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Studies on Land Resource Inventory for Agricultural Land Use Planning in Northern Transition Zone of India through Remote Sensing and GIS Techniques

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Abstract

Land suitability analysis is a prerequisite to achieving optimum utilization of available land resources. Hence, a study on land resource inventory for agricultural land use planning was conducted in the Northern Transition Zone of India to determine land capability and develop a suitability map for wheat and sorghum-based on physical and climatic factors of production using remote sensing and GIS techniques. Detailed soil survey information was used for this exercise. Four series (Singhanhalli, Mugli, Bogur and Venkatapur series) were identified and mapped into seventeen mapping units. Land capability classification showed that a greater portion of the study area belonged to class III followed by class IV with limitations of erosion, wetness and varying soil properties. Four land capability classes viz., II, III, IV, and VI, and seven subclasses *viz.*, IIsf, IIItsf, IVs, IVt, IVts, IVtsf and VIt were identified. Major limitations of these subclasses were slope, erosion, depth, texture, coarse fragments, pH, organic carbon and base saturation. Soil suitability assessment revealed that the soils are moderately suitable to permanently not suitable. About 234 ha (31.6%) is moderately suitable, 494 ha (65.0%) marginally suitable and 10.2 ha (1.3%) permanently not suitable for wheat; while 78.5 ha (10.3%) is moderately suitable, 633.4 ha (82.3%) marginally suitable and 32.6 ha (4.3%) permanently not suitable for sorghum respectively. The moderate, marginal and permanent non-suitability was due to moderate, severe and very severe limitations respectively. However, it is possible to achieve potential yield of the crops in the study area if these limitations are addressed.

Keywords

Land Resource Inventory, Soil Suitability, Land Use Planning, Land Evaluation, Soil Survey, Remote Sensing, Soil Mapping

1. Introduction

Land use planning involves the evaluation of land for alternative land uses for the purpose of selecting the best land-use option from among multiple purposes including agriculture, pasture and forestry. Depending on the nature and properties of soils, land may be suitable for one or other uses. Based on the capability or limitations, lands are grouped into eight classes [1]. Among them, the first four classes (I - IV) of lands are used for cultivation of crops. These four classes are differentiated based on the extent of soil slope, erosion, depth, structure, soil reaction and drainage. The classes from V to VIII are not capable of supporting cultivation of crops but are however fit for other uses such as growing grasses, forestry and supporting wildlife and recreation. The classes V to VIII lands are normally delineated based on problems like streamflow, flooding, ponding, rocky nature, short growing season, snow cover, etc.

The land resources of Karnataka State Particularly Dharwad District are under severe threats due to competing demands of various land uses and increasing population pressure. According to [2] [3] [4], the increasing population and demand for food production and supply does not only lead to increased pressure on land per unit area but would cause further degradation [5]. Several studies on the land resources of Karnataka have been carried out [6]-[15] but most of information available is on a smaller scale, which cannot address site or location-specific issues. The generation of detailed site-specific soil and land resource information can help to identify the constraints and potentials of these scarce resources. This will help to provide suitable site-specific land use options, thereby helping to manage the scarce resources in a sustainable manner [16] [17] [18].

Information on soil and related properties obtained from the soil survey and soil classification can help in better delineation of soil and land suitability for irrigation and efficient irrigation water management. The performance of any crop is largely dependent on soil properties such as depth, drainage, texture, etc., as conditioned by climate and topography. The study of the soil-site characterization for predicting the crop performance of an area forms a part of land evaluation process. According to [19], land evaluation is the rating of soil for optimum returns per unit area. The yield influencing factors for important crops have to be evaluated and the results obtained may be applied for higher production of these crops through proper utilization of similar soils occurring elsewhere in similar agro-climate sub-region under scientific management practices [20]. Information on soil-site suitability evaluation for wheat and sorghum is not available for the study area. In view of this, the present study was carried out.

2. Material and Methods

2.1. Description of Study Area

Singhanhalli-Bogur micro-watershed has an area of 760.6 ha (**Figure 1**), and is located in the hot semi-arid agro-ecological region of India between latitude 15.60˚N to 15.70˚N and longitude 74.97˚E to 74.98˚E in the Dharwad Taluk of

