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Land Evaluation for Site Specific Pigeon Pea (*Cajanus cajan*) - Sorghum (*Sorghum bicolor*) Management - A Case Study of Mormanchi Microwatershed, Gulbarga District, Karnataka, India

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Authors' contributions

This work was carried out in collaboration between all authors. Author RH concept and designed the basic data structure of microwatershed study and wrote the protocol. Author BD involved in field survey and crop data collection and author GB prepared manuscript and the analyses of the study. Author BPB involved in analysis and interpretation of watershed data. Author SKS made critical revisions. All authors read and approved the final manuscript.

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Case Study

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ABSTRACT

Aim: Integration of land resource inventory with land suitability to derive optimal land use at farm level.
Study Design: Land resource inventory for farm level planning using transect approach for soil profile studies and then classified soils as per USDA soil taxonomy. The soil series information was used to derive soil map and used GIS to derive crop suitability maps.
Place and Duration of Study: Mormanchi microwatershed in Gulburga tehsil.
Methodology: Detailed soil survey at 1:10000 scale using remote sensing data sets and cadastral maps with transect method of soil profile studies. Identification of soil series and defining soil

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phases as mapping units to derive soil map for land evaluation for sorghum and pigeon pea using GIS.

Results: The land resource information obtained from detailed soil survey shows that this micro watershed has six soil series belongs to the subgroups of vertisols and vertic integrades having low available sulphur and boron with wide spread phosphorus and Zn deficiency. The soil map with fifteen mapping units was used in land evaluation for sorghum and pigeon pea. The results showed that 35% of total area is evaluated as suitable with limitations of soil depth, gravelliness and slope. To enhance productivity, it is suggested to go for early sowing of pigeon pea with supplementary irrigation in times of dry spells but for sorghum, soil-water conservation measures must be integrated with nutrient management.

Conclusion: The fifteen shrink-swell soil mapping units in Mormanchi Microwatershed were evaluated for sorghum and pigeon pea in northern dry zone having short length of growing period. The results showed that 35% of area is suitable as against the current land use of 85% of total cultivated area.

Keywords: Land resource inventory; soil series; GIS; biophysical; soil-site suitability; Deccan plateau; watershed.

1. INTRODUCTION

Land evaluation constitutes a valuable resource inventory that is linked with the survival of life on the earth and involves the process of evaluation of a particular tract of land for specific purposes involving the execution and interpretation of data of natural resources and other related aspects of land in order to identify and make a comparison of promising kinds of land uses. Information on soil and related properties obtained from land evaluation can help in better delineation of land suitability for irrigation and efficient irrigation water management. Hence, depending on the suitability of the mapped land units for a set of crops, optimum cropping patterns could be suggested by taking into consideration the present cropping system and the socio-economic conditions of the farming community [1].

In India, the land resources available for agriculture are shrinking. Most of the soils in rainfed regions are at the verge of degradation having low cropping intensity, relatively low organic matter status, poor soil physical health and low fertility [2].

Appraisal of land is essential for its optimal use for agricultural development on sustainable basis. Accordingly, Soil survey and land evaluation helps better land use planning and management with realization of inherent potentials and constraints of biophysical factors in the region [3]. The land resource inventory provides adequate information in terms of landforms, vegetation as well as characteristics of soils (*viz*., texture, depth, structure, stoniness, drainage, acidity, salinity etc.), which can be utilized for land use planning and development [4].

In the twenty-first century, to steer the agricultural achievements towards the path of an 'evergreen revolution' there is a need to blend the traditional knowledge with frontier technologies. Information and communication technology; space technology; geographical information systems (GIS) are the tools of such frontier technologies which would help in creating agricultural management systems; making plans for sustainable agriculture; and bringing new areas (through development of wastelands) into productive agriculture. The role of remote sensing and GIS in agricultural applications can be broadly categorized into two groups- inventorying/mapping and management. Suggesting sustainable agricultural land use plan based on integration of land capability, land productivity; soil suitability; terrain characteristics and socio-economic etc. information using GIS [5]. In the dry ecosystem, climatic variability in terms of mean annual rainfall (MAR) and mean annual temperature (MAT) results in affect crop performance and often leads to low crop yield [6]. The large scale mapping using IRS-P6-LISS-IV merged with cartosat were used in generation of land resource data at village level [7,8,9,10]. The watershed management programs are aimed at designing suitable soil and water conservation measures, productivity enhancement of existing crops, crop diversification with horticultural species, greening the wastelands with forestry species of multiple uses and improving the livelihood opportunities for landless people. The objectives can be met to a great extent when an appropriate Natural Resources Management

(NRM) plan is prepared and implemented. It is essential to have site specific Land Resources Inventory (LRI) indicating the potentials and constraints for developing such a site specific plan [11]. The district economy is mainly dry land agriculture with an irrigated area of 18.8% of the net area sown (below the state average of 25 per cent). The district is a drought prone with an occurrence of drought once in three years [12]. The agricultural landscapes in rural sectors of drought prone Gulberga district and provide an opportunity to look into the reflective realties of drought and difficulties faced by farmers to enhance farm productivity with rudimentary farming systems. Hence present study was aimed at integrating soil-land information with land evaluation for crop planning at landscape level. The objectives of present study are: (i) to characterize and classify soils and then mapping for land evaluation and (ii) to integrate soil-land information in GIS environment for assessing their suitability to locally adopted crops for crop development in the watershed level.

2. MATERIALS AND METHODS

2.1 Description of the Study Area

Mormanchi microwatershed in Gulburga tehsil (17°36'-17°38' N and 77°4'-77°6' E) covers 597 hectare (Fig. 1). This area comes under the agroclimatic zone of north eastern transition zone with mean annual rainfall of 740 mm with 46 rainy days and also comes under Semi arid Deccan Plateau, hot arid ecosubregion [13]. Of the total rainfall, seventy three per cent of rainfall (540 mm) is received during the southwest monsoon (June to September), seventeen per cent during the north-east monsoon (October to early December) and the remaining ten per cent (74 mm) during the remaining period. December is the coldest with mean daily minimum temperature of 10℃ but in summer (May) the temperature rises to 45℃ with a relative humidity of 26%. The soil water balance diagram [14] shows that this area has average potential evapo-transpiration (PET) of 159 mm with a variation of 115 mm in December to 232 mm in May exceeding precipitation in all the months except August and September (Fig. 2). The length of crop growing period (LGP) is 120-150 days and starts from 3rd week of May to first week of October. The agroclimate is characterized as ustic soil moisture regime and soil temperature regime [15] at an elevation of 300-450 m above mean sea level. The cropping pattern is dominated by food crops, which accounts for 78.6% of the net area sown. Sorghum, pigeon pea and sunflower are the major crops, occupying 20.7 per cent 24.8 and 11.3 per cent of the net area sown. The district is called 'Tur' bowl of the state as the area under Pigeon pea occupies 65.7 per cent. The system of farming and the cropping pattern reveals low levels of living of the people in rural areas. This crop assumes a great importance in Karnataka agricultural economy, which ranks second in area (0.51 m ha) and fifth in terms of production (0.25 mt) in the country. But ironically the yield of this crop is below all India average. It is grown both as a sole crop and intercrop with pearl millet, groundnut, chickpea, green gram and cowpea. It is largely grown in the northern parts of the state especially in Gulbarga, Raichur, Bidar and Bellary districts of Karnataka predominantly under rainfed cropping system [16]. The productivity of pigeon pea in Karnataka is 581 kg ha^{-1}, which is much below the national average of 671 kg ha^{-1} [17].

