



International Journal of Research in Agronomy

E-ISSN: 2618-0618
P-ISSN: 2618-060X
© Agronomy
NAAS Rating (2026): 5.20
www.agronomyjournals.com
2026; SP-9(7): 335-350
Received: 02-03-2026
Accepted: 05-04-2026

Praveenkumar B Naikodi
Department of Natural resource
management, University of
Horticultural Sciences Bagalkot,
Karnataka, India

Praveen B Jholgiker
Department of fruit science,
University of Horticultural
Sciences Bagalkote, Karnataka,
India

Ashok S Alur
Department of Natural resource
management, University of
Horticultural Sciences Bagalkote,
Karnataka, India

Ganesh Gowda Patil
Department of Social & Allied
Science, University of
Horticultural science Bagalkote,
Karnataka, India

Vijayshree
Watershed Development for
Prevention of Drought Project,
University of Horticultural
Sciences Bagalkote, Karnataka,
India

Ruben Ashirvadam
Watershed Development for
Prevention of Drought Project,
University of Horticultural
Sciences Bagalkote, Karnataka,
India

Aparna
Watershed Development for
Prevention of Drought Project,
University of Horticultural
Sciences Bagalkote, Karnataka,
India

Corresponding Author:
Praveenkumar B Naikodi
Department of Natural resource
management, University of
Horticultural Sciences Bagalkot,
Karnataka, India

Multi-criteria analysis of land resource properties for assessment of soil and land potential zones

**Praveenkumar B Naikodi, Praveen B Jholgiker, Ashok S Alur, Ganesh
Gowda Patil, Vijayshree, Ruben Ashirvadam and Aparna**

DOI: <https://www.doi.org/10.33545/2618060X.2026.v9.i7Se.6113>

Abstract

Favorable and limiting physical, chemical and biological characters of surface and subsurface soil of any given parcel of a land will decide the potential of land to fulfill the requirement of any crop to attain its highest productivity. It is only possible when capabilities land and requirement of crop plants are integrated to derive best possible combination who can support one another. To develop a robust decision support system for sustainable soil and land management towards enhancing their productivity with suitable crops, identifying potential zones of an area becomes very important. The objective of the present study is to identify soil and land potential zones by analyzing LRI properties of Kumar-Chincholi micro-watershed of Humnabad Taluk, Karnataka state through multi-criteria analysis using GIS and AHP. Surface features of the study area were recorded along with collection of 61 representative samples at an interval of 320m grid. Similarly, with the help of 9 representative soil profiles sub-surface characters were also studied. On the basis of field and lab analysis data, characterization of soil and land were achieved. Further, the status of properties like soil texture, depth, slope, erosion and soil organic carbon content was processed through multi-criteria analysis on GIS platform. Respective ratings of these parameters were analyzed through AHP to get weightages. Out of which, highest sum weightage value of 1.20000 was obtained for soil organic carbon and lowest sum weightage value of 0.66667 for sandy clay texture and shallow soil depth. All the thematic layers with their respective weightage values were integrated using spatial analytical tool. Through weighted overlay analysis, it was found that an area of 419.95 ha was identified as High potential zone, whereas an area of 144.81 ha belongs to Low potential zone respectively, out of the total study area (585.74 ha). The findings were cross verified with crop suitability categories (S1, S2, S3 and N) established as per the FAO 1976 for selected fruit, vegetable, flower, cereal, and pulse crops of the area. Crops with S1 & S2 category were found falling under high soil and land potential zone, whereas S2, S3, and N suitability categories were found falling under low soil and land potential zone. Availability of location of soil and land potential zone on a large scale map can make it possible to decide suitable and specific interventions to ensure sustainable enhancement of productivity. The outcome of such research findings, which includes intensive assessment of soil and land resources of a segment of an area in the form of soil mapping unit to a micro watershed similar condition can be a critical input in developing a robust decision support system towards sustainable enhancement of productivity.

Keywords: Land resource inventory (LRI), spatial data, GIS approach, Analytic Hierarchic Process (AHP), weighted overlay analysis, soil and land potential zones

1.Introduction

Most of the ecosystem services and functions that enable life to exist on earth are supported by soil as a medium where up to 95 per cent of the food we eat is directly or indirectly produced through soil (FAO, 2015) [66]. As per UN projection, disproportionate increase in world total human population would reach 9.15 billion in 2050, which may lead to overall demand for agricultural products is expected to grow at 1.1 per cent per year from 2005/2007-2050 (Alexandratos, N., & Bruinsma, J. (2012) [6].

It has also alarmed that around 24 billion tons of fertile soil are being lost per year largely due to unsustainable agriculture practices. If this trend continues, 95 percent of the earth's land area could become degraded by 2050 (Hossain, A *et al.*, 2021) [32]. In spite of this, the pressure on shrinking resources like soil for producing more food and providing shelter to all the species is mounting at a very rapid rate.

In addition to this unfavorable weather conditions posed due to climate change have shown an immediate and direct impact on yields, income sources of farmers and other farming sector, now and then. Consequently, the long-term resilience of agroecosystems and the stability of food production systems are becoming increasingly vulnerable (FAO, 2022). As a result, approaches followed in intensification of agricultural production are leading towards lower environmental, social, and economic critical limits (Antunes, P *et al.*, 2017)^[8]. Unscientific utilization of natural resources in the agriculture has caused a variety of negative environmental outcomes, such as raise in the area under problematic soils, soil erosion leading to land degradation, groundwater depletion, agrochemical pollution, increase of greenhouse gas emissions, reduction in productivity, etc. (Fallah-Alipour, S *et al.*, 2018; Roy, R. & Chan, N. W. (2012); Mandal, D *et al.*, 2021)^[26, 51, 40]. The achievement of targeted productivity in many intensive systems has become complicated due to current management practices and the situation where levels of difficulty are increasing (McKenzie, C.F., and Williams, J. (2015)^[41]. But stabilizing and improving crop productivity has to be assured in order to meet global food demand and to sustain the economic profitability of farms and social well-being (Ikerd, J. (1993)^[33]. The efforts have to be reinforced with more eco-efficient management strategies to minimize the negative effects on the environment (Shennan, C *et al.*, 2017; Stuart, A. M *et al.*, 2018)^[59, 62]. Several research findings have reported that the unscientific use of land and soil leads to a decline in the health and productivity of global land resources (Cowie, A. L *et al.*, 2018; Akbari, M *et al.*, 2019)^[16, 4]. Worldwide collaborative programmes are being implanted under a broad terminology called Sustainable Land Management (SLM) where, use of land resources such as soils, water, animals and plants for the production of goods to meet changing human needs while assuring the long-term productive potential of these resources and the maintenance of their environmental functions (Alemu, M. M. (2016); Burnham, P *et al.*, 2003)^[5, 13].

To conserve, protect and enhance the productivity of natural resources in a sustainable way, detailed understanding about nature and properties, productive functions of soil and land is very important as they are the key indicators of quality, capabilities and potentials apart from being integral part of ecosystems (Novak, P *et al.*, (2010)^[44]. Capabilities of soil and land resources to support growth and development of a crop will be decided by individual and collective influence of physical, chemical and biological properties of soil (Parikh *et al.*, 2012)^[48]. Critical soil functions that influence productivity in any soil are those that provide physical support, rooting environment, available water, aeration, and essential nutrients (Karlen, 2005)^[36]. Limitations and potentials of the land, sets the baseline for land uses planning (Bandyopadhyay *et al.*, 2009)^[10]. Therefore, a land utility for crop production based on site specific data on important chemical and physical properties of surface and sub-surface soil will be key factors which decides crop management plan for a given parcel of land towards enhancing crop productivity (AbdelRahman *et al.*, 2016)^[11].