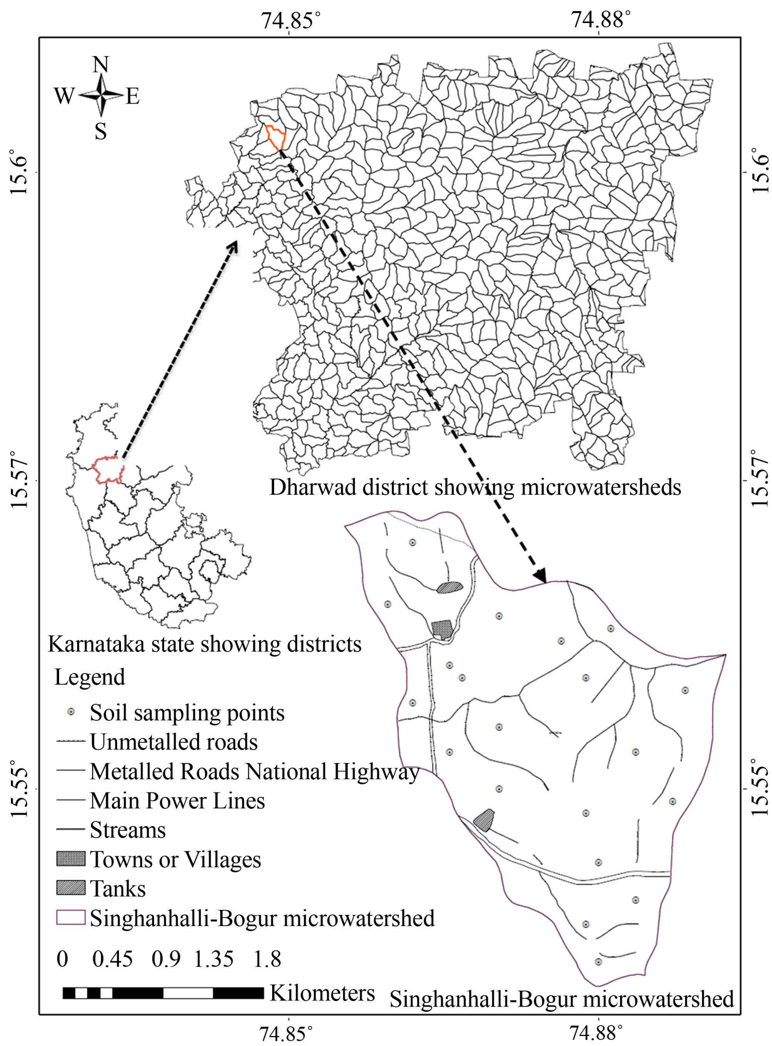

Figure 1. Map of study area.

Dharwad District in the Northern Transition Zone of Karnataka State. This area has a medium to high available water content with a length of growing period of 150 - 180 days. The climate is characterized by hot and humid summer and mild and dry winter. The average annual rainfall is 755.2 mm, which is distributed over May to October and annual temperature ranges from 24˚C - 28˚C with a Ustic Soil Moisture and Isohyperthermic soil temperature regimes [21]. The highest elevation is 754 m above mean sea level and the relief is very gently to strongly sloping.

The general slope is towards the northeast, southeast and southwest but it is more in the southwest direction. The drainage pattern is parallel. Soils are derived from chlorite schist with shale as dominant parent material containing banded iron oxide quartzite. The soils are coarse-textured and shallow at the higher elevations but gradually, fineness and depth of particles increase towards the lower elevations. The main soil types are the black and red soils but the red soils are in a much higher proportion than the black soils. The natural vegetation is mainly comprised of trees and shrubs including Acacia (***Acacia auriculiformis***), Neem (***Azadirachta indica***) and Eucalyptus (***Eucalyptus sideroxylon*** and ***Eucalyptus regnana***).

2.2. Soil Survey and Mapping

A detailed soil survey of the study area was carried out using IRS P6 LISS-IV satellite image and Dharwad district Toposheet as per procedure outlined by [22], during which the area was intensively traversed and 20 pedon locations were fixed based on soil heterogeneity. At each pedon location, a fresh profile was opened and horizon-wise soil samples were collected and analyzed for important physical and physicochemical properties following standard analytical procedures. After the correlation of soil properties, soils were classified into four series according to "Keys to Soil Taxonomy" [23] and mapped into seventeen mapping units based on variation in texture, depth, slope and erosion.

2.3. Land Capability and Soil Suitability Assessment

The soil-site characteristics of different soil units were calculated as the weighted average of each soil property and interpreted for land capability and soil suitability for wheat and sorghum production in the study area. The properties were matched with the criteria for land capability classification and soil site suitability evaluation [2] [24] [25] (**Tables 1-3**). The land capability classification was mainly based on the inherent soil characteristics, external land features and environmental factors. The land capability classes and subclasses were arrived at as per the guidelines proposed in Soil Survey Manual [22] and soil-site suitability evaluation was done based on the FAO framework for land evaluation [2]. Soil-site suitability for wheat and sorghum was evaluated based on the criteria suggested by [25]. Land capability maps and soil-site suitability maps were prepared in the ArcView Interface of ArcGIS 10.1 software.

Table 1. Criteria for land capability classification.

Characteristics	Class I	Class II	Class III	Class IV	Class V	Class VI	Class VII	Class VIII
Topography (t)								
Slope (%)	0 - 1	1 - 3	3 - 8	8 - 15	up to 3	15 - 35	35 - 50	>50
Erosion	nil	slight	moderate	severe	nil	severe	very severe	
Wetness (w)								
Flooding	nil (F0)	nil (F0) (F0/F1)	nil to slight (F1/F2)					
Drainage (l)	well	mod. well	imperfect	poor	v. poor	excessive	excessive	excessive
Permeability	moderate	mod. rapid	rapid, slow	v. rapid, v. slow	-	-	-	-
Infiltration rate (cm·hr^{-1})	2 - 3.5	1 - 2 3 - 5	0.5 - 1.0 5 - 10	<0.5 >10	2.0			
Soil conditions (s)								
Surface texture	l	sil & cl	sl & c	scl	s, c(m)	ls, cl	ls, s, c	ls, s, c (m)
Surface coarse fragments (vol %)	1 - 3	3 - 15	15 - 40	40 - 75	15 - 75	75+		
Surface stoniness (%)	<1	1 - 3	3 - 5	5 - 8	8 - 15	15 - 40	40 - 75	>75
Subsurface coarse fragments (%)	<15	<15	15 - 35	35 - 50	50 - 75	50 - 75	50 - 75	>75
Soil depth (cm)	>150	150 - 100	100 - 50	50 - 25	-	25 - 10	25 - 10	<10
Profile development	Cambic/ Argillic hor. A - (B) - C	A - B - C	Stratified A - C; A - B - C	Salic(Z)/Calcic (Z) hor. A - Bz - C/ ABk - C	Az - C, A - Bz - C	Gypsic (y) hor. A - Cy	A – C (Stony)	A - C (bouldery)
Fertility (f)								
CEC (cmol (p+)/kg	40 - 16	16 - 12	16 - 12	-	-	-	-	-
Base saturation (%)	80+	80+	80 - 50	50 - 35	50 - 35	35 - 15	<15	-
Organic carbon (0 - 15 cm) (g·kg^{-1})	>10	7.5 - 10	5 - 7.5	<5	<5	-	-	-
Salinity EC (dS·m^{-1})	<1.0	1 - 2	2 - 4	4 - 8	8 - 15	15 - 35	35 - 50	>50
Gypsum	0.3 - 2.0	2 - 5	5 - 10	10 - 15	15 - 25	>25	-	-

Table 2. Soil–site suitability criteria (crop requirement) for wheat.