2.2 Field Survey

Land resource inventory on 1:10000 scale using false colour composites of Cartosat-1 and LISS-IV merged satellite data was carriedout with the preparation of landform form map as prerequisite for field survey as per standard guidelines given in Soil Survey Manual [18,19]. The intensive field traverse was made to check field boundaries and to acquaint with landscape patterns. The soil transects were selected at respective landscape elements and dug out 16 soil profiles and recorded latitude/longitude and elevation of each site with the help of Global Positioning System (GPS). Morphological descriptions of each pedon were recorded [20] and classified upto family level as per [21]. The soil map was generated with six soil series identified and derived 15 soil mapping units defined as phases of series in GIS environment with ARCinfo *ver.10.2.*

2.3 Laboratory Analysis

Horizon wise soil samples were collected and sieved air dry samples through 2 mm sieve for fine earth fraction. The routine and standard procedures were used for bulk density by clod method, pH, Electrical conductivity (1:2.5 soil water ratio) by [22] in the supernatant suspension of 1:2.5 (soil: water ratio). The method described by [23] was used for cation exchange capacity (CEC) estimation. Soil organic carbon (OC) was estimated using the method [24] and expressed in percentage. 1*N* ammonium acetate (NH4OAc) solution at pH extractable potassium (K^+) was determined by Flame photometer [22]. DTPA-extractable micronutrients Fe, Mn, Zn and Cu were extracted by 0.005 M DTPA at pH 7.3 according to the method of [25] and the concentration of the micronutrients were estimated using atomic absorption spectrophotometer (Agilent Technologies, 200 series AA model). Available phosphorus determined by Olsen method [26] and available S by $CaCl_2$ extraction method [27]. The available Boron estimated by the Azomethine-H method by using LabIndia (analytical) UV/VIS spectrophotometer [28]. Fertility status of N, P, K and S were interpreted as low, medium and high and that of DTPA extractable zinc, iron, copper and manganese interpreted as deficient, sufficient and excess by following the criteria [29].