Through adoption of an intensive detailed soil survey called land resource inventory (LRI), the ground data on site specific soil and land characters grouped into different units based on their respective management requirements at a micro watershed scale can be achieved. Information on inherent properties, their influence on each other's potential and capabilities (Greenland, D. J *et al.*, 1998; Richardson, G. S *et al.*, 2023)^[30, 50] guides to evaluate land suitability for different crops thereby becomes critical input in deciding suitable intervention of increasing

productivity (Pramanik, M. K. (2016)^[49] and sustainable development of agriculture (El Baroudy, A. A. (2016; Falasca, S. L *et al.*, 2012)^[19, 25]. Such interventions applied in implementing the land management programs have to be problem and area specific along with a mechanism to assess the effectiveness of practices, policies, and strategies followed by follow up actions (Daniel, 2020). In this line, several efforts have been made by various researchers around the world, in identifying potential zones with due importance to the characters of soil and land through multi criteria analysis at different scales. But most of the studies have been done considering large scale spatial and ancillary data. For development of site or micro watershed specific suitable and sustainable productivity enhancement plan, integration of intensive ground and spatial data of higher resolution is crucial (Delgado, J. A *et al.*, 2019; Nhamo, L *et al.*, 2020; Wang, G *et al.*, 2016)^[18, 46, 65]. Accordingly, land resource inventory on a base map of 1:7920 scale was conducted (LRI) for Kumarchincholi micro watershed, through which characterization of surface and subsurface properties was achieved and mapped with the help of GIS. Further data of LRI was statistically processed to identify the weightage (%) by considering ratings of different soil and land properties to assess the influence of these properties in deciding the potential of a given land parcels (O'geen, 2008)^[47]. The study also focused on identifying the most influential property of a land parcel in determining crop suitability, as well as mapping its spatial distribution. The analysis allows identifying important limiting factors for cultivation of a crop and enables decision makers to develop a crop management system for increasing the land productivity (Halder *et al.*, 2013)^[31]. Therefore, AHP was applied to the individual and set of characters (mapping unit) of soil and land to achieve higher accuracy in the process of establishing soil and land potential zones. Further, the outcome was evaluated against the crop suitability categories (S1, S2, S3 & N). Delineation of soil and land potential zones was done with the help of spatial analyst tool like weighted overlay analysis, integrated with multi-criteria analysis on GIS platform (Ennaji *et al.*, 2018)^[21].

Such database can be a part of decision support system for bringing out the site specific recommendations at cadastral level for a given micro watershed (MWS). The outcome of such study will also give an insight for prioritization of the area in the MWS planning and implementation of site specific developmental activities aimed at enhancement of productivity rejuvenation of degraded lands in a sustainable way on the basis of science. Importantly, to explore the wide applicability of such models can be extrapolated for designing a management decision support system in different parts of the world. Where, productivity of similar sets of soil and land resource are to be enhanced (Mueller, L *et al.*, 2010)^[43].

2. Study Area

The study area selected for this work falls in the lateritic landscape of the north eastern transitional zone of Karnataka state of India. The Kumarchincholi micro-watershed covering an area of 585.74 ha belongs to the Belhalli sub watershed in Humanabad Taluka, Bidar districts, Karnataka, India. The MWS lies between 77°9'2.894"E longitude & 17°55'21.430"N latitude (Figure 1). Rain fed agriculture is a common practice in the micro-watershed, which receives an average rainfall of 847 mm with mean annual evapo-transpiration of 645.2 mm. The elevation of the study area ranges from 523 to 576 above MSL. The major area of the watershed is under agricultural and horticultural activities. Agricultural crops like red gram, soya

bean, bengal gram, sorghum, wheat and sugarcane are grown traditionally. Perennial Horticulture crops like mango, guava, lime, banana, sapota, papaya, cashew, tamarind and seasonal

crops like solanaceous vegetables, marigold and chrysanthemum are commonly cultivated. The cropping seasons in MWS are kharif (rainy) and Rabi (winter).

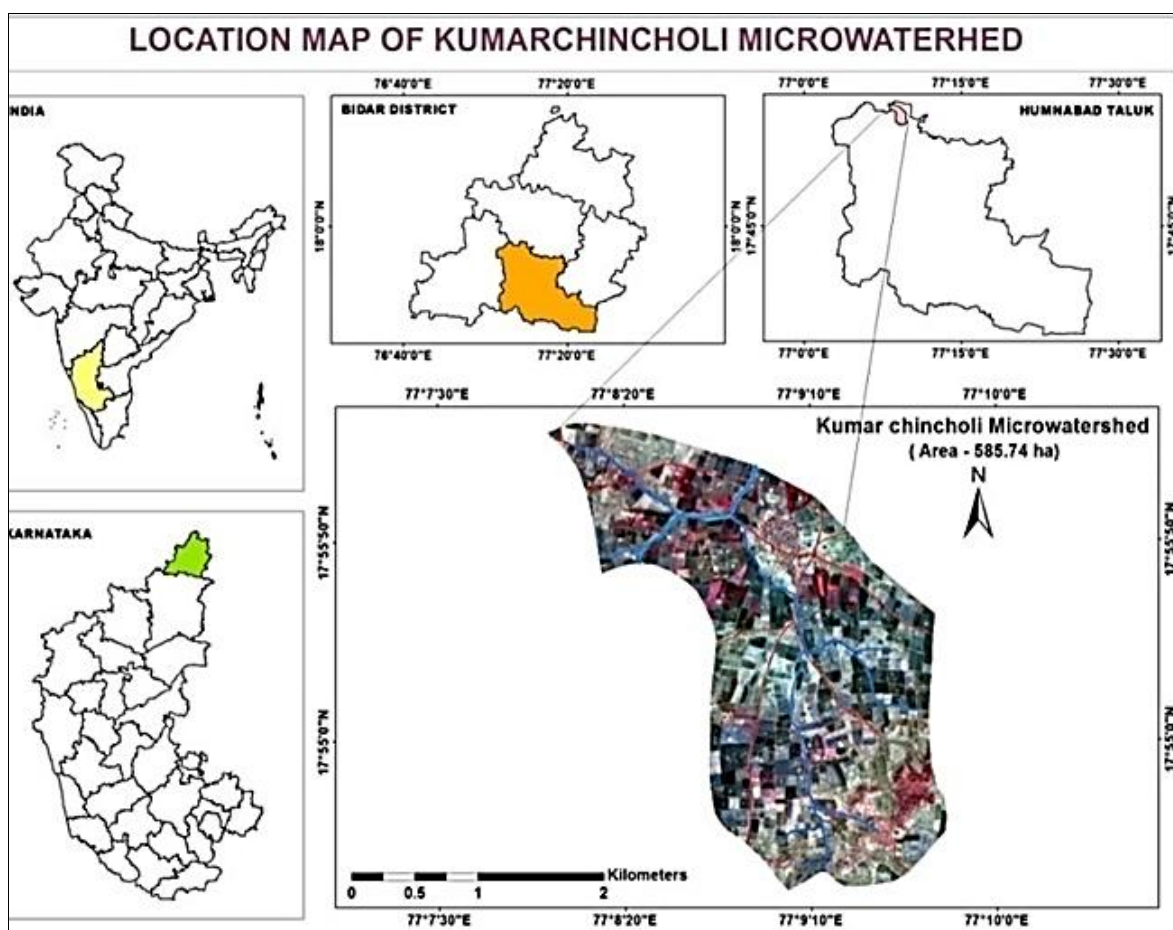


Fig 1: Location Map of Kumarchincholi Micro watershed

3. Materials and Method

For evaluating soil and land potential zones of an area, parameters like soil texture, depth, slope, soil erosion and soil organic carbon status (Table 1) have been considered as critical inputs in several research findings. The data required for the present study is generated through a standardized methodology of the soil and land survey called “Land Resource Inventory (LRI)” using base maps (cadastral and satellite imagery) of scale 1:7920 provided by KSRSAC.

Where the assessment of soil physical properties like slope, erosion, depth, texture etc. have been done along with the generation of soil map. Also, the soil samples were collected using a systematic sampling method at a grid interval of 320m. Further, these soil samples were processed in a lab to obtain the soil organic carbon status data. The outcomes of the LRI and the lab were further processed on a GIS platform to generate layers. Then using AHP technique and expert opinion weights has been assigned to all the parameters. The thematic layers for all these contributing parameters were superimposed by a weighted overlay method in ArcGIS 10.6.1 software. Two categories of soil and land potential zones were identified to generate the final map of soil and land potential zone as high and low soil and land

potential zones. The complete methodology adopted for the present study has been depicted in the form of flowchart (Figure 2).