Soil-site characteristics		Unit	Rating: Highly suitable S1	Moderately suitable S2	Marginally suitable S3	Not suitable N
Climatic regime	Mean temperature in growing season	˚C	20 - 25	26 - 28 18 - 19	29 - 34 14 - 17	<14 >34
Land quality	**Land characteristics**					
Moisture availability	Length of growing period	Days	>150	120 - 150	90 - 120	<90
	AWC	mm·m^{-1}				
Oxygen availability to roots	Soil drainage	Class	Well-drained to moderately well-drained	Imperfectly drained	Poorly drained	Very poorly drained; excessively drained
Nutrient availability	Texture	Class	l, cl, sil, scl	sc, sic, c, ls, sicl, sl	C+ (45% - 60%)	C++ (>60%)
	pH	1:2.5	6.5 - 7.5	7.6 - 8.5; 5.5 - 6.4	8.6 - 10; 4.5 - 5.4	<4.5; >10
	OC	%	0.6 - 0.7	0.5 - 0.6	0.3 - 0.5	<0.3
Rooting conditions	Effective soil depth	cm	65 - 100	65 - 50	50 - 25	<25
	Stoniness	%	<15	15 - 35	>35	
Soil toxicity	Salinity (EC saturation extract)	dS·m^{-1}	<4.0	4.0 - 6.0	>6.0	
	Sodicity (ESP)	%	<15	15 - 30	30 - 40	>40
Erosion hazard	Slope	%	<3	3 - <5	5 - 10	>10

C+ = Clay (45 - 60 per cent), C++ = Clay > 60%. Source: [25].

Table 3. Soil-site suitability criteria (crop requirement) for Sorghum.

Soil-site characteristics		Unit	Rating: Highly suitable S1	Moderately suitable S2	Marginally suitable S3	Not suitable N
Climatic regime	Mean temperature in growing season	˚C	26 - 30	31 - 34 24 - 25	35 - 40 20 - 23	>40 <20
	Mean max. temp. in growing season	˚C	31 - 33	33 - 35	>35	-
	Mean max. temp. in growing season	˚C	22 - 18	18 - 15	<15	-
	Mean RH in growing season	%	50 - 70	50 - 40	<40	-
	Total rainfall	mm	650 - 850 >850	650 - 550	450 - 550	<450
	Rainfall in growing season	mm	500 - 700	400 - 500	300 - 400	<300

Continued

Land quality	Land characteristics					
Moisture availability	Length of growing period	Days	120 - 150	120 - 90	<90	-
	AWC	$mm \cdot m^{-1}$	150 - 200	100 - 150	50 - 100	<50
Oxygen availability to roots	Soil drainage	Class	Well to moderate	Imperfect	Poor/Excessive	Very poor
	Water logging in growing season	Days	2 - 3	3 - 4	4 - 5	>5
Nutrient availability	Texture	Class	c, cl, sicl, sc	l, sil, sic	sl, ls	s, fragmental skeletal
	pH	1:2.5	6.0 - 8.0	5.5 - 5.9 8.1 - 8.5	<5.5 8.6 - 9.0	>9.0
	CEC	cmol (p+)/kg	30 - 20	20 - 10	<10	
	BS	%	80 - 50	50 - 35	<35	
	$CaCO_3$ in root zone	%	5 - 10	10 - 25	>25	
	OC	%	0.50 - 0.75	0.50 - 0.20	<0.20	
Rooting conditions	Effective soil depth	cm	100 - 75	50 - 75	30 - 50	<30
	Stoniness	%	5 - 15	15 - 30	30 - 60	>60
	Coarse fragments	Vol (%)	5 - 15	15 - 40	40 - 75	>75
Soil toxicity	Salinity (EC saturation extract)	$dS \cdot m^{-1}$	2 - 4	4 - 8	8 - 10	>10
	Sodicity (ESP)	%	5 - 8	8 - 10	10 - 15	>15
Erosion hazard	Slope	%	2 - 3	3 - 8	8 - 15	>15

Source: [24]-[29].

3. Results and Discussion

3.1. Soil Map and Soil Mapping Units

A soil map is designed to show the distribution of soil types or other soil mapping units in relation to other prominent physical and cultural features of the earth's surface. The mapping units of soils are phases of soil series considering texture, depth, slope and erosion characteristics of the site. In the identification of soil mapping units of the study area, soil series, soil texture, soil depth, slope and erosion were used as inputting parameters.