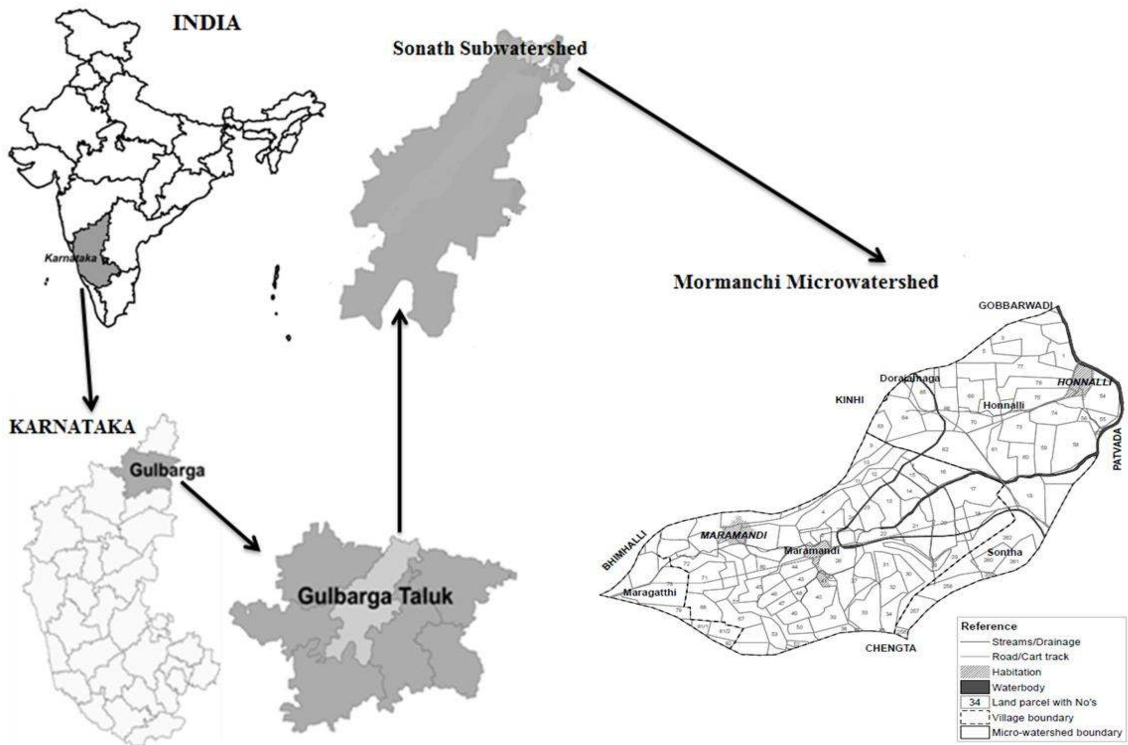


Fig. 1. Location map of Mormanchi Microwatershed

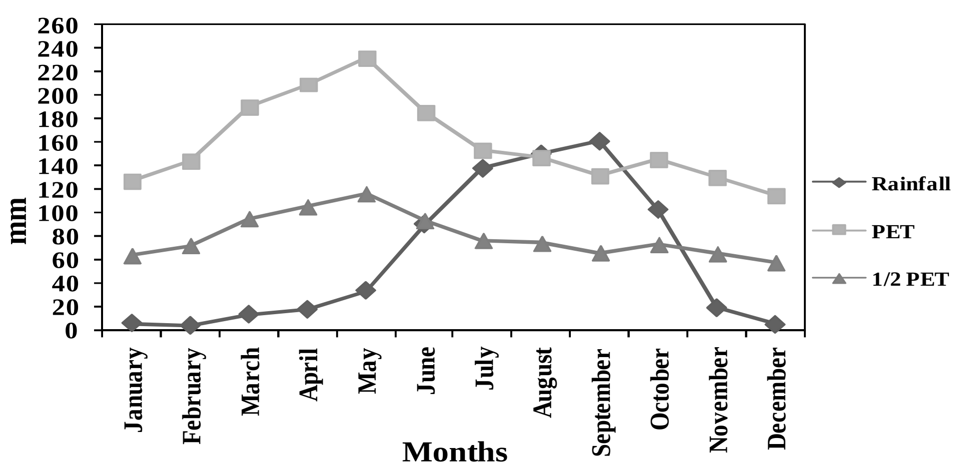


Fig. 2. Rainfall distribution in Gulbarga Taluk, Gulbarga District

2.4 Land Evaluation for Crops

Land evaluation process: After assessing the suitability of the land for general cultivation use, the land evaluation (LE) process was proceed based on the maximum limitation method in terms of FAO's framework comparing the LCs or LQ values of each LMU with the requirements of the proposed LUT (Pigeon pea and sorghum) to identify the actual qualitative land suitability depending on physical environment data generated from topographic features, current soil characteristics, wetness condition and growing period climate data. The LE process comprised of computing the LCs values, suitability classification and land suitability mapping. Land evaluation classification was undertaken according to the [30,31,32,33] system to assess the suitability of the studied area soils for agriculture and development.

Suitability mapping: As an output, the land suitability map of the study area was displayed and shown on individual, transparent maps using different colors to indicate the suitability classes which had all its corresponding land qualities and land characteristics in its attribute table with the help of ArcGIS (Fig. 7a and b). The FAO-SYS system had divisions of suitability classes that indicate degree of suitability. These classes are: '*S*1' = suitable, '*S*2' = moderately suitable, '*S*3' = marginally suitable, '*N*1' = unsuitable for economic reasons but otherwise marginally suitable, '*N*2' = unsuitable for physical reasons. The steps followed in land evaluation for crops and in deriving thematic map of suitability zones were as follows (Fig. 3):

Step 1: Soil map with limiting biophysical parameters was used to define limitations of each series.

Step 2: Development of land capability of soil units as per the guidelines of [18].

Step 3: Suitability for crops as per the frame work of FAO [4,34].

Step 4: Development land management units considering biophysical and homogeneity of soil units in terms of properties and land use for making decisions on crop plans for a defined priority areas suitable for crops under GIS environment.

3. RESULTS AND DISCUSSION

Brief description of basaltic soil resources occurring in the microwatershed is given given below in Table 1. The six soil series identified and classified upto family in the subgroups level as (i) Margutti: clayey, mixed, isohyperthermic family of Typic Ustorthents; (ii) Dinsi: Very fine, smectitic isohyperthermic, family of Leptic Haplusterts; (iii) Novinihala: loamy, mixed, isohyperthermic family of Typic Ustorthents; (iv) Matki; clayey, mixed, isohyperthermic paralithic Ustorthents; Nirgudi; (v)Very fine, smectitic, calcareous, isohyperthermic family of Typic Haplusterts; (vi) Mannur: Very fine, smectic, calcareous, isohyperthermic family of Typic Haplusterts [35].

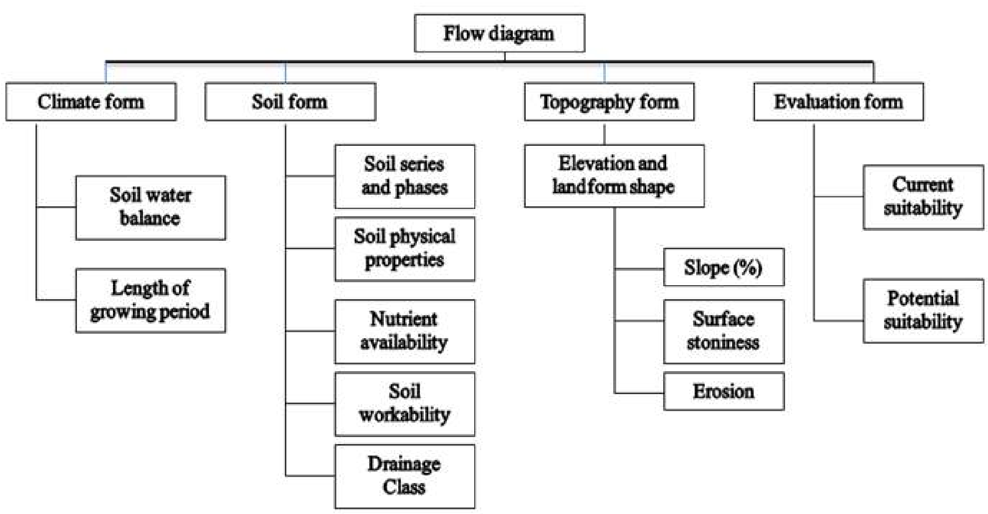


Fig. 3. Flow diagram of site specific land evaluation for crop management of Mormanchi Microwatershed

3.1 Soil Map

In the present study, fifteen mapping units defined as phases of soil series was used to derive soil map of mormanchi microwatershed (Fig. 4). The map shows that Margutti (MGT) series with seven phases identified with variations in gravelliness, slope and severity of erosion. This series cover 311.43 ha (52.15% of total area). The mapping unit (MGTmB2g2 as in soil map) covers 19.68 per cent with severe limitation of rooting depth and very low available water holding capacity. These land units are concentrated in the middle and foot slopes of microwatershed indicating high degree of sheet erosion. Matki soil series covering 57.84 ha (9.68%) has two phases viz., (i) MAThD3g3 having very shallow (<25 cm) clayey soils , on 5 to 10% slopes slopes and (ii) MATmB1g1 covering 14 ha (2.4% of total area) has clayey texture, occurring on 1-3% slopes, slightly eroded and gravelly (15 to 35%). These land units are mostly concentrated in north western fringes with horizontal bend towards south western part of microwatershed as depicted in whitish patch (Fig. 4). The Novinihala soils series (NHA, 87.33 ha, 14.62% of total area) are shallow with two phases viz., (i) NHAmB1 covering 79 ha i.e. 89.7% of this entire unit under watershed, but (ii) NHAmB2g1 has 9 ha with limitations of gravelly and moderate erosion. This unit is mostly located in northern parts of the watershed and 61.43 ha (10.29%). The Dinsi soil series (DSI) are moderately shallow with two phases (i) DSImB1 (58 ha, 9.77%) and DSImB2g1 (southern and northeastern zone) identified with limitations of moderate erosion and gravelliness. The consociations of Nirgudi (NIR) and Mannur (MAR) soils are clayey and moderately to very deep with NIRmB1 (19.7 ha, 3.3%) and MARmB1 (36.67 ha, 6.14%) with 1-3 per cent slopes and slightly eroded. These land units are concentrated in all along the depositional zones of stream floors and northern fringes of microwatershed.