Table 1: Data and data sources

Sl No.	Data	Data sources
1.	Soil texture	LRI field data
2.	Soil depth	
3.	Slope	
4.	Soil erosion	
5.	Soil organic carbon	LRI and Lab analysis

Number of case studies around the world for assessment of agricultural land suitability analysis, analytical hierarchy process (AHP) (Saaty 1980) technique integrated with GIS application has been used which involves pairwise and weighted multi-criteria analysis on a number of selected biophysical drivers. Land suitability analysis of local and regional levels for watershed planning has been achieved through said technique (Steiner *et al.* 2000)^[61], vegetation (Zolekar and Bhagat 2015)^[68] and agriculture (Shalaby *et al.* 2006; Bandyopadhyay *et al.* 2009; Motuma *et al.* 2016)^[58, 10, 42]

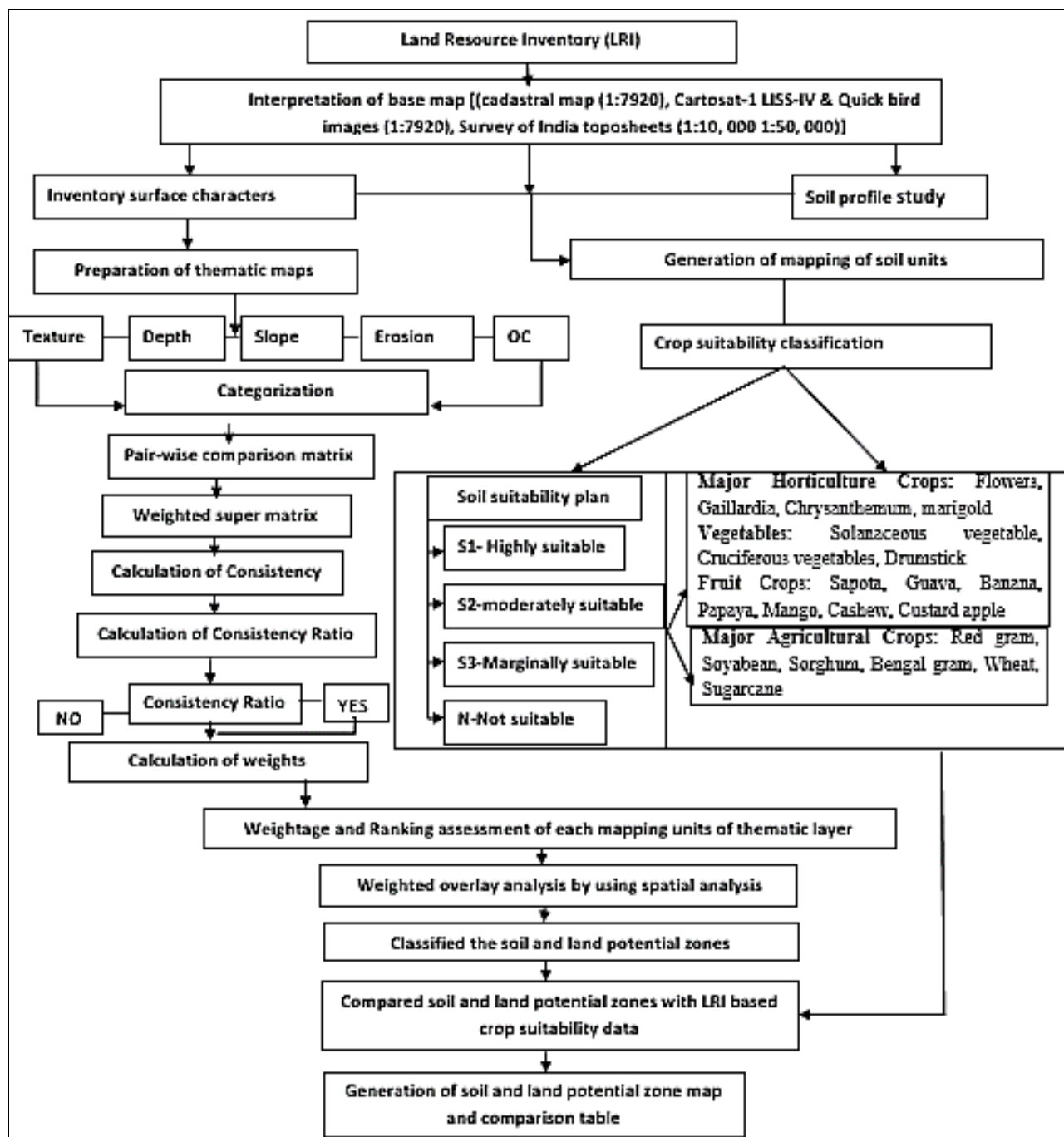


Fig 2: Flow chart of methodology adopted in the study

3.1 Land Resource Inventory

Land Resource Inventory (LRI) is an assessment of the status and changing condition of soil, water and related resources at the field level. Using satellite imagery (merged image of Cartosat-II and LISS-IV) provided by KSRSAC visual interpretation of satellite image was done considering distinguishable variations in spectral signature, shape, size, pattern, tone and texture. Then reconnaissance traversing of the Kumarchincholi micro watershed was carried out. The detailed soil survey of the study area was conducted to and surface land features like soil texture, extent of erosion, slope, aspect and amount of gravel/rock fragments cover on the surface were studied at a grid interval of

320 m. To study the sub-surface characteristics like depth soil profiles were opened at 9 representative locations in different transects spread across the MWS and horizon wise soil properties in the profile were recorded (Figure 3). The soil and site characteristics were recorded for all profile sites on a standard Performa as per the guidelines given in the USDA Soil Survey Manual. Soil mapping units were identified based on the interpretation of data in the MWS. The mapping units based on their potentials and limiting characters were grouped into different management units on the basis of similarity of requirements management practices (Soil Survey Staff, 1993) [60].