The soil map shows four series namely, Singhanhalli (SGH), Bogur (BGR), Mugli (MGL) and Venkatapur (VKP) series (Figure 2(a)). These were mapped into seventeen mapping units at different phases of soil series with the help of Arc View Interface of ArcGIS 10.1 GIS software (Figure 2(b)). The mapping legend is presented as e.g., SGH-c-d4/Be1, numerator represents the name of the series (e.g., SGH—Singhanhalli), surface texture (c—clay) and depth of the soil (d4 - 75 to 100 cm) and the denominator indicates slope (B—1 to 3%) of the land and erosion status (e1—slight). Maps of one or more soil features were

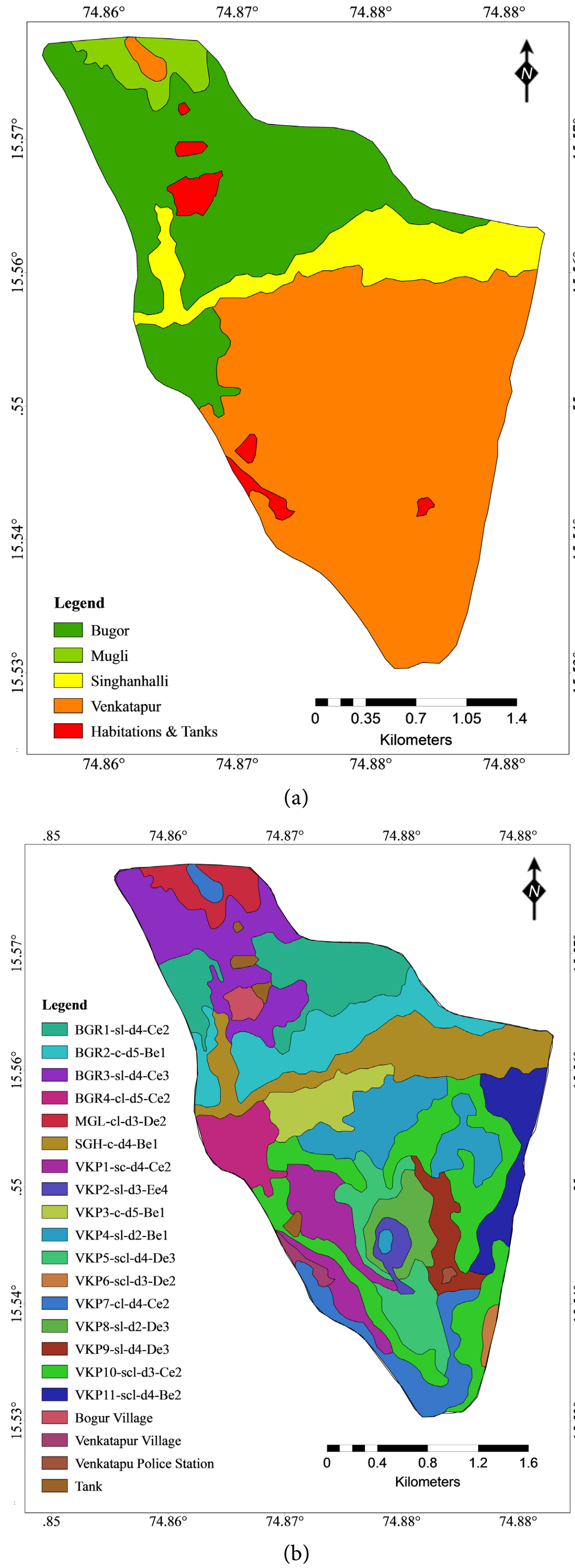

Figure 2. (a) Soil series map of study area; (b) Soil mapping units of study area.

made directly from field observations and as well by selection and generalization from the soil map. The legend design and the kinds of mapping units for the study area were determined by the procedure and kind of survey as indicated by [26].

Singhanhalli series covers 78.5 ha (10.3%) of the study area and were classified as Typic Haplusterts. They are deep, moderately well-drained clay soils located on very gentle slopes found in lowlands, associated with moderate to rapid permeability and slight erosion. Mugli series which cover 22.1 ha (2.9%) were classified as Ultic Haplustalfs. They are moderately deep and moderately well-drained clay loam soils located on moderate slopes found in undulating midlands, associated with moderate to rapid permeability and moderate erosion. Bogur series covers 237.3 ha (31.2%) and were classified into three families, namely, Typic Ustorthents, Typic Calciusterts and Ultic Haplustalfs. The Typic Ustorthents were deep and well-drained sandy loam soils located on gentle slopes found in undulating midlands, associated with rapid permeability and moderate erosion. The Typic Calciusterts were very deep, moderately well-drained clay soils located on very gentle slopes found in lowlands, associated with slow permeability and slight erosion. The Ultic Haplustalfs were very deep, well-drained clay loam soils located on gentle slopes found in lowlands, associated with rapid permeability and moderate erosion.

Venkatapur series covers 406.6 ha (53.5%) of the study area and were classified into six families, namely, Typic Ustorthents, Typic Ustipsamments, Chromic Haplusterts, Typic Haplustalfs, Ultic Haplustalfs and Lithic Haplustalfs. The Typic Ustorthents were deep and well-drained sandy clay soils located on gentle slopes found in lowlands, associated with slow permeability and moderate erosion. The Typic Ustipsamments were deep and well-drained sandy loam soils located on steep slopes found in uplands, associated with rapid permeability and very severe erosion. The Chromic Haplusterts were deep and moderately well-drained clay soils located on very gentle slopes found in lowlands, associated with moderate to rapid permeability and slight erosion. The Typic Haplustalfs were shallow and well-drained sandy loam soils located on very gentle slopes found in uplands, associated with moderate to rapid permeability and slight erosion. The Ultic Haplustalfs were moderately deep to deep, moderately drained to well-drained clay loams and sandy clay loam soils located on very gentle to gentle and moderate slopes found in lowlands and undulating midlands, associated with moderate to rapid permeability and moderate to severe erosion. The Lithic Haplustalfs were shallow, moderately well-drained sandy loam soils located on moderate slopes found in uplands, associated with moderate to rapid permeability and severe erosion.