3.2 Climate Analysis

Karnataka is located on the western coast of peninsular India, enclosed between 11.50° N to 18.50° N and 74° E to 78.5° E. The study area Gulbarga belongs to semi arid climatic conditions. The south western monsoon rainfall occurs mainly in June to September and constitutes over 75% of the total rainfall. Normal rainfall of the Gulbarga district is 777 mm and actual rainfall is 881.10 mm. December is the coldest month but in summer, maximum temperature goes upto 45℃. Relative humidity varies from 26% in summer and 62% in winter.

It is reported that, low rainfall epochs return at a periodicity of 17 years at Bijapur and at 13 years at Dharward. The results further said that the return of such events co-existed at both places during the present episode. Similar analysis at other stations may also indicate the wide spread nature of the last epoch of low rainfall at all places [36]. It is deduced from the report of Centre for sustainable technologies [37], Gulbarga, has very low values of water resource vulnerability index (WRVI) and therefore belong to the category of very high vulnerability (cluster 4) due to : low availability of surface water, high crop water stress, and exposure to flood and drought. The water balance diagram shows that the length of growing period is 120 to 150 days with erratic rainfall and prolonged dry spells during crop season and made to choose locally adopted dryland sorghum and pigeon pea.

3.3 Current Land Use

Major crops grown in the mormanchi microwatershed revealed that pigeon pea (*Cajanus cajan*) and sorghum (*Sorghum bicolor*) are the principal crops. The current land use of Mormanchi microwatershed (Fig. 5) with respect to fifteen soil mapping units shows that about 80% area under cultivation of pigeon pea, out of that pegion pea with sorghum multicropping cultivation was adapted mostly in five mapping units viz., MGTmB2g2 (5), NHAmB1 (10), DSImB1 (12), NIRmB1 (14) and MARmB1 (15) with the area of 312 ha (52%), whereas mapping unit MGThD3g3 and MAThD3g3 of 89 ha (15%) were under grassland area.

3.4 Biophysical Constraints

The seven biophysical constraints for pigeon pea and sorghum are considered under this study and reported area under each constraints of each soil mapping unit in Table 2. The microwatershed under study has 62% of total under very shallow; 75% area under very gently slopes and 50% under moderate to severe erosion (50%). About 21% area has extremely gravelly with 74.6% of area under clay texture. About 61.83% soils are affected by very low (<50 mm/m) available water capacity (Table 2). The soil pH measured in soils varied from neutral (9.68%) to moderately alkaline (41%) and strongly alkaline (2%).

3.5 Fertility Status of Soils

The chemical properties of six soil series is given in Table 3 and Fig. 6. Soil pH is slightly alkaline in MGT and MAT to moderately alkaline for NHA, NIR and MAR soil series. All these soils have low salt concentration with EC less than 0.2 dS m^{-1}. Margutti series (MGT) have high organic carbon with mean of 0.78 ± 0.1 with a variation of 13.25 per cent (least variable).

Similar kind of least variability of soil organic carbon is recorded in Nirgudi and Mannur series whereas moderate variation of organic carbon with CV of 21 to 23% in case of Matki, Novinihala and Dinsi series. Available phosphorous was low and potassium was medium with high per cent of variability CV > 35%, [38] (Wilding, 1985) in all soil series under study. Similar trends of low status of available sulphur and boron (B) are recorded all soil series with moderate CV% (<35%) in NHA, NIR and MAR soil series but for boron 32% and 33% under Dinsi and Mannur series. The mean values of micronutrients (Cu, Fe, Mn and Zn) are sufficient to high [25] with higher CV%, except in Fe and Mn under DSI and NIR soil series respectively.