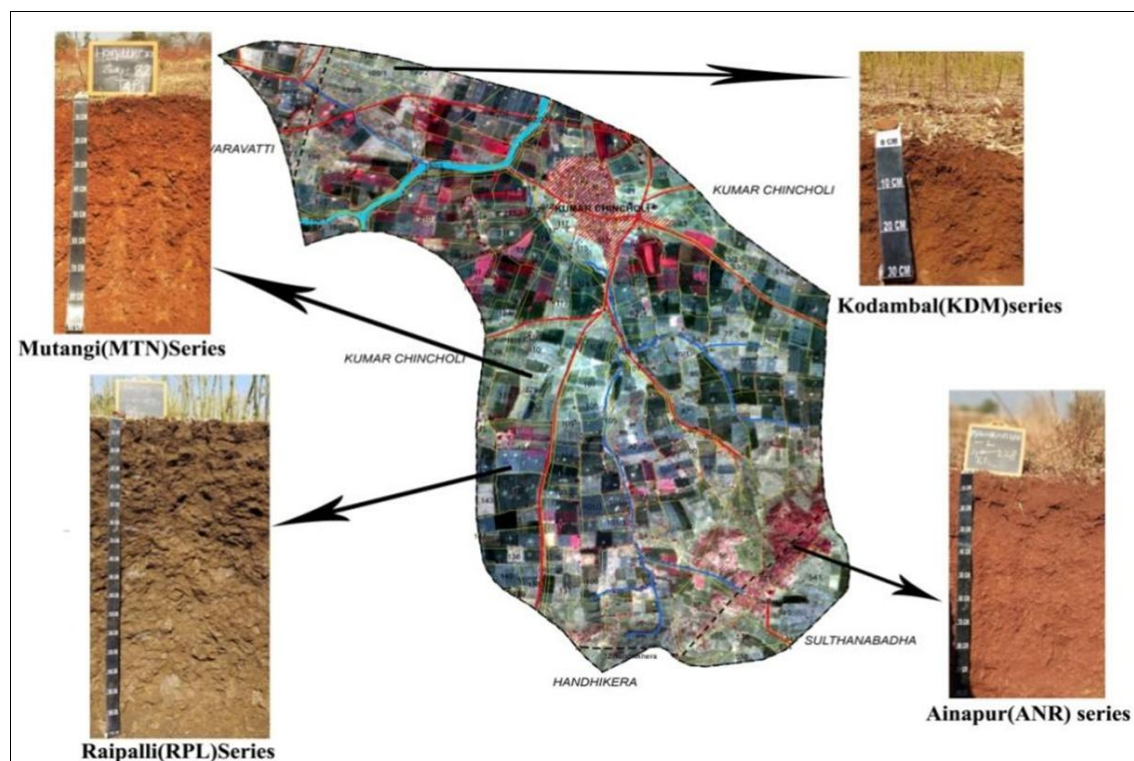


Fig 3: Profile Locations of Kumarchincholi micro watershed

Table 2: Brief description of soil series identified and their mapping units

Brief description of soil series	
1. Kodambal(KDM) series Classification: Fine, mixed, isohyperthermic, Lithic Ustorthents Location: 17° 37' 56.2'' N, 77° 16' 16.2'' E Village: Babhulgaon, Tehsil: Humanabad, District: Bidar, Profile No : BabhulgaonT1/P3 Physiographic position: Nearly level upland (side slope) Elevation : 655m Slope and erosion status: 1 to 3 percent, moderately eroded Drainage and permeability: Well drained with rapid permeability Surface gravelliness: 15-35 percent Land use: Red gram Geology: Laterite Depth of the soil: 40 to 46 cm (shallow). Soil colour: Dark red to dark reddish brown. Soil texture: sandy clay surface textured and sandy clay to clay subsurface. The gravel range from 15 to 35 percent. Mapping units: KDMiB2g1	2. Mutangi(MTN) Series Classification: Clayey-skeletal, mixed, isohyperthermic, TypicHaplustalfs Location: 13° 38' 45.6'' N, 77° 16' 30.6'' E Village: Mustarwadi, Tehsil: Humanabad, District: Bidar, Profile No: MWT4/P1 Physiographic position: Nearly level upland, midslope Elevation: 643m Slope and erosion status: 1 to 3 percent, moderately eroded Drainage and permeability: Well drained with rapid permeability Surface stoniness: <2 percent Land use: Red gram Geology: Laterite Depth of the soil :> 150 cm (very deep). Soil colour: dark red to dark reddish brown. Soil texture: sandy clay surface textured and sandy clay to clay subsurface. The gravel range from 35 to 60 percent. Mapping units: MTNiB2g1
3. Ainapur(ANR) series Classification: Clayey-skeletal, mixed, isohyperthermic, RhodicHaplustalfs. Location: 17°38' 23.2'' N, 77° 11' 3.6'' E Village: Raipalli, Tehsil: Humanabad, District: Bidar, Profile No: T2/P2 Physiographic position: Upland to mid-up land Elevation: 632m Slope, and erosion status: 1 to 3 per cent, moderate to severe erosion Drainage and permeability: Moderately Well drained with Moderate permeability Surface gravelliness: 15-35 percent Land use: Sorghum, Redgram Geology: Laterite Depth of the soil: 75 to 100 cm (moderately deep). Soil colour: Dark reddish brown to red, clayey soils. Soil texture: Gravelly sandy clay to clay with gravel ranges from 15 to 35 per cent. Mapping units: ANRiB2g1	4. Raipalli(RPL) Series Classification: Very fine, mixed, isohyperthermic, TypicHaplusterts Location: 13° 38' 32'' N, 77° 16' 51.3'' E Village: Badrapur, Tehsil: Humanabad, District: Bidar, Profile No : MWT2/P4 Physiographic position: Nearly level upland (side slope) Elevation : 638m Slope and erosion status: 1 to 3 percent, moderately eroded Drainage and permeability: Well drained with rapid permeability Land use: Sorghum Geology: Laterite Depth of the soil :> 150 cm (very deep). Soil colour: of the soil is very dark greyish brown to very dark grey. Soil texture: Clay textured both surface and subsurface. Mapping units: RPLmB2

Four soil series were identified in the study area (585.74 ha) through LRI which were Kodambal (KDM), Ainapur (ANR), Muttangi (MTN) and Raipalli (RPL). Brief description with profile photos of the soil series has been furnished in (Table 2&3). Maximum area of 419.95 ha (71.55%) has been covered by RPL series which is denoted with RPLmB2 mapping unit,

ANR series with a mapping unit ANRiB2g1 is occupying an area of 73 ha (12.51%), MTN series with MTNiB2g1 mapping unit is covering an area of 53 ha (9.07%) and least area of 18ha (3.15%) has been covered by KDM series with mapping unit of KDMiB2g1 as shown in (Figure 4 & Table 4).

Table 3: Mapping Unit Description

Sl.No.	Mapping units	Mapping Units description	Area covered (ha)	Area in%
1	KDMiB2g1	Shallow, sandy clay soils developed from lateritic on very gently sloping level midlands; sandy clay surface texture on 1-3% slope, moderately eroded with gravelly(15-35%)	18	(3.15)
2	ANRiB2g1	Moderately deep, sandy clay soils developed from lateritic on very gently sloping level midlands; sandy clay surface texture on 1-3% slope, moderately eroded with gravelly (15-35%)	73	(12.51)
3	MTNiB2g1	Moderately deep, sandy clay soils developed from lateritic on very gently sloping level midlands; sandy clay surface texture on 1-3% slope, moderately eroded with gravelly(15-35%)	53	(9.07)
4	RPLmB2	Very deep, clay soils developed from lateritic on very gently sloping level lowlands; clay surface texture on 1-3% slope, moderately eroded	420	(71.62)

Table 4: Area Distribution of Mapping units

Sl. No.	Mapping units	Area in ha	Area in percentage
1.	ANRiB2g1	73	12.51%
2.	KDMiB2g1	18	3.15%
3.	MTNiB2g1	53	9.07%
4.	RPLmB2	420	71.62%
5.	Others	21	3.64%
Total area		585	100%

