, very gently to gently sloping, slight to moderately eroded well drained soils. Soil structure was weak to medium sub-angular blocky. Available water capacity of the soils was 116.6 mm. It comes under double crop LULC category.
LMU7	Grazing lands/pasture lands and fallow lands, on very deep, loamy sand, moderately sloping terraces, somewhat excessively drained, severely eroded soils and comes under rainfed ecosystem. Soil structure was single grain structure. Available water capacity of the soils was 37.5 mm. This LMU falls under rainfed ecosystem.

Table.2 Important soil physico-chemical parameters of LMUs considered in soil suitability evaluation of crops for sustainable production in Buraka micro-watershed area of Mewat Region in Haryana

LMU	Depth class (cm)	Texture class	Slope (%)	Stoniness/ Rockiness	Erosion	Drainage	Flooding	pH	OC (%)	CEC [cmol (+)/kg]	BS (%)	CaCO$_3$	Salinity EC (dSm^{-1})	Sodicity (ESP)
1*	Very shallow	Gravelly sandy loam	Gentle (3-5%) to strongly sloping (5-10 % & more)	Moderately stony and rocky	Severe	Excessively	Nil	6.8	0.41	11.2	78.2	0.0	0.3	6.8
2	Very deep	Loamy sand	Gently sloping (3-5%)	Nil	Moderate	Somewhat excessively	Nil	8.2	0.04	2.2	81.0	7.5	0.4	24.4
3	Very deep	Sandy loam	Nearly level (<1%) to gently sloping (3-5%)	Nil	Slight to moderate	Well	Nil	7.8	0.36	4.6	79.4	0.0	0.3	6.6
4	Very deep	Loamy sand to sandy loam	Very gently (1-3%) to gently sloping (3-5%)	Nil	Slight to moderate	Somewhat excessively	Nil	7.8	0.08	4.5	82.6	3.4	0.3	7.0
5	Very deep	Sandy loam	Nearly level (<1%) to very gently sloping (1-3%)	Nil	Slight	Well	Nil	7.6	0.14	13.0	68.9	1.3	0.4	5.7
6	Very deep	Sandy loam	Very gently (1-3%) to Gently sloping (3-5%)	Nil	Slight to moderate	Well	Nil	7.6	0.09	3.8	80.2	0.3	0.4	9.6
7	Very deep	Loamy sand	Moderately sloping (5-10 %) stream terraces	Nil	Severe	Somewhat excessively	Nil	8.2	0.03	1.3	81.4	6.4	0.3	31.4

*Coarse fragments (43.5%) were observed only in LMU1

Table.3 Current and potential soil suitability of pearl millet under various LMUs of Buraka micro-watershed in Mewat Region of Haryana

LMUs	Rainfall	Temperature	Depth class (cm)	Texture	Coarse fragments %	Slope	Stoniness/ Rockiness	Erosion	Drainage/ permeability	OC (%)	BS (%)	pH	EC (Salinity)	ESP (Sodicity)	LGP	Current Suitability	Potential Suitability
LMU 1	S1	S1	N	N	S3	S3	S2	N	N	S2	S1	S1	S1	S1	S1	N2	N2
LMU 2	S1	S1	S1	S2	S1	S2	S1	S2	S3	N1	S1	S1	S1	S3	S1	S3	S2
LMU 3	S1	S1	S1	S1	S1	S2	S1	S2	S1	S2	S1	S1	S1	S1	S1	S2	S1
LMU 4	S1	S1	S1	S2	S1	S2	S1	S2	S3	N1	S1	S1	S1	S1	S1	S3	S2
LMU 5	S1	S1	S1	S1	S1	S1	S1	S1	S1	S2	S1	S1	S1	S1	S1	S1	S1
LMU 6	S1	S1	S1	S1	S1	S2	S1	S2	S1	N1	S1	S1	S1	S1	S1	S2	S1
LMU 7	S1	S1	S1	S2	S1	S3	S1	N	S3	N1	S1	S1	S1	S3	S1	N1	S3

Table.4 Current and potential soil suitability of wheat under various LMUs of Buraka micro-watershed in Mewat Region of Haryana