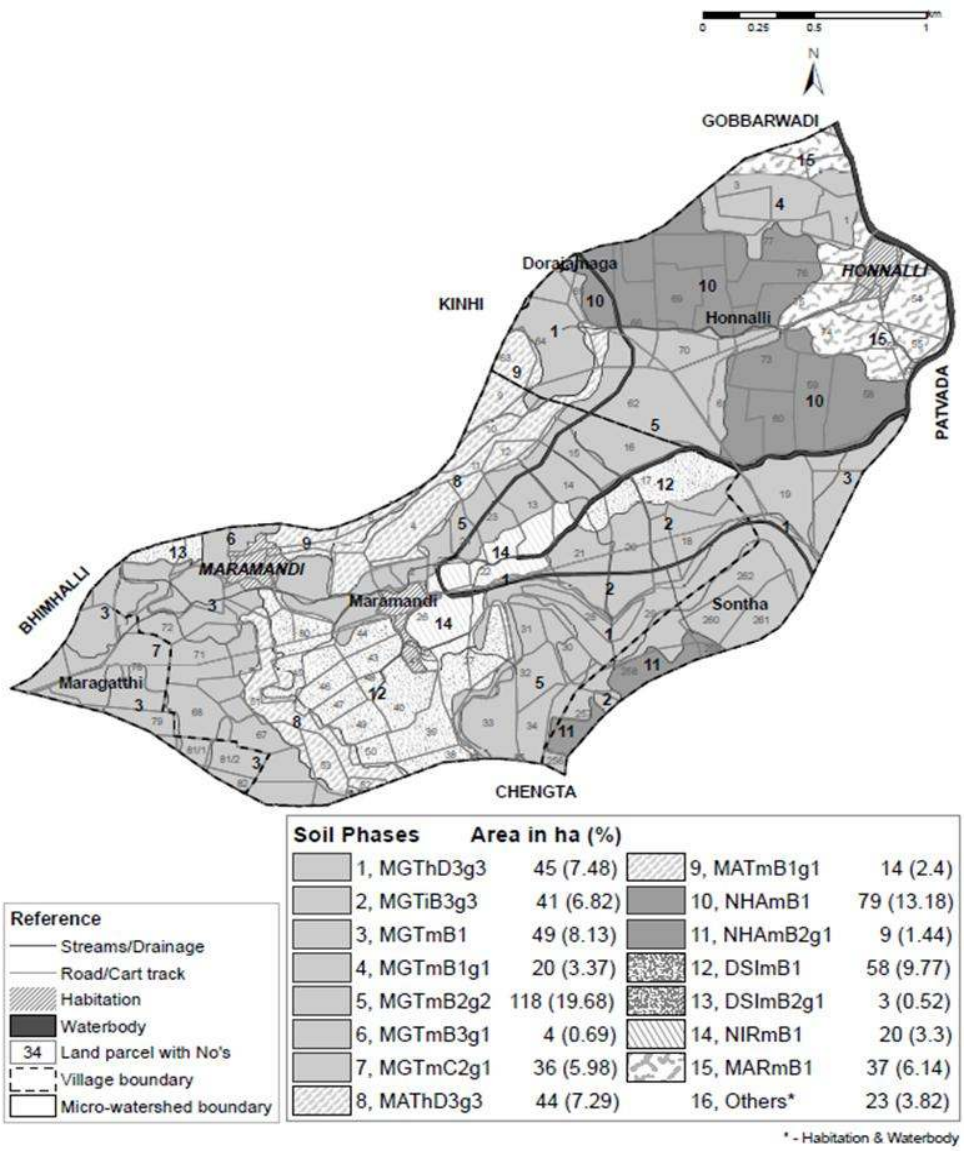


Fig. 4. Soil phase units map of the study area Mormanchi Microwatershed

Table 1. Description of soil series under basaltic soil resources in Mormanchi Microwatershed

Margutti (MGT) Series: Marguti soils are very shallow (<25 cm), well drained, have very dark grayish brown to dark brown clay soils. They have developed from basalt and occur on very gently sloping to moderately sloping uplands. The thickness of A horizon ranges from 7 to 18 cm. Its colour is in 10 YR and 7.5 YR hue with value 3 to 4 and chroma 2 to 3. The thickness of B horizon ranges from 18 to 24 cm. Its colour is in 10 YR hue with value 3 to 5 and chroma 3 to 4.

Novinihala (NHA) Series: Novinihala soils are shallow (25-50 cm), well drained, have very dark grayish brown to dark brown clay soils. They have developed from basalt and occur on very gently to gently sloping uplands. The thickness of A horizon ranges from 12 to 20 cm. Its colour is in 7.5 YR and 10 YR hue with value 3 to 4 and chroma 2 to 4. The thickness of B horizon ranges from 32 to 45 cm. Its colour is in 10 YR and 7.5 YR hue with value 3 to 4 and chroma 2 to 4.

Dinsi (DSI) Series: Dinsi soils are moderately shallow (50-75 cm), moderately well drained, have very dark gray to brown clay soils. They have developed from basalt and occur on very gently sloping uplands. The thickness of A horizon ranges from 9 to 24 cm. Its colour is in 10 YR hue with value 3 and chroma 1 to 3. The thickness of B horizon ranges from 40 to 62 cm. Its colour is in 10 YR hue with value 3 to 4 and chroma 4.

Matki (MAT) Series: Matki soils are very shallow (<25 cm), well drained, have very dark reddish brown to dark reddish gray clayey soils. They have developed from basalt and occur on very gently sloping to moderately sloping uplands. The thickness of A horizon ranges from 7 to 18 cm. Its colour is in 10 YR and 7.5 YR hue with value 3 to 4 and chroma 2 to 3. The thickness of B horizon ranges from 18 to 24 cm. Its colour is in 10 YR hue with value 3 to 4 and chroma 3.

Nirgudi (NIR) Series: Nirgudi soils are moderately deep (75-100 cm), moderately well drained, have very dark grayish brown to very dark gray calcareous clayey soils. They have developed from basalt and occur on nearly level to very gently sloping uplands. The thickness of A horizon ranges from 10 to 22 cm. Its colour is in 10 YR hue with value 3 and chroma 1 to 2. The thickness of B horizon ranges from 63 to 79 cm. Its colour is in 10 YR hue with value 3 and chroma 2 to 1.

Mannur (MAR) Series: Mannur soils are deep (>150 cm), moderately well drained, have very dark grayish brown to gray clayey soils. They have developed from basalt and occur on very gently sloping to moderately sloping uplands. The thickness of A horizon ranges from 18 to 25 cm. Its colour is in 10 YR hue with value 3 and chroma 2 to 1. The thickness of B horizon ranges from 45 to 78 cm. Its colour is in 10 YR hue with value 3 and chroma 2 to 1.