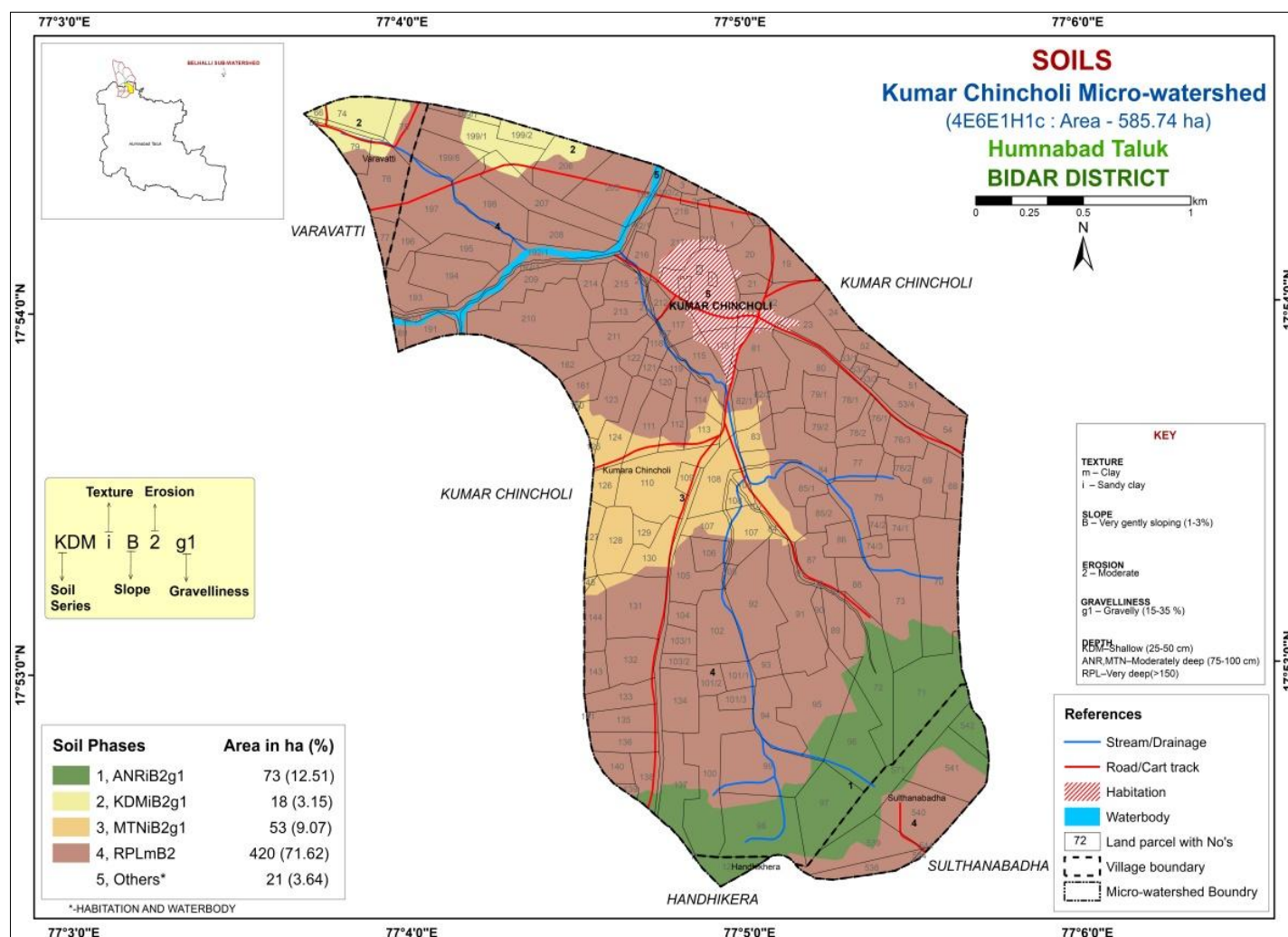


Fig 4: Soil Map of Kumarchincholi micro watershed.

The data obtained from LRI were reclassified and thematic maps were generated using ArcGIS 10.6.1 software. Out of total surveyed area (585.74 ha), 71.62% of the soils were found to be of clay textured and the remaining 24.73% belongs to sandy clay textural subclass (Figure 5). Studies on soil depth revealed that the soil in MWS existed in three soil depth classes. A Major area

of 71.62% falls under very deep, followed by 21.58% with moderately deep and only 3.15% belonged to the shallow soil depth class (Figure 6). With respect to slope features, 96.36% of the area were identified as very gently sloping coupled with moderate erosion hazard (Figure 7 & 8).

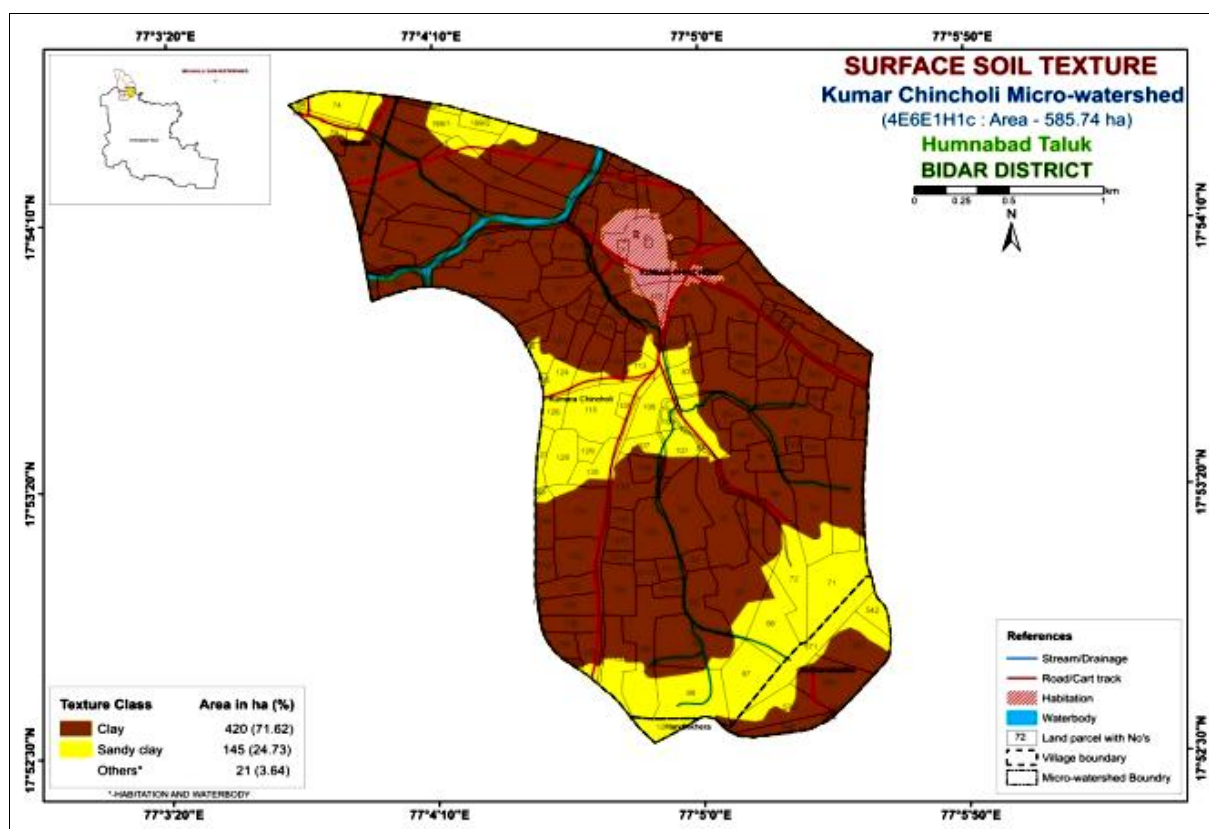


Fig 5: Soil Texture of Kumarchincholi micro- watershed

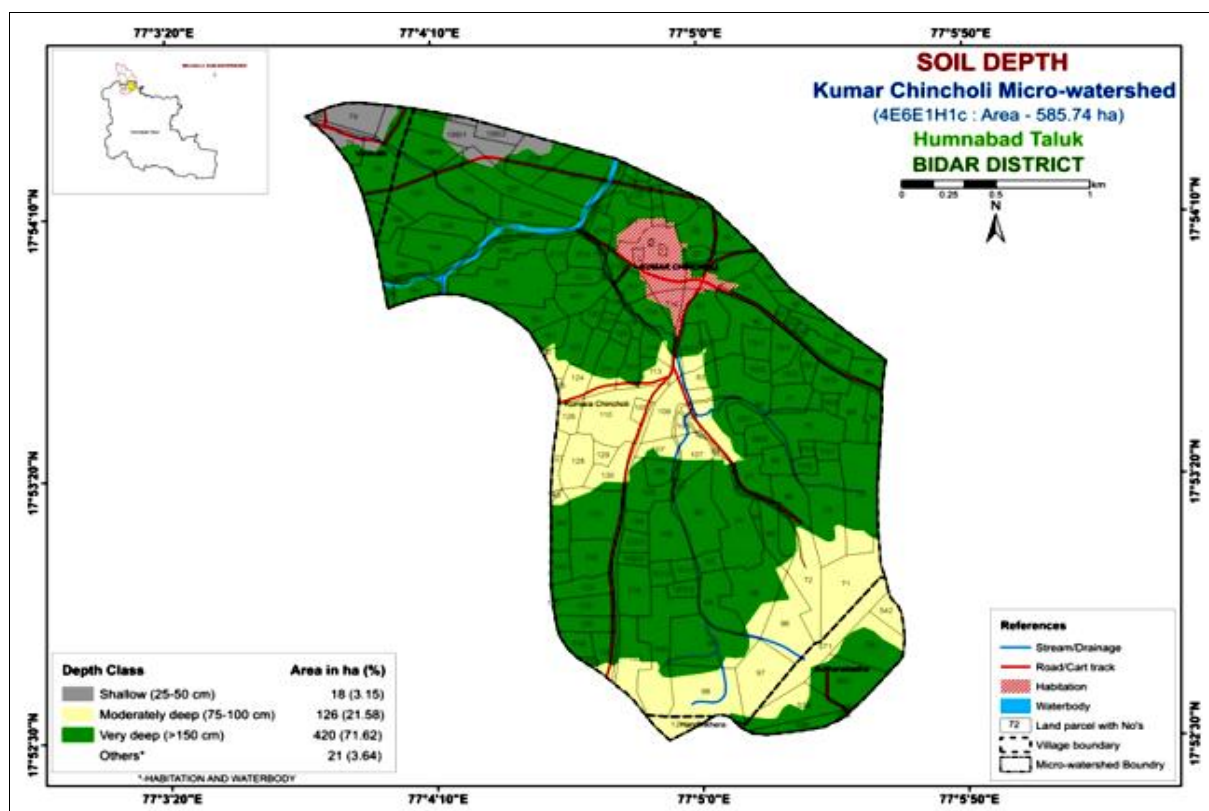


Fig 6: Soil Depth of Kumarchincholi micro- watershed.