3.2. Land Capability Classification

Based on the soil-site characteristics of the study area, the soils were classified into four land capability classes (**Table 4** and **Figure 3** and **Figure 4**). These four land capability classes are discussed below:

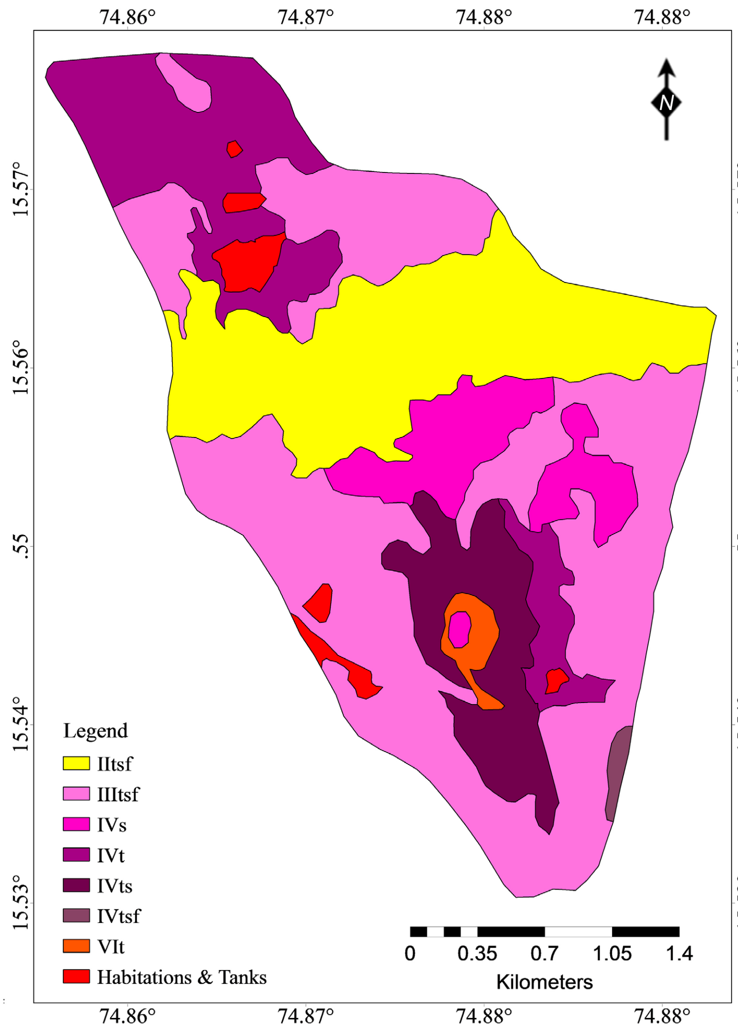

Figure 3. Land capability classes.

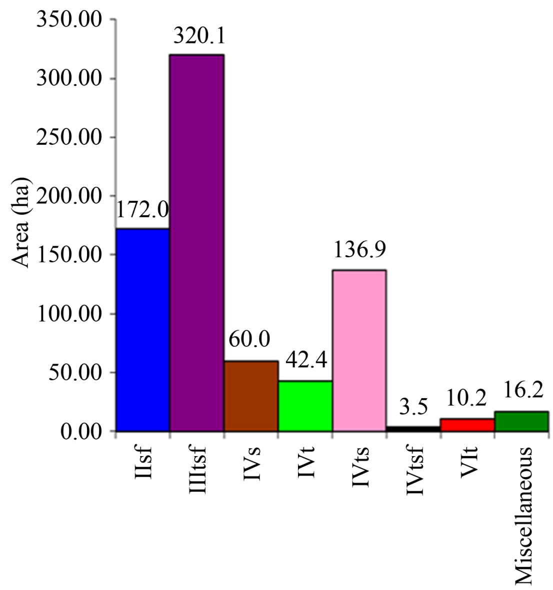

Figure 4. Extent of land capability classes.

Table 4. Extent of land capability subclasses of Singhanhalli-Bogur micro-watershed.

Mapping unit	Land Capability		
	Subclass	Area (ha)	% of study area
SGH-c-d4/Be1 BGR2-c-d5/Be1 VKP3-c-d5/Be1	IItsf	172.0	22.6
BGR1-sl-d4/Ce2 BGR4-cl-d5/Ce2 VKP1-sc-d4/Ce2 VKP6-cl-d4/Ce2 VKP5-scl-d3/Ce2 VKP5-scl-d4/Be2	IIItsf	320.1	42.1
MGL-cl-d3/De2 BGR3-sl-d4/Ce3 VKP8-sl-d4/De3	IVt	115.6	15.2
VKP4-sl-d2/Be1	IVs	59.5	7.8
VKP5-scl-d4/De3 VKP7-sl-d2/De3	IVts	63.7	8.4
VKP5-scl-d3/De2	IVtsf	3.5	0.5
VKP2-sl-d3/Ee4	VIt	10.2	1.3

Note: SGH is Singhanhalli; BGR is Bogur; MGL is Mugli; VKP is Venkatapur; c is clay; cl is clay loam; sl is sandy loam; scl is sandy clay loam; d is depth; B is slope class B; C is slope class C; D is slope class D; E is slope class E; e is erosion; t is limitations relating to topography; s is limitations relating to soil conditions and f is limitations relating to fertility of the soil.

Class II: Soils in this class are referred to as good cultivable lands, which have limitations that restrict their use [24] [25] [26]. These soils are limited by one or more of factors such as: 1) moderate limitations which reduce choice of crop, 2) gentle slope (1% to 5%), 3) moderate erosion hazards, 4) inadequate soil depth, 5) less than ideal soil structure and workability, 6) slight to moderate alkaline or saline condition, 7) somewhat restricted drainage, 8) require moderate conservation practices to prevent deterioration and 9) capable of sustaining less intensive cropping systems.

The result showed that 172.0 ha (22.6%) of the study area was occupied by land capability class II lands. These soils were moderate to rapidly permeable and moderately well-drained with slight limitations of slope, drainage, depth, texture, profile development, soil reaction, organic carbon and base saturation. In order to realize sustainable production of wheat and sorghum on these soils, the management practices may include terracing, strip cropping, contour-tillage, rotation, etc.