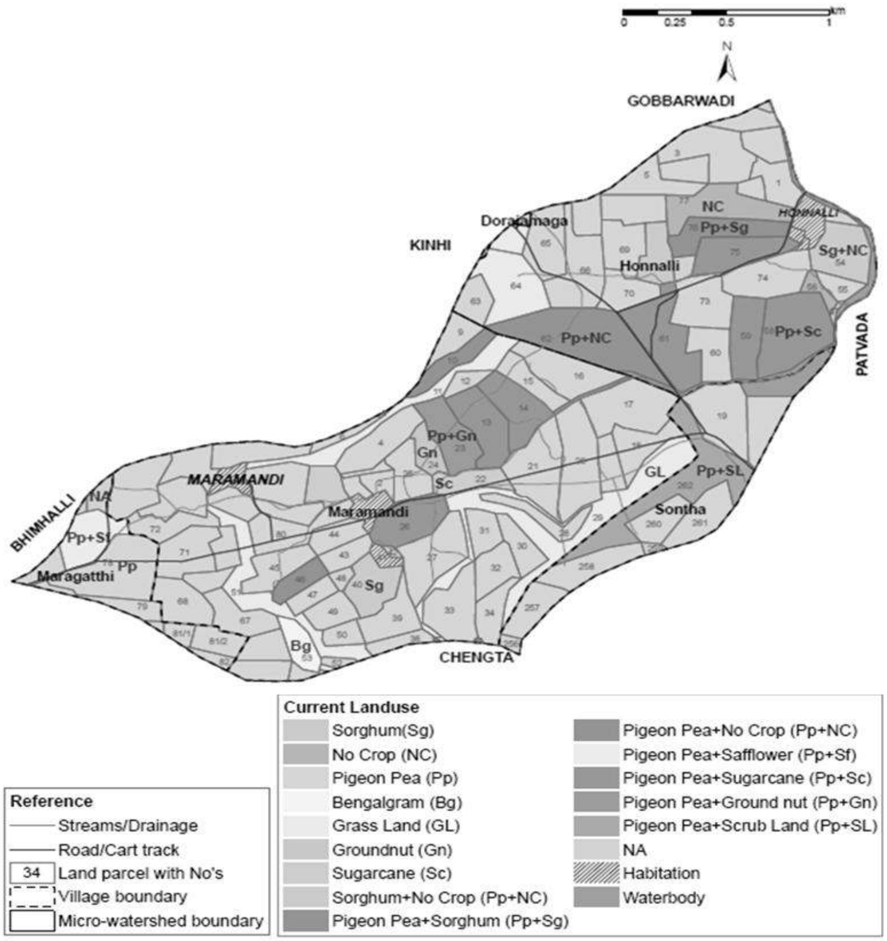


Fig. 5. Current landuse map of the study area Mormanchi Microwatershed

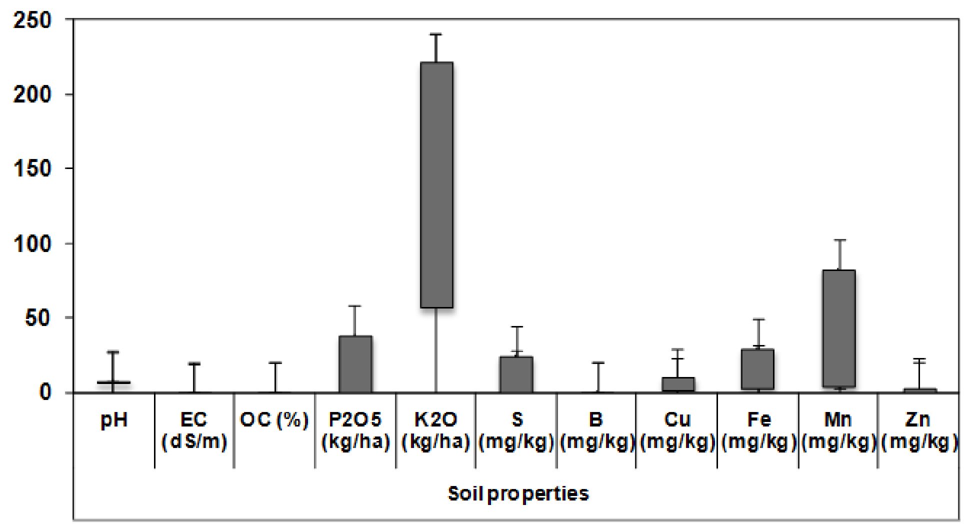


Fig. 6. Box-plot diagram showing different soil properties under study (Mean, maximum, minimum ± SD)

Table 2. Soil depth, soil slope and soil erosion of the study area

Class	Soil mapping units	Cultivation area in ha (%)
	Soil depth	
Very shallow (<25 cm)	1-MGThD3g3, 2-MGTiB3g3, 3-MGTmB1, 4-MGTmB1g1, 5-MGTmB2g2, 6-MGTmB3g1, 7-MGTmC2g1,8-MAThD3g3, 9- MATmB1g1	369 (61.83)
Shallow (25-50 cm)	10-NHAmB1 ,11-NHAmB2g1	87 (14.62)
Moderately Shallow (50-75 cm)	12-DSImB1, 13-DSImB2g1	61 (10.29)
Moderately deep (75-100 cm)	14-NIRmB1	20 (3.3)
Very deep (<150 cm)	15- MARmB1	37 (6.14)
Soil gravelliness		
Non-gravelly (<15%)	3-MGTmB1, 10-NHAmB1, 12-DSImB1, 14-NIRmB1, 15- MARmB1	242 (40.52)
Gravelly (15-35%)	4-MGTmB1g1, 6-MGTmB3g1, 7-MGTmC2g1, 9- MATmB1g1, 11-NHAmB2g1, 13-DSImB2g1	86 (14. 4)
Very gravelly (35-60%)	5-MGTmB2g2	118 (19.68)
Extremely gravelly (60-80%)	1-MGThD3g3, 2-MGTiB3g3, 8-MAThD3g3,	129 (21.58)
	Soil erosion	
Slight	3-MGTmB1, 4-MGTmB1g1, 9- MATmB1g1, 10-NHAmB1, 12-DSImB1, 13-DSImB2g1, 14-NIRmB1, 15- MARmB1	276 (46.29)
Moderate	5-MGTmB2g2, 7-MGTmC2g1, 11-NHAmB2g1	165 (27.62)
Severe	1-MGThD3g3, 2-MGTiB3g3, 6-MGTmB3g1, 8-MAThD3g3	133 (22.28)
	Soil slope	
Very gently sloping (1-3%)	2-MGTiB3g3, 3-MGTmB1, 4-MGTmB1g1, 5-MGTmB2g2, 6-MGTmB3g1, 9- MATmB1g1, 10-NHAmB1 ,11-NHAmB2g1, 12-DSImB1, 13-DSImB2g1, 14-NIRmB1, 15- MARmB1	451 (75.44)
Gently sloping (3-5%)	7-MGTmC2g1	36 (5.96)
Moderately sloping (5-10%)	1-MGThD3g3, 8-MAThD3g3	88 (14.76)
	Surface soil texture	
Sandy clay loam	1-MGThD3g3, 8-MAThD3g3	88 (14.76)
Sandy clay	2-MGTiB3g3	41 (6.82)
Clay	3-MGTmB1, 4-MGTmB1g1, 5-MGTmB2g2, 6-MGTmB3g1, 7-MGTmC2g1, 9- MATmB1g1, 10-NHAmB1 , 11-NHAmB2g1, 12-DSImB1, 13-DSImB2g1, 14-NIRmB1, 15-MARmB1	445 (74.6)

Available water capacity		
Very low (<50 mm/m)	1-MGThD3g3, 2-MGTiB3g3, 3-MGTmB1, 4-MGTmB1g1, 5-MGTmB2g2, 6-MGTmB3g1, 7-MGTmC2g1, 8-MAThD3g3, 9- MATmB1g1	369 (61.83)
Low (51-100 mm/m)	10-NHAmB1, 11-NHAmB2g1	87 (14.62)
Medium (101-150 mm/m)	12-DSImB1, 13-DSImB2g1, 14-NIRmB1	81 (13.58)
Very high (>200 mm/m)	15- MARmB1	37 (6.14)
Soil pH		
Neutral (pH 6.5-7.3)	3-MGTmB1, 8-MAThD3g3, 11-NHAmB2g1,	58 (9.68)
Slightly Alkaline (7.3-7.8)	1-MGThD3g3, 3-MGTmB1, 5-MGTmB2g2, 6-MGTmB3g1, 7-MGTmC2g1, 8-MAThD3g3, 9-MATmB1g1, 12-DSImB1, 13-DSImB2g1	255 (42.69)
Moderately Alkaline (7.8-8.4)	2-MGTiB3g3, 3-MGTmB1, 4-MGTmB1g1, 5-MGTmB2g2, 10-NHAmB1, 12-DSImB1, 14-NIRmB1, 15- MARmB1	248 (41.51)
Strongly Alkaline (8.4-9.0)	10-NHAmB1	14 (2.30)