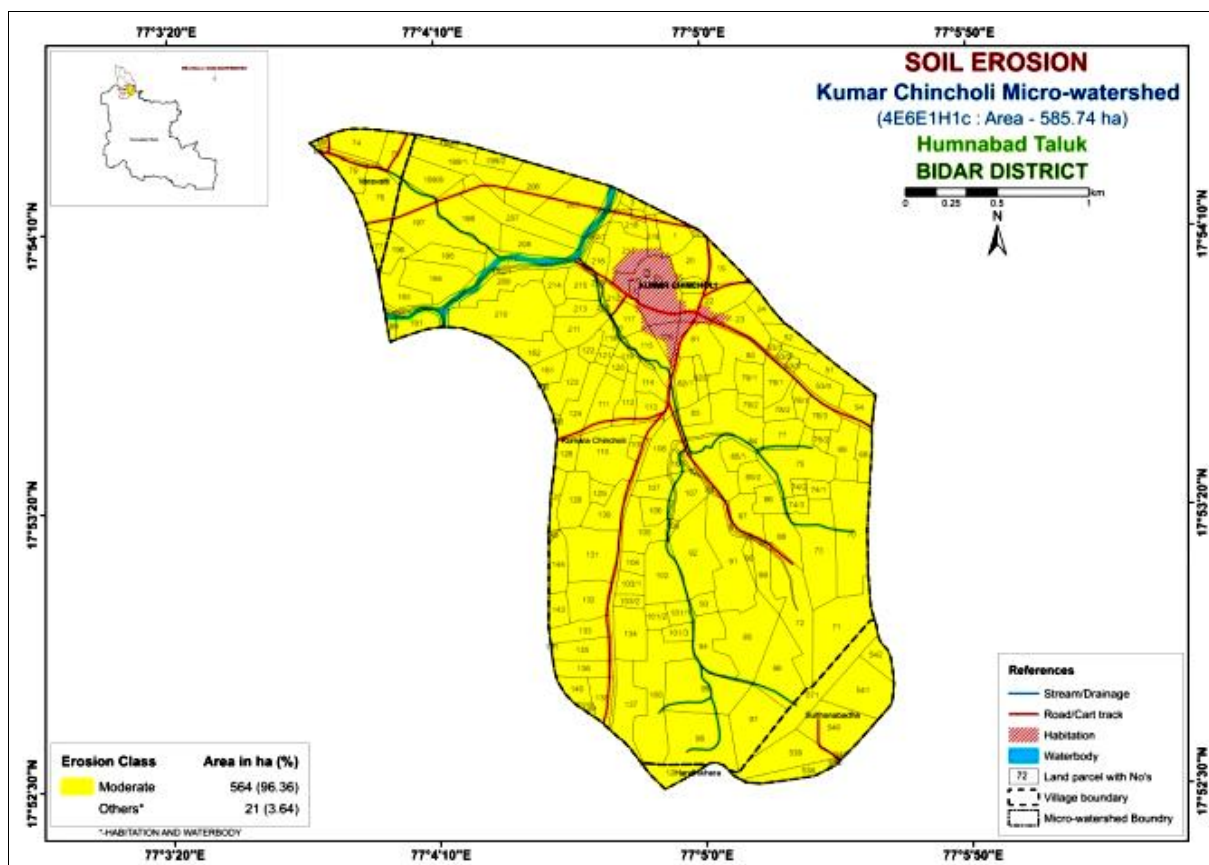


Fig 7: Soil Erosion of Kumarchincholi micro watershed.

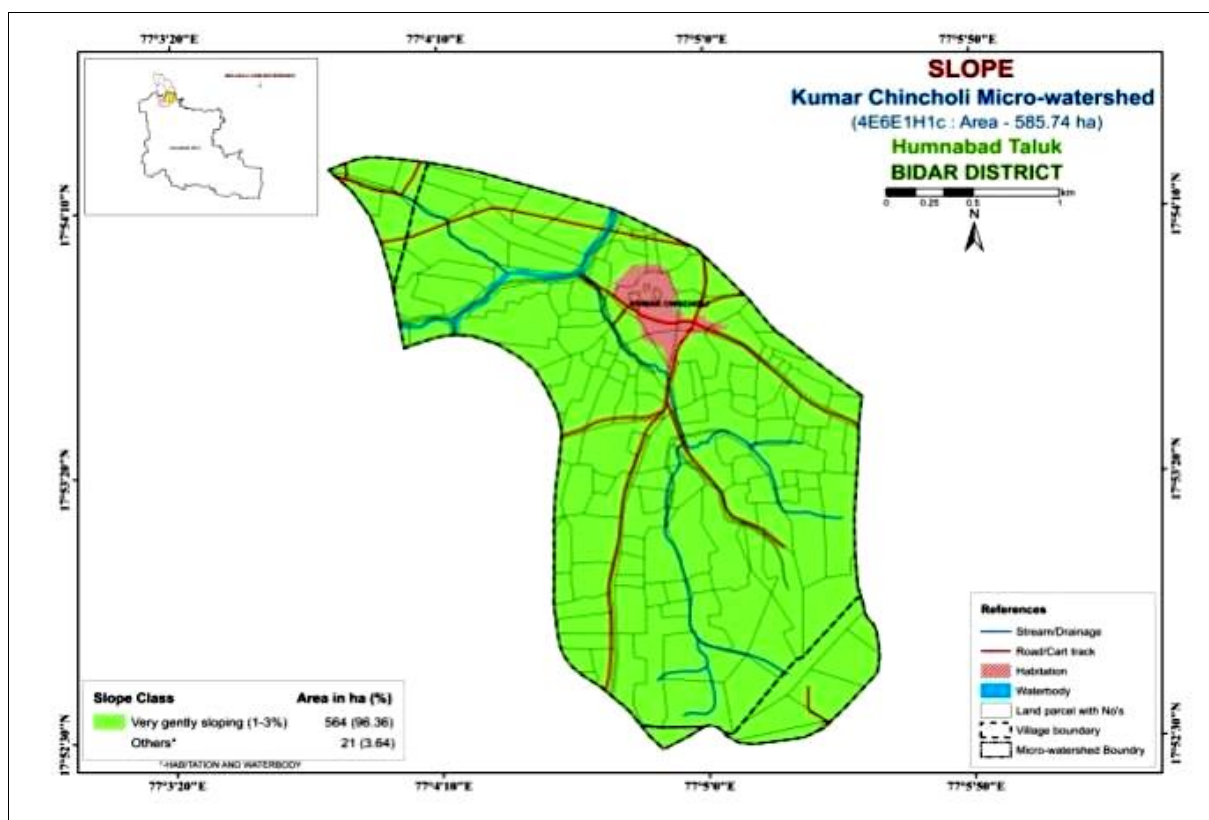


Fig 8: Soil Slope of Kumarchincholi micro watershed

3.2 Soil sampling and Analysis

The surface soil samples (61 No's) were collected using a systematic sampling method at different grid locations at an interval of 320m and at a depth of 0-30 cm for lab analysis.