Class III: Soils in this class are referred to as moderately good cultivable lands, which have severe limitations that restrict their use [24] [25] [26]. These soils are limited by one or more of factors such as: 1) severe limitations which reduce the choice of crops, 2) moderately steep slope (5% to 10%), 3) high erosion hazards, 4) very slow water permeability, 5) shallow depth and restricted root zone, 6) low water holding capacity, 7) low fertility, 8) moderate alkalinity and salinity and 9) unstable structure.

The result showed that 320.1 ha (42.1%) of the study area was occupied by land capability class III lands. These soils were moderate to rapidly permeable and moderately well-drained with moderate limitations of slope, erosion, depth, coarse fragments, profile development, organic carbon and base saturation. These soils require special conservation practices in order to cultivate wheat and sorghum and special management practices are required in addition to the management practices listed above for the Class II soils.

Class IV: Soils in this class are referred to as fairly good cultivable lands suitable for occasional cultivation, which have very severe limitations that restrict their use [24] [25] [26]. These soils are limited by one or more factors such as: 1) severe limitations which reduce the choice of crops, 2) severe erosion susceptibility, 3) steep slope, 4) severe erosion, 5) shallow soils, 6) low water holding capacity, 7) poor drainage and 8) severe alkalinity and salinity.

The result showed that 242.2 ha (31.8%) of the study area was occupied by land capability class IV lands. These soils were moderate to rapidly permeable and moderately well-drained with severe limitation of slope, moderate to severe limitations of erosion and depth, profile development and base saturation; and moderate limitations of coarse fragments and organic carbon. For optimum production of wheat and sorghum on these soils, careful management practices are required.

Class VI: Soils in this class are referred to as non-cultivable lands located on steep slopes, highly erosion-prone with shallow soils [24] [25] [26]. They are limited by one or more factors such as: 1) extreme limitations of depth and slope and 2) severe erosion hazards, etc. The result showed that 10.2 ha (1.3%) of the study area was occupied by Class VI lands. These soils were very severe limitations of slope. These lands area is unsuitable for cultivation of wheat and sorghum and hence, their use could be restricted to forestry, wildlife, grazing and silviculture and other non-agricultural land uses.

There was no class I lands in the study area. Major proportions of the study area belonged to class IIItsf followed by class IIsf, IVts, IVs, IVt, VIt and IVtsf.

3.3. Soil-Site Suitability

In the present study, the mapped soils of the study area were evaluated to assess their suitability for wheat and sorghum production and presented in **Table 5(a)** and **Table 5(b)** and **Table 6** and **Figure 5** and **Figure 6**.

Table 5. (a) Soil-site suitability characteristics of soil mapping units of Singhanhalli-Bogur Microwatershed; (b) Soil-site suitability characteristics of soil mapping units of Singhanhalli-Bogur Microwatershed.

(a)

Mapping unit	Climate (c)						Topography (t)	Erosion
	Rainfall (mm)	LGP (days)	Maximum Temperature (˚C)	Minimum Temperature (˚C)	Mean Temperature (˚C)	Relative Humidity (%)	Slope (%)	
SGH-c-d4/Be1	755.2	150 - 180	30.9	18.8	24.8	64.9	Very gently sloping	Slight
MGL-cl-d3/De2	755.2	150 - 180	30.9	18.8	24.8	64.9	Moderately sloping	Moderate
BGR1-sl-d4/Ce2	755.2	150 - 180	30.9	18.8	24.8	64.9	Gently sloping	Moderate
BGR2-c-d5/Be1	755.2	150 - 180	30.9	18.8	24.8	64.9	Very gently sloping	Slight
BGR3-sl-d4/Ce3	755.2	150 - 180	30.9	18.8	24.8	64.9	Gently sloping	Severe
BGR4-cl-d5/Ce2	755.2	150 - 180	30.9	18.8	24.8	64.9	Gently sloping	Moderate
VKP1-sc-d4/Ce2	755.2	150 - 180	30.9	18.8	24.8	64.9	Gently sloping	Moderate
VKP2-sl-d3/Ee4	755.2	150 - 180	30.9	18.8	24.8	64.9	Strongly sloping	Very severe
VKP3-c-d5/Be1	755.2	150 - 180	30.9	18.8	24.8	64.9	Very gently sloping	Slight
VKP4-sl-d2/Be1	755.2	150 - 180	30.9	18.8	24.8	64.9	Very gently sloping	Slight
VKP5-scl-d4/De3	755.2	150 - 180	30.9	18.8	24.8	64.9	Moderately sloping	Severe
VKP5-scl-d3/De2	755.2	150 - 180	30.9	18.8	24.8	64.9	Moderately sloping	Moderate
VKP5-scl-d3/Ce2	755.2	150 - 180	30.9	18.8	24.8	64.9	Gently sloping	Moderate
VKP5-scl-d4/Be2	755.2	150 - 180	30.9	18.8	24.8	64.9	Very gently sloping	Moderate
VKP6-cl-d4/Ce2	755.2	150 - 180	30.9	18.8	24.8	64.9	Gently sloping	Moderate
VKP7-sl-d2/De3	755.2	150 - 180	30.9	18.8	24.8	64.9	Moderately sloping	Severe
VKP8-sl-d4/De3	755.2	150 - 180	30.9	18.8	24.8	64.9	Moderately sloping	Severe

(b)