Table 3. Soil properties of different soil series of the study area

Soil series		pH	EC dS m^{-1}	OC (%)	P_2O_5 kg ha^{-1}	K_2O kg ha^{-1}	S mg kg^{-1}	B mg kg^{-1}	Cu mg kg^{-1}	Fe mg kg^{-1}	Mn mg kg^{-1}	Zn mg kg^{-1}
Margutti (MGT)	Mean	7.8	0.13	0.78	6.62	225.60	7.56	0.34	3.99	12.41	26.24	0.74
	Std	0.53	0.06	0.10	7.27	116.38	6.57	0.17	1.69	5.68	21.72	0.63
	CV%	6.77	44.61	13.2	109.9	51.59	86.88	51.09	42.29	45.79	82.78	85.8
Matki (MAT)	Mean	7.6	0.11	0.66	8.31	168.58	11.50	0.42	4.52	13.04	26.52	0.65
	Std	0.61	0.05	0.15	4.34	82.42	7.30	0.19	2.08	6.87	19.09	0.29
	CV%	8.0	40.7	23.3	52.2	48.9	63.5	46.1	46.1	52.7	72.0	43.8
Novinihala (NHA)	Mean	7.9	0.14	0.77	6.87	188.88	14.69	0.40	4.19	10.77	12.74	0.52
	Std	0.54	0.07	0.16	4.24	133.19	3.42	0.16	2.68	4.32	6.24	0.20
	CV%	6.8	46.9	21.1	61.7	70.5	23.3	41.3	63.9	40.1	49.0	38.7
Dinsi (DSI)	Mean	7.9	0.15	0.75	7.85	274.26	5.61	0.44	4.07	9.81	19.78	0.69
	Std	0.44	0.10	0.16	8.40	166.51	4.86	0.14	2.11	3.08	15.36	0.53
	CV%	5.6	65.6	21.1	107.1	60.7	86.7	31.9	51.8	31.4	77.6	77.3
Nirgudi (NIR)	Mean	7.5	0.09	0.86	1.15	145.20	2.08	0.25	4.96	14.05	25.63	0.63
	Std	0.13	0.05	0.08	1.62	58.79	0.59	0.18	0.34	3.27	7.76	0.24
	CV%	1.7	53.3	9.9	141.4	40.5	28.6	72.2	6.8	23.3	30.3	38.2
Mannur (MAR)	Mean	8.1	0.12	0.72	5.15	224.53	13.89	0.32	3.81	11.38	11.46	0.48
	Std	0.50	0.05	0.13	3.67	151.38	2.82	0.11	1.63	4.43	5.74	0.21
	CV%	6.2	46.1	17.6	71.3	67.4	20.3	33.3	42.7	38.9	50.1	42.8

3.6 Crop Suitability Maps with Area

Using the criteria in Table 4, the soil map units of the microwatershed are evaluated and land suitability maps for 2 major crops are generated. The crop requirements for growing pigeon pea *(Cajanus cajan)* (Table 4) were matched with the soil-site characteristics of the soils of the microwatershed and land suitability map for growing pigeon pea was generated. An area of about 117 ha (20%) is moderately suitable (S2) for pigeon pea and is distributed dominantly in the southwestern, central and northern part of the microwatershed. (Table 5) They have moderate limitations of texture, depth of rooting and erosion. An area of about 87 ha (15%) is marginally suitable (S3) and distributed in the southeastern, northeastern and northwestern part of the microwatershed (Fig. 7a). They have major limitations of depth of rooting and texture. Majority of area of about 369 ha (62%) is not suitable (N) for growing pigeon pea and distributed in all parts of the microwatershed. They have severe limitations of gravelliness, rooting depth and texture. In case of pigeon pea, it is suggested to sow early to obtain higher yields and also give one or two protective irrigations in the event of dry spells during crop season. The length of growing period is in support of pigeon pea cultivation in the areas rainfall exceeds half PET from the mid week of July and then extends upto mid week of October. The popular pigeon pea grown in the areas are CP-8863, BSMR-736, ICPL-87119, Guyul local, TS-3R (New), WRP1, GC11-39 and normally sown in 2nd fortnight of June [39]. The land evaluation exercise clearly brought out that only 35% of total area is suitable for pigeon pea as against current area of 80% of total area in the watershed. Approximately 50% of area can be used for other crops such as sunflower wherever supplementary irrigation facilities are available.

Table 4. Crop suitability criteria for two major crops in Mormanchi Microwatershed

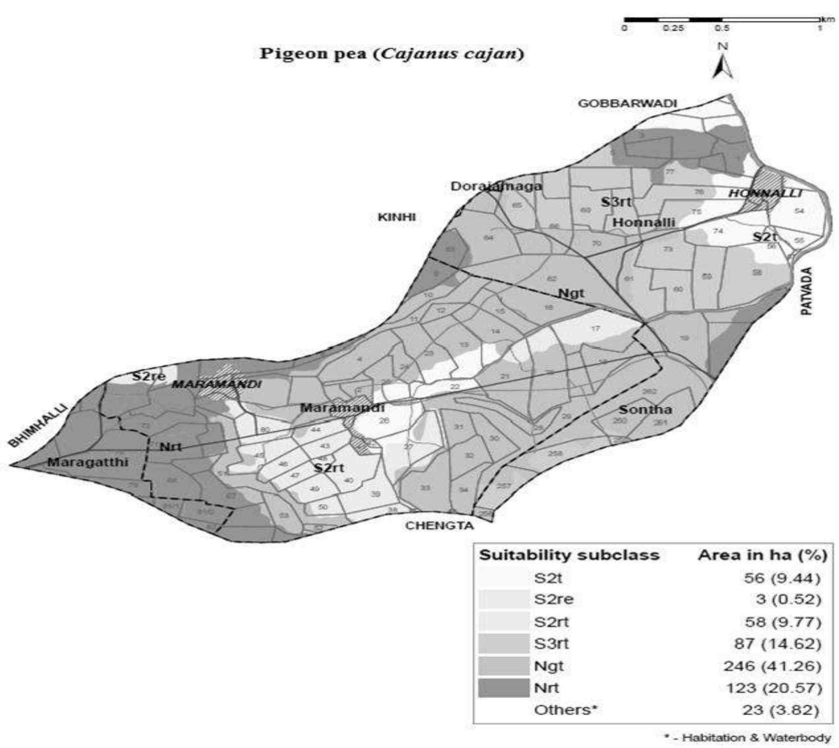
Crop requirement		**Rating**			
		Pigeon pea			
Soil –site characteristics	**Unit**	**Highly suitable (S1)**	**Moderately suitable (S2)**	**Marginally suitable (S3)**	**Not suitable (N)**
Slope	%	<3	3-5	5-10	>10
LGP	Days	>210	180-210	150-180	<150
Soil drainage	class	Well drained	Mod. to well drained	Imperfectly drained	Poorly drained
Soil reaction	pH	6.5-7.5	5.0-6.5 7.6-8.0	8.0-9.0	>9.0
Surface soil texture	Class	l, scl, sil, cl, sl	sicl, sic, c(m)	ls	S, fragmental
Soil depth	Cm	>100	85-100	40-85	<40
Gravel content	% vol.	<20	20-35	35-60	>60
Salinity (EC)	dS m^{-1}	<1.0	1.0-2.0	>2.0	-
Sodicity (ESP)	%	<10	10-15	>15	-
		Sorghum			
Slope	%	2-3	3-8	8-15	>15
LGP	Days	120-150	120-90	<90	
Soil drainage	class	Well to mod. drained	imperfect	Poorly/excessi vely	V. poorly
Soil reaction	pH	6.0-8.0	5.5-5.9 8.1-8.5	<5.5 8.6-9.0	>9.0
Surface soil texture	Class	C, cl, sicl, sc	l, sil, sic	Sl, ls	S, fragmental skeletal
Soil depth	Cm	100-75	50-75	30-50	<30
Gravel content	% vol.	5-15	15-30	30-60	>60
Salinity (EC)	dS m^{-1}	2-4	4-8	8-10	>10
Sodicity (ESP)	%	5-8	8-10	10-15	>15