Surface and profile soil samples were air dried and sewed through 0.5 mm sew for analysis of organic carbon content through Potassium di-chromate method (CA, W. (1934). Later, the results of the lab were processed under GIS environment.

The fertility data was interpolated using kriging method and soil organic carbon layer and map was generated using ArcGIS 10.6.1 software. With respect to soil organic carbon status, all

the area was found to be belonging to High category as depicted in the form of maps (Figure 9).

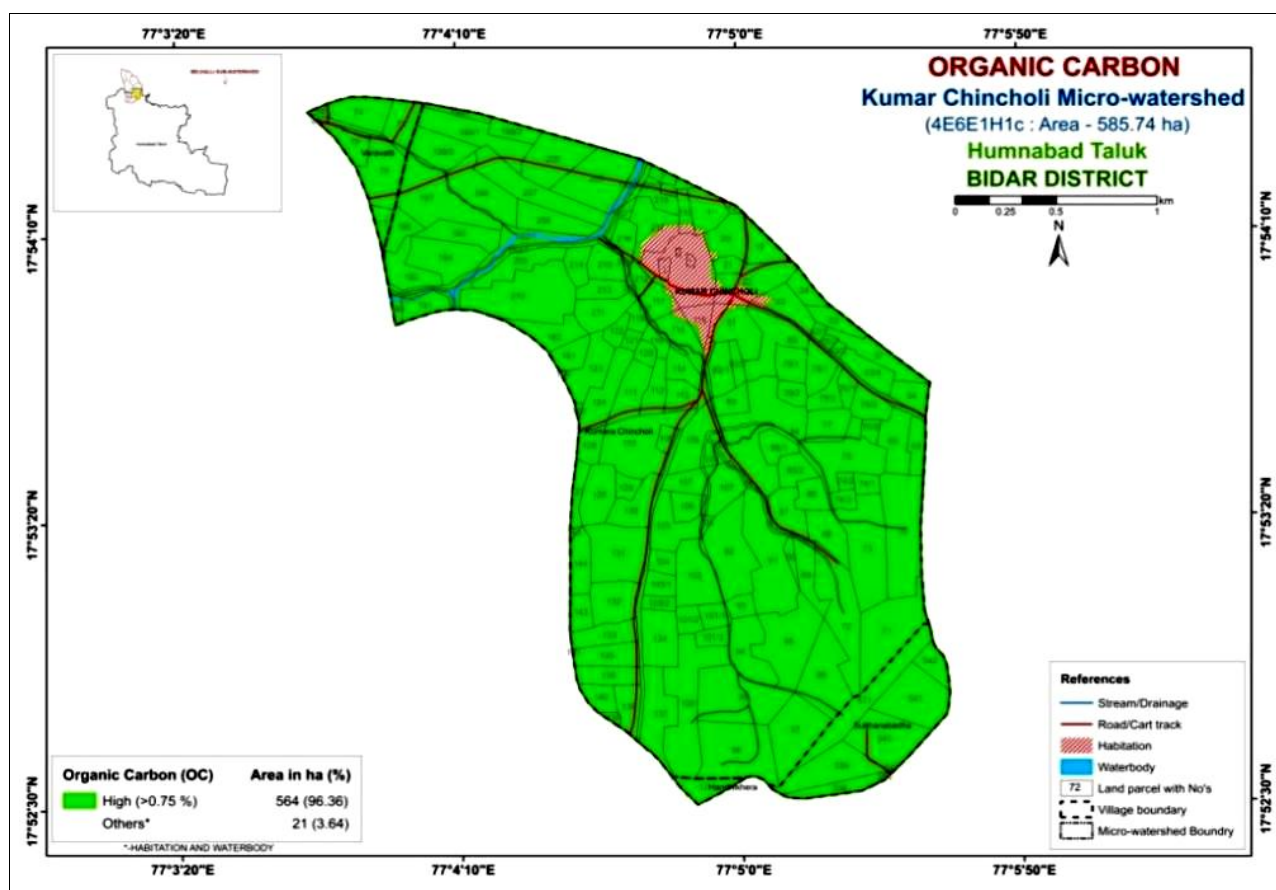


Fig 9: Soil Organic Carbon Map of Kumarchincholi micro watershed

3.3 Land suitability for major crops

The soil mapping units established in the kumarchincholi micro watershed were assessed for their suitability for growing food, fodder, fiber and other horticulture crops by following the procedure as outlined by (FAO 1983). Crop requirements were identified for sustainable cultivation of crops from the available research data and also by referring to crop suitability manual prepared by (Naidu *et al.*, (2006) ^[45] and Natarajan *et al.*, (2015) ^[1]. The crop requirements were matched with the soil and land characteristics (Table 9) to arrive at the crop suitability. The land suitability classification for different crops, viz., two orders were recognized, order S-Suitable and order N-Not suitable. Further, the orders have classes, sub-classes and units. Order-S has three classes, Class S1-Highly Suitable, Class S2-Moderately Suitable and Class S3-Marginally Suitable. Order N has two classes, N1-Currently not Suitable and N2-Permanently not Suitable. There are no sub-classes within the class S1 as they will have very minor or no limitations for crop growth. Classes S2 and S3 are divided into sub-classes based on the kinds of limitations encountered during cultivation. The limitations that affect crop production are erratic rainfall and its distribution(c), erosion hazard (e), rooting condition (r), texture of soil (t), gravelliness (g), stoniness (st), nutrient availability (n), topography (l), moisture availability (m) drainage (w) and calcareousness (z). These limitations are indicated as lower case letters to the class symbol. In the present investigation the soil mapping units in the MWS were evaluated and classified up to subclass level.

The soil map units of the micro watershed were evaluated using the criteria mentioned earlier and land suitability maps for 17

major annual and perennial crops were generated. The detailed information on the kind of suitability of each of the soil phase for the crops assessed is given in (Table 9).

3.4 Deriving weights for criteria maps using Analytic hierarchy process(AHP)

The analytic hierarchy process is a multi-attribute land evaluation technique which allows to determine the weights of these multiple and heterogeneous criteria indicating relative importance (Zhang *et al.*, 2014). In the present investigation, an effort has been made to assess the soil and land potential index to a mapping unit which includes the soil series and different phases of characters of soil and land in Kumarchincholi MWS. Thematic layers of different surface and sub-surface characters with their respective ratings were analyzed through AHP (Agarwal *et al.*, 2013) method to get their weightages.

Based on the degree of role played by the different soil and land characters in deciding the productivity, the relative importance values were determined following Storrie index (O'geen, 2008) ^[4]. Where a saaty's scale score of 1 to 9 of the respective importance were obtained from (Table 5). A pairwise comparison matrix is derived using Storrie rating methods 9 point importance scale based on thematic and fertility layers used for soil and land suitability.

The AHP captures the idea of uncertainty in judgments through the principal Eigen value and the consistency index (CI) (Saaty, 2004). Consistency Index (CI) as a deviation or the degree of consistency was derived using the following equation:

$$CI = (\lambda_{max} - n) / (n - 1)$$

Where $\lambda_{\max}$ is the largest Eigen value of the pairwise comparison matrix and n is the number of classes (Alonso *et al.*, 2006)
Consistency Ratio (CR) is a measure of consistency of pair wise comparison matrix and is given by the equation.
 $CR = CI/RI$

Where, RI is the ratio Index. The value of RI for different n values is given in (Table 6). When the CR value is less than 0.10, the matrix indicates a reasonable consistency. The calculated results of weight would be accepted when the consistency ratio was satisfactory.