Mapping unit	Moistness (w)	Physical conditions of soil (s)				Soil fertility (f)				Alkalinity (n)
	Drainage	Depth (cm)	Texture	Coarse fragments (%)	Free $CaCO_3$ (%)	pH	OC ($g \cdot kg^{-1}$)	CEC (cmol (p+) kg^{-1})	BS (%)	EC ($dS \cdot m^{-1}$)
SGH-c-d4/Be1	Well drained	Deep (110+)	c	5.2	2.4	7.7	4.4	34.9	75.8	0.14
MGL-cl-d3/De2	Well drained	Moderately deep (73)	gcl	23.1	8.0	6.5	8.6	18.3	64.8	0.08
BGR1-sl-d4/Ce2	Well drained	Deep (80)	gsl	41.9	2.1	6.4	6.4	18.6	66.4	0.12
BGR2-c-d5/Be1	Poorly drained	Very deep (130+)	c	8.1	9.4	8.1	2.3	41.0	84.5	0.11
BGR3-sl-d4/Ce3	Well drained	Deep (106)	gsl	41.8	8.5	7.0	5.0	23.3	58.7	0.09
BGR4-cl-d5/Ce2	Well drained	Very deep (270)	gcl	22.6	1.8	6.7	4.9	17.3	63.0	0.08
VKP1-sc-d4/Ce2	Imperfectly drained	Deep (85)	gsc	22.1	0.5	7.1	11.9	29.1	66.0	0.13

Continued

VKP2-sl-d3/Ee4	Well drained	Deep (78)	gsl	24.1	1.5	5.5	10.4	25.4	49.0	0.09
VKP3-c-d5/Be1	Moderately well drained	Deep (120+)	c	11.5	1.4	7.9	5.3	44.0	85.1	0.13
VKP4-sl-d2/Be1	Well drained	Shallow (43)	gsl	25.3	2.2	7.5	5.5	29.9	74.2	0.33
VKP5-scl-d4/De3	Well drained	Deep (86)	gscl	24.7	0.4	7.0	7.3	27.7	54.4	0.13
VKP5-scl-d3/De2	Moderately well drained	Moderately deep (56)	scl	22.5	3.04	6.5	12.8	23.0	49.3	0.11
VKP5-scl-d3/Ce2	Well drained	Moderately deep (70)	gscl	28.9	1.8	6.1	11.7	27.3	49.4	0.14
VKP5-scl-d4/Be2	Well drained	Deep (110)	gscl	23.5	4.9	6.0	7.0	26.0	58.7	0.11
VKP6-cl-d4/Ce2	Moderately well drained	Deep (80)	gcl	26.5	1.2	6.5	7.1	24.8	48.5	0.13
VKP7-sl-d2/De3	Moderately well drained	Shallow (40)	gsl	17.5	1.9	6.3	11.1	24.9	54.6	0.10
VKP8-sl-d4/De3	Well drained	Deep (100)	gsl	25.0	3.3	6.1	16.4	28.7	52.1	0.10

Table 6. Status of soil-site suitability for wheat and sorghum.

Mapping unit	Suitability subclasses	
	Wheat	Sorghum
SGH-c-d4/Be1	S3f	S2efn
MGL-cl-d3/De2	S3e	S3e
BGR1-sl-d4/Ce2	S2e	S3es
BGR2-c-d5/Be1	S3f	S3esfn
BGR3-sl-d4/Ce3	S3ef	S3es
BGR4-cl-d5/Ce2	S3f	S3e
VKP1-sc-d4/Ce2	S2en	S3en
VKP2-sl-d3/Ee4	Non-cultivable land (NTE)	
VKP3-c-d5/Be1	S2sfn	S3n
VKP4-sl-d2/Be1	S2sfn	S3sn
VKP5-scl-d4/De3	S3e	S3e
VKP5-scl-d3/De2	S3e	S3e
VKP5-scl-d3/Ce2	S3ef	S3e
VKP5-scl-d4/Be2	S2ef	S3t
VKP6-cl-d4/Ce2	S2ef	S3e
VKP7-sl-d2/De3	S3e	N2es
VKP8-sl-d4/De3	S3e	S3es

Note: SGH is Singhanhalli; BGR is Bogur; MGL is Mugli; VKP is Venkatapur; c is clay; cl is clay loam; sl is sandy loam; scl is sandy clay loam; d is depth; B is slope class B; C is slope class C; D is slope class D; E is slope class E; S is suitability; N is not suitable; NTE is not to be evaluated for crop production; e is erosion; t is limitations relating to topography; s is limitations relating to soil conditions, f is limitations relating to fertility and n is limitations relating to alkalinity.

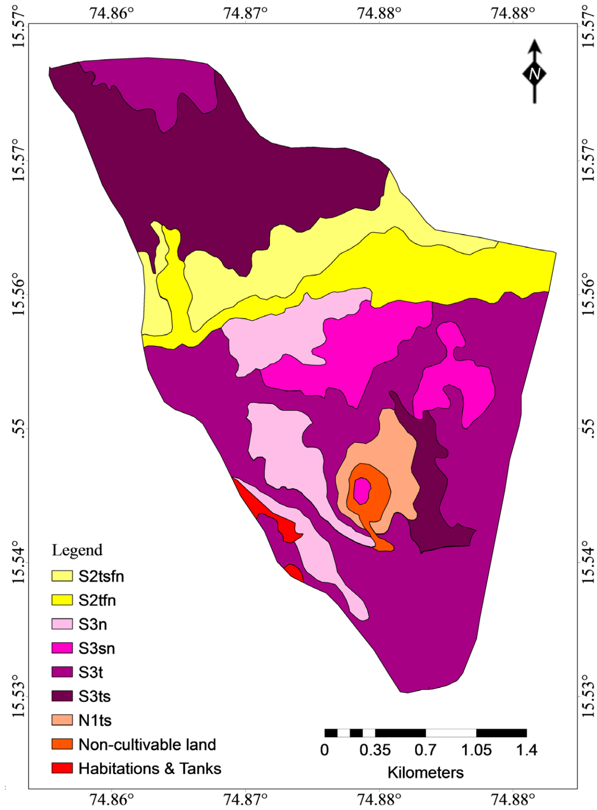

Figure 5. Soil suitability for wheat.