Source: [22]

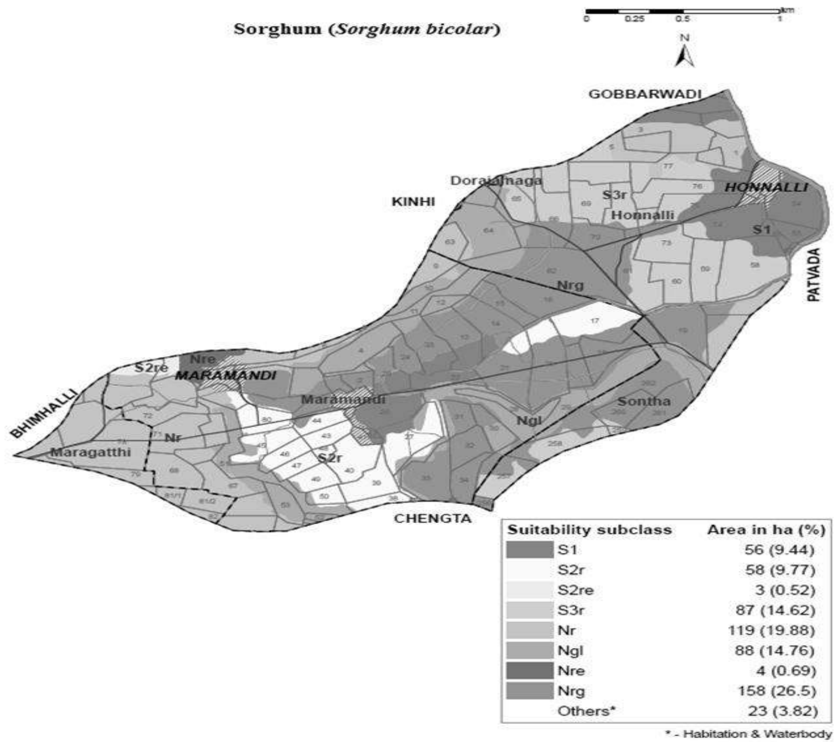
Table 5. Land suitability for various crops of the study area (Mormanchi Microwatershed)

Crops	Highly suitable (S1)	Moderately suitable (S2)	Marginally suitable (S3)
Mapping units	15- MARmB1, 14-NIRmB1	15- MARmB1, 14-NIRmB1	3-MGTmB1, 9- MATmB1g1, 10-NHAmB1, 12-DSImB1
		Suitability area in ha (%)	
Pigeon pea (*Cajanus cajan*)	-	117 (19.73%)	87 (14.62%)
Sorghum (*Sorghum bicolor*)	56 (9.4%)	61 (10.29%)	87 (14.62%)

The crop requirements for growing sorghum *(Sorghum bicolor)* (Table 4) are matched with the soil-site suitability. About 56 ha (9%) areas are highly suitable (S1) for growing sorghum with no limitations and distributed mainly in the central, northern and northeastern part of the microwatershed (Fig. 7b). Whereas 61 ha (10%) is moderately suitable (S2) distributed in the southwestern and central part with moderate limitations of erosion and rooting depth and 87 ha (15%) marginally suitable lands (S3) concentrated in southeastern, central and northern part with severe limitations of rooting depth (Table 5). About 369 ha (62%) is not suitable (N) for growing sorghum and distributed in all parts of the microwatershed. They have severe limitations of gravelliness, topography, erosion and rooting depth. They are grown under limited irrigation sorghum usually grown in dryland areas with soils less than 15 cm deep, using farmyard manures and household produced biofertilisers [40]. Short duration varieties are grown with duration of 65 days. They are mainly grown by small and marginal farmers (i.e. those with farm size less than 5 hectares) [41]. It is hereby suggested to modify the depth criteria in land evaluation exercises for sorghum to bring marginal areas under cultivation in the watershed. This is possible with the crop interventions suggested to enhance productivity of sorghum by organizing on farm demonstration trials with the integration of package of practices involving moisture conservation, integrated nutrient management, and improved varieties and by popularizing the "seed village" programme through gram panchayats.



(a)



(b)

Fig. 7. (a) Land suitability map of Pigeon pea (*Cajanus cajan*) and (b) sorghum (*Sorghum bicolor*)

4. CONCLUSION

The land resource information obtained from detailed soil survey shows that this micro watershed has six soil series belongs to the subgroups of vertisols and vertic integrades having low available sulphur and boron with wide spread phosphorus, Zn deficiency. The soil map with fifteen mapping units was used in land evaluation for sorghum and pigeon pea. The results showed that 35% of total is evaluated as suitable with limitations of soil depth, gravelliness and slope. To enhance productivity, it is suggested to go for early sowing of pigeon pea with supplementary irrigation in times of dry spells but for sorghum, soil-water conservation measures must be integrated with nutrient management.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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