LMUs	Temp-erature	Depth class (cm)	Texture	Coarse fragments %	Slope	Stoniness/ Rockiness	Erosion	Drainage/ permeability	OC (%)	BS (%)	pH	EC (Salinity)	ESP (Sodicity)	LGP	Current Suitability	Potential Suitability
LMU 1	S1	N	N	S3	N2	S2	N	N	S3	S1	S1	S1	S1	S3	N2	N2
LMU 2	S1	S1	S2	S1	S2	S1	S2	S3	N1	S1	S2	S1	S2	S3	S3	S2
LMU 3	S1	S1	S2	S1	S2	S1	S2	S1	N1	S1	S2	S1	S1	S3	S2	S2
LMU 4	S1	S1	S2	S1	S2	S1	S2	S3	N1	S1	S2	S1	S1	S3	S3	S2
LMU 5	S1	S1	S2	S1	S1	S1	S1	S1	N1	S1	S2	S1	S1	S3	S2	S2
LMU 6	S1	S1	S2	S1	S2	S1	S2	S1	N1	S1	S1	S1	S1	S3	S2	S2
LMU 7	S1	S1	S2	S1	N2	S1	N	S3	N1	S1	S2	S1	S3	S3	N1	S3

Table.5 Current and potential soil suitability of mustard under various LMUs of Buraka micro-watershed in Mewat Region of Haryana

SLMUs	Rainfall	Temperature	Depth class (cm)	Texture	Slope	Stoniness/ Rockiness	Erosion	Drainage/ permeability	OC (%)	pH	EC (Salinity)	ESP (Sodicity)	LGP	Current Suitability	Potential Suitability
LMU 1	S3	S1	N	N	S3	S2	S3	N	S3	S1	S1	S2	S3	N2	N2
LMU 2	S3	S1	S1	S1	S2	S1	S2	S3	N1	S2	S1	N1	S3	S2	S1
LMU 3	S3	S1	S1	S1	S2	S1	S2	S1	S3	S2	S1	S2	S3	S2	S1
LMU 4	S3	S1	S1	S1	S2	S1	S2	S3	N1	S2	S1	S2	S3	S2	S2
LMU 5	S3	S1	S1	S1	S1	S1	S1	S1	S3	S2	S1	S2	S3	S1	S1
LMU 6	S3	S1	S1	S1	S2	S1	S2	S1	N1	S2	S1	S2	S3	S2	S1
LMU 7	S3	S1	S1	S1	S3	S1	S3	S3	N1	S2	S1	N1	S3	S3	S2

Soil suitability of mustard

Current and potential soil suitability for mustard crop revealed that soils of LMU5 evaluated to be class S1 followed by soils of LMU4 under class S2 and soils of LMU1 in the class N2 (Table 5). Further, results of current soil suitability indicated highest area (285.7 ha) under class S2 followed by class S1 (92.2 ha) and least class S3 (18.1 ha), and this is respectively constituted to 52.7, 17.0 and 3.3% area of the whole micro-watershed (Fig. 8). However, significant increase was registered under class S1 area (244 ha) while evaluated to their potential soil suitability as compared to their current acreage (92.2 ha), and this area (potential suitability) under class S1 constituted to 45.0% of the entire micro-watershed (Fig. 9). Current and potential suitability evaluation indicated a positive sign for mustard cultivation in the micro-watershed, as no area belonged to class N1 but at the same time it also depicted a gloomy picture due to significant area (116.5 ha) under class N2, which comes to around 21.5% of the total micro-watershed area. Significant increase in class S1 area while evaluated to their potential suitability could be attributed to improved management and scientific cultivation practices that helped in rectification of correctable limitations. Girmay *et al.* (2018) also suggested management option and the conservation measure to improve the suitability of land units particularly the class S3 and class N1 lands, fortunately no land found to be N1 for mustard crop but these measure also proves effective in areas which are permanently not suitable. Organic carbon was major limitation for mustard in the soils of LMU2, LMU4, LMU6 and soils of LMU7. Major limitations in the soils of LMU1 were depth, texture, coarse fragments, drainage as well as permeability while organic carbon and soil sodicity (ESP) in soils of LMU2 as well as soils of LMU7. Therefore, appropriate interventions *viz.,* soil and water conservation, integrated soil fertility management, moisture conservation and water harvesting, and agronomic practices need to be adopted to enhance the current land suitability of the micro-watershed for sustainable crop production. Similar interventions were suggested in several studies from areas where this kind of limitations exists for crop production (Alemu *et al.,* 2013; Girmay *et al.,* 2018). In this study specific soil and climate requirements for mustard were determined based on Naidu *et al.* (2006), modification over Sys *et al.* (1993). Current (actual) and potential soil suitability closely follows the previous research studies (Sabalia and Gundalia, 2010; Meena *et al.,* 2017; Girmay *et al.,* 2018). Thematic maps were prepared to depict the spatial information using GIS to depict the suitable and not-suitable areas to suggest effective policy and management options in these areas. Bagherzadeh and Mansouri Daneshvar (2011) also suggested use of GIS to depict spatial information for easy understanding of the spatial information.