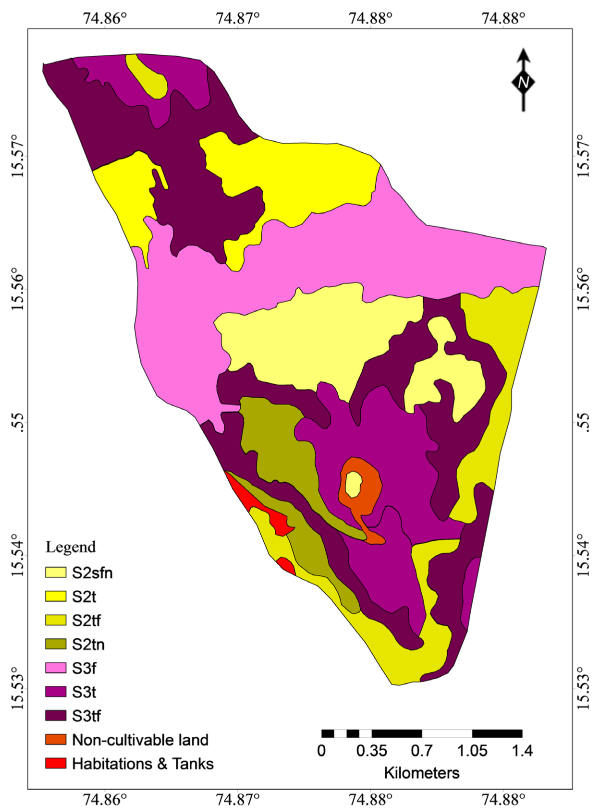

Figure 6. Soil suitability for sorghum.

3.3.1. Wheat (*Triticum aestivum* L.)

Wheat is the world's number one cereal crop. It is an annual crop and a very important winter crop contributing about 32% of the total food grain production in India [27]. The soil-site suitability assessment for wheat revealed that about 270.3 ha (35.5%) of the study area is moderately suitable due to slight to moderate limitations ranging from slope, erosion, pH and base saturation, whereas 436.9 ha (57.4%) is marginally suitable for wheat due to moderate to severe limitations ranging from slope, erosion, pH and base saturation (**Figure 5**).

The result revealed that the slope, erosion, texture, pH, organic carbon and base saturation are the major constraints that could influence the growth and productivity of wheat in the study area. Overall, the soils are highly suitable for wheat production with respect to rainfall (755.5 mm), length of growing period (150 - 180 days), depth (deep to very deep), drainage (moderately drained to well drained), electrical conductivity and $CaCO_3$ content(0.4% - 9.4%). According to [28] [29], wheat grows well in well-drained soil with pH range of 6 to 8. These results are in conformity with earlier reports that stated that optimum mean maximum temperature of 25˚C and mean minimum temperature of 12˚C, annual rainfall of 250 to 1800 mm [28] [29] [30] [31] [32]; soils with good drainage, depth of 65 to 100 cm and organic carbon of 0.6% to 0.7% [33] [34] [35] are highly suitable for wheat.

The crop's potential yield (2.98 tonnes/ha) is achievable if erosion, pH, organic carbon and base saturation constraints, as well as deficiencies of major and micronutrients, are addressed. In view of this, farmers growing this crop should take note of these constraints if high yields are to be achieved.

3.3.2. Sorghum (Sorghum Bicolor L. Moench)

The soil-site suitability assessment for sorghum revealed that about 78.5 ha (10.3%) is moderately suitable due to moderate limitations ranging from erosion and organic carbon. About 633.4 ha (83.3%) is marginally suitable due to moderate to severe limitations ranging from temperature, relative humidity, slope, erosion, drainage, texture and free $CaCO_3$ while 22.3 ha (2.9%) is permanently not suitable due to severe limitations ranging from slope, erosion, depth and texture (**Figure 6**).

It was observed that the major constraints that could limit sorghum production in the study area are slope, erosion, depth, texture, coarse fragments, organic carbon, cation exchange capacity and base saturation. The rainfall (755.5 mm), length of growing period (150 - 180 days), temperature (30.9), relative humidity (64.9), drainage (moderately drained to well-drained), pH (5.5 - 8.1), electrical conductivity and $CaCO_3$ content (0.4 - 9.4)$_,$ are shown to be favourable for sorghum production. This confirms earlier work conducted by [19] [36] [37] [38] [39] [40]. It is however expected that the potential yield of sorghum could be achievable in the study area if the major constraints such as erosion, organic carbon, cation exchange capacity and base saturation as well as deficiencies of major and micronutrients are addressed. Through these efforts, soils could be made moderately suitable for the crop.

4. Conclusion

The major portion of the study area is class III lands, which are marginally suitable for the cultivation of crops but very suitable for other uses like wildlife, forestry and grazing. However, these lands cannot be put under intensive and very intensive cultivation. The second-largest area is occupied by class IV lands which are fairly suitable for cultivation. These lands can be used for limited cultivation, but are most suitable for wildlife, forestry and grazing. Next are the class II lands, which can be used for all types of cultivation (except for very intensive cultivation) in addition to wildlife, forestry and grazing. However, since class II lands are limited, they should be reserved purely for the cultivation of wheat and sorghum. Class VI lands occupy only a very small area. Because of the very severe limitations of slope in these lands, they are recommended for wildlife, forestry and grazing. The soil suitability ranged from moderately suitable to permanently not suitable. The soils were more suitable for wheat than sorghum.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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