It can be concluded that despite, multiple uses of land, it plays crucial role in achieving food security however, in the recent years sustainable crop production is seriously challenged due to indiscriminate land use practices and resultant land and soil related problems. Under such situations, it becomes imperative to employ land evaluation strategies *viz.,* soil suitability evaluation which not only helpful in effectively addressing these problems but also helps to improve the land use efficiency. Current and potential soil suitability reveals soils of LMU5 found to be highly suitable (S1) for pearl millet and mustard cultivation. Current soil suitability indicated pearl millet occupied maximum acreage (171.2 ha) under marginally suitable class (S3) while, wheat (206.7 ha) and mustard (285.7 ha) under moderately suitable class (S2). Area under presently not suitable class (N1) as well as permanently not suitable class (N2) occupied

large part of the micro-watershed, and thus land evaluation based scientific interventions becomes even more relevant to bring these areas under suitable land uses such as silvi-culture, silvi-pastures, recreational and wildlife purposes, and also under the cultivation through conscious efforts. Thus, soil suitability evaluation helps in developing alternate land use options for sustainable agricultural land use planning, and also enables the policy planners to formulate and implement policies for effective planning at various levels including micro-watershed scale.

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References

Abd-Elmabod, S.K., Bakr, N., Muñoz-Rojas, M., Pereira, P., Zhang, Z., Cerdà, A., Jordán, A., Mansour, H., De la Rosa, D., and Jones, L. 2019. Assessment of soil suitability for improvement of soil factors and agricultural management. *Sustainability*11:1588 doi: 10.3390/su11061588.

Alemu, W.G., Amare, T., Yitaferu, B., Selassie, Y.G., Wolfgramm, B., and Hurni, H. 2013. Impacts of soil and water conservation on land suitability to crops: the case of Anjeni watershed, North-West Ethiopia. *Journal of Agricultural Science*5:95-109. doi:10.5539/jas.v5n2p95

Anaya-Romero, M., Abd-Elmabod, S.K., Muñoz-Rojas, M., Castellano, G., Ceacero, C.J., Alvarez, S., Méndez, M., and De la Rosa, D. 2015. Evaluating

soil threats under climate change scenarios in the Andalusia region. Southern Spain. *Land Degradation and Development* 26:441-449.

Bagherzadeh, A., and MansouriDaneshvar, M.R. 2011. Physical land suitability evaluation for specific cereal crops using GIS at Mashhad Plain, Northeast of Iran. *Frontiers of Agriculture in China* 5:504-513. DOI: 10.1007/s11703-011-1102-6.

Chartzoulakis, K., and Bertaki, M. 2015. Sustainable water management in agriculture under climate change. *Agriculture and Agricultural Science Procedia* 4:88-98.

Elaalem, M., Comber, A., and Fisher, P. 2010. Land suitability analysis comparing Boolean logic with fuzzy analytic hierarchy process. Accuracy Symposium. July 20-23, 2010. Leicester, UK.

FAO. 1976. A framework for land evaluation. Food and Agriculture Organization of the United Nations, *Soils Bulletin* 32. FAO, Rome.

FAO. 1985. Guidelines: Land evaluation for irrigated agriculture; Soils Bulletin 55. FAO: Rome, Italy.

FAO.1993. Guidelines for Land Use Planning; FAO Development Series 1. FAO: Rome, Italy, p. 96.

FAO. 2007. A framework for land evaluation. FAO *Soil Bulletin* 6. Rome, Italy.

Girmay, G., Sebnie, W., and Reda, Y. 2018. Land capability classification and suitability assessment for selected crops in Gateno watershed, Ethiopia. Cogent Food & Agriculture 4: 1532863. https://doi.org/10.1080/23311932.2018.1532863

Gomiero, T. 2016. Soil degradation, land scarcity and food security: reviewing a complex challenge. *Sustainability*8: 281.

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.

Maji, A., Reddy, Obi G. P., and Sarkar, D. 2010. Degraded and wasteland of India. Prasad, R. and Pathak, P. S. (Eds), Indian council of agricultural research, New Delhi, India.

Meena, R. L., Verma, T.P., Singh, R.S., Tailor, B.L., and Singh, S.K. 2017. Soil-site suitability evaluation for groundnut (*Arachishypogaea*) in Western Saurashtraregion of Gujarat, India. *International Journal of Current Microbiology and Applied Sciences* 6:3074-3083.

Naidu, L. G. K., Ramamurthy, V., Challa, O., Hegde, R., and Krishnan, P. 2006. Manual soil-site suitability criteria for major crops. *NBSS Publ. No. 129*, NBSS&LUP,Nagpur. 118 pp.

Pan, G., and Pan, J. 2012. Research in crop land suitability analysis based on GIS. *Computer and Computing Technologies in Agriculture*365:314-325.

Panagos, P., Borrelli, P., Poesen, J., Ballabio, C., Lugato, E., Meusburger, K., Montanarella, L., and Alewell, C. 2015. The new assessment of soil loss by water erosion in Europe. *Environmental Science and Policy* 54:438-447.

Perveen, M.F., Nagasawa, R., Uddin, M.I., and Delowar, H.K.M. 2007. Crop-land suitability analysis using a multicriteria evaluation & GIS approach, *5th International symposium on digital earth (ISDE5)*, 5-9 June 2007, University of California, Berkeley, USA.

Perveen, F., Nagasawa, R., Uddin, I., and Delowar, H.K.M. 2012. Crop-land suitability analysis using a multicriteria evaluation and GIS approach.

http://www.digitalearthisde.org/cms/upload/Paper%20and%20Abstract/Perveen.pdf

Rossiter, D.G.1996. A theoretical framework for land evaluation. *Geoderma* 72:165-202

Sam, K., Coulon, F., and Prpich, G. 2016. Working towards an integrated land contamination management framework for Nigeria. *Science of the Total Environment* 571:916-925.

Savalia, S. G., and Gundalia, J. D. 2010. Characterization and evaluation of soil-site suitability for groundnut in the soils of uben irrigation command area of Saurashtra region in Gujarat. *Legume Research*33:79-86.

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 the Soil Science* 44:465-469.

Shahbazi, F., Jafarzadeh, A.A., Sarmadian, F., Neyshaboury, M.R., Oustan, S., Anaya- Ramero, M., and De La Rossa, D. 2009. Suitability of wheat, maize, sugar beet and potato using MicroLEIS DSS software in Ahar area, Northwest of Iran. *American- Eurasian Journal of Agriculture and Environmental Science*5:45-52.

Singh, A. 2016. Soil salinization and waterlogging: A threat to environment and agricultural sustainability. *Ecological Indicator* 57:128-130.

Sys, C., Van Ranst, E., and Debaveye, I.J. 1991a. Land evaluation part I: Principles in land evaluation and crop production calculations. General administration for development cooperation, Agricultural publication No.7, Brussels-Belgium, 274.

Sys, C., Van Ranst, E., and Debaveye, I.J.1991b. Land evaluation Part II:

Methods in land evaluation. General Administration for Development Cooperation, Agricultural Publication No.7, Brussels-Belgium, 247.

Sys, C., Van Ranst, E., Debaveye, I. J., and Beernaert, F. 1993. Land evaluation part III: Crop requirements. General administration for development cooperation, Agricultural publication No.7, Brussels-Belgium, 199.

Velmurugan, A., Swarnam, T.P., Ambast, S.K., and Kumar, N. 2016. Managing waterlogging and soil salinity with a permanent raised bed and furrow system in coastal lowlands of humid tropics. *Agricultural Water Management* 168: 56-67.

Verheye, W. 2008. Land evaluation. In Land Use and Land Cover (II). Belgium: UNESCO-EOLSS, Ghent University Library.

Zengin, M., and Yılmaz, S. 2008. Ardahan Kura Nehri Ve Yakın Çevresi Alan Kullanımlarının Belirlenmesi ve Optimal Alan Kullanım Önerileri˙, *Atatürk Üniversitesi Ziraat Fakültesi Dergisi* 39: 43-54.