Table 5: Saaty's scale 1-9 scale of relative importance

Scale	1	2	3	4	5	6	7	8	9
Importance	Equal importance	Weak	Moderate importance	Moderate plus	Strong importance	Strong plus	Very strong importance	Very, very strong	Extreme importance

Table 6: Saaty's ratio index for different values of $n=22$ (Saat'y T.L. *et al.*, 1977, 2004, 2008; Alonso *et al.*, 2006)

N	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.46	1.49	1.52	1.54	1.56	1.58	1.59

Pairwise Comparison matrix

Criteria	Rankings	5	7	5	8	9	9	8	9
soil texture	5	1.00	0.71	1.00	0.63	0.56	0.56	0.63	0.56
	7	1.40	1.00	1.40	0.88	0.78	0.78	0.88	0.78
soil depth	5	1.00	0.71	1.00	0.63	0.56	0.56	0.63	0.56
	8	1.60	1.14	1.60	1.00	0.89	0.89	1.00	0.89
	9	1.80	1.29	1.80	1.13	1.00	1.00	1.13	1.00
slope	9	1.80	1.29	1.80	1.13	1.00	1.00	1.13	1.00
Erosion	8	1.60	1.14	1.60	1.00	0.89	0.89	1.00	0.89
organic carbon	9	1.80	1.29	1.80	1.13	1.00	1.00	1.13	1.00
	SUM	12.00	8.57	12.00	7.50	6.67	6.67	7.50	6.67

Weighted Super Matrix

Criteria	Rankings	5	7	5	8	9	9	8	9	SUM	WEITHAGE
soil texture	5	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.67	0.083333
	7	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.93	0.116667
soil depth	5	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.67	0.083333
	8	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	1.07	0.133333
	9	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	1.20	0.150000
slope	9	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	1.20	0.150000
Erosion	8	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	1.07	0.133333
organic carbon	9	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	1.20	0.150000
											1.000000

Consistency Calculation

Criteria	Rankings	5	7	5	8	9	9	8	9	SUM weightage	Ratio
Soil texture	5	0.0833	0.0833	0.0833	0.0833	0.0833	0.0833	0.0833	0.0833	0.66667	8.0000
	7	0.1166	0.1166	0.1166	0.1166	0.1166	0.1166	0.1166	0.1166	0.93333	8.0000
Soil depth	5	0.0833	0.0833	0.0833	0.0833	0.0833	0.0833	0.0833	0.0833	0.66667	8.0000
	8	0.1333	0.1333	0.1333	0.1333	0.1333	0.1333	0.1333	0.1333	1.06667	8.0000
	9	0.1500	0.1500	0.1500	0.1500	0.1500	0.1500	0.1500	0.1500	1.20000	8.0000
Slope	9	0.1500	0.1500	0.1500	0.1500	0.1500	0.1500	0.1500	0.1500	1.20000	8.0000
Erosion	8	0.1333	0.1333	0.1333	0.1333	0.1333	0.1333	0.1333	0.1333	1.06667	8.0000
Organic carbon	9	0.1500	0.1500	0.1500	0.1500	0.1500	0.1500	0.1500	0.1500	1.20000	8.0000
										sum	64.000
										$\lambda_{\max}$	8.0000

Different thematic layers identified in the study with their respective weightages were further integrated with each other in ArcGIS 10.6.1 software as per weighted overlay technique using the spatial analyst tool. Through weighted overlay analysis, potential zones of different mapping units as high and low potential zone were obtained.

The results obtained from the assessment are presented in (Table 7). The interpretation of data revealed that among all the variables, higher percentage of weightage *i.e.* 37% was scored by soil depth followed by soil texture (20%) similar findings

were reported by (Sarkar *et al.*, 2019) and (Bandyopadhyay *et al.*, 2009) ^[10]. The least weightage percentage was scored by moderate erosion status of the soil, whereas slope and organic carbon status scored 15% weightage each. The findings pointed out the relative important role of these factors or variables in influencing potential of the land to support the growth and development of a crop. The weightage percentage of individual parameter of LRI was also confirmed by comparing with their respective rating as per storie rating index in deciding potentials of soil and land.

Table 7: Distribution of Soil Classes, Rankings, & Weightage

Soil class	Area in Ha.	Percentage	Ratings	Weightage	Weightage in%
SOIL TEXTURE					
Sandy clay	144.95	24.73	7	0.116667	11.67
Clay	419.95	71.62	5	0.083333	8.33
Soil Depth					
Shallow (25-50cm)	18.47	3.15	5	0.083333	8.33
Moderately Deep (75-100cm)	126.34	21.58	8	0.133333	13.33
Very Deep(>150cm)	419.95	71.62	9	0.15	15
Soil Erosion					
Moderate erosion	564.76	96.36	8	0.13333	13.33
Slope					
Very gently sloping (1-3%)	564.76	96.36	9	0.15	15
Organic Carbon					
High (>0.75)	564.76	96.36	9	0.15	15
Others*	21.31	3.64			

The result with respect to soil depth revealed that maximum area *i.e.* 420.00 ha (71.62%) in the MWS belongs to very deep soils whereas remaining 126.00 ha (21.58%) were found in moderately deep soils and only 18.00 ha (3.15%) noted shallow soil depth class respectively. According to Storie rating the soil depth class, *i.e.* shallow, moderately deep and very deep depth class have been ranked as 5, 8 and 9 respectively. When the data of soil depth was analyzed through weighted overlay analysis, the results indicated that higher weightage of 0.15 (15%) was scored by very deep soil as compared to lowest 0.08 (8.33%) score for shallow depth class (Table 5). According to storie rating sandy clay and clay texture recorded 7 & 5 respectively. However, the assessment of weightage revealed that the clay textured soils noted lower weightage of 0.833 (8.33% weightage) in comparison with Sandy clay textured soils which recorded higher weightage of 0.15 (15% weightage). The interpretation of data pertaining to erosion status and slope of the study area revealed that the land parcels with moderate erosion status were ranked with high rating of 8 (storie rating) which scored 0.13 weightage (13.33%) weightage (Aderonke and Gbadegesin 2013)^[2].

The Results of slope analysis revealed that the majority of the area in the MWS (96.36%) were found belonging to very gently sloping which scored rating of 9 (Storie rating). However, the same parameter recorded 0.15 weightage (15%) when interpreted through weighted overlay analysis. A similar trend was observed for organic carbon status in the MWS.

Overall the major land parcels in Kumarchincholi MWS are with very deep soils (71.62%), moderate erosion (96.36%), very gently sloping (96.36%) and high soil organic carbon (96.36%) have been identified with highest weightage value of 15% and with high rating of 9. Whereas soils with sandy clay texture and shallow depth recorded the lowest weightage value of 8.33% but with 7 and 5 ratings respectively (Table 7) (Gami *et al.*, (2009)^[28].

In this method, the total weights of the final integrated polygons were derived as sums of the weights assigned to the different layers according to their importance. The equation used in GIS

for the assessment of soil and land potential for agricultural purposes is as per (Bandyopadhyay *et al.*, (2009)^[10], which is derived as below.

$$\text{Soil and land potentials} = 0.2(\text{ST})_{i=(1-2)} + 0.37(\text{SD})_{j=(1-3)} + 0.15(\text{SL})_{k=1} + 0.15(\text{OC})_{i=(1)} + 0.13(\text{E})_{m=1}$$

Where, soil and land potentials are in the numerical index of the land suitability, ST indicates soil types based on texture, erosion, *etc.* (with classes 1-5), SL is the slope factor (with classes 1), OC indicates the organic carbon of the soil (with classes 1) and D indicates the depth factor (with classes 1-3). The subscripts i, j, k, l and m indicate subclasses based on importance in determining the land suitability. The results pertaining to soil and land potential mapping as interpreted through GIS platform were used in separation of different polygons in the thematic maps. Unique attributes were assigned to all the features of different thematic maps. Initially, each one of the polygons in the final thematic layer was qualitatively visualized into one of the categories: (i) High zone, (ii) Low zone- in terms of their importance with respect to land suitable for agriculture purposes. All the thematic maps were superimposed and integrated with one another through ArcGIS 10.6.1. By weighted overlay method. The soil and land potential zones, of high and low potential in the MWS were derived for four mapping units as identified during detailed soil survey through LRI and were mapped on GIS platform.

4. Results

Favorable and limiting characters of soil are the deciding factors of the potential of that land which make a piece of land suitable or not suitable for cultivation of various crops in achieving the productivity, sustainably. Potential lands with more favorable and less limiting conditions will be high to moderately suitable (S1 and S2) for many crops as compared to Low potential lands which are Moderate to marginally and not suitable (S2 to S3 and N) for many crops (El Behairy, R.A *et al.*,2022)^[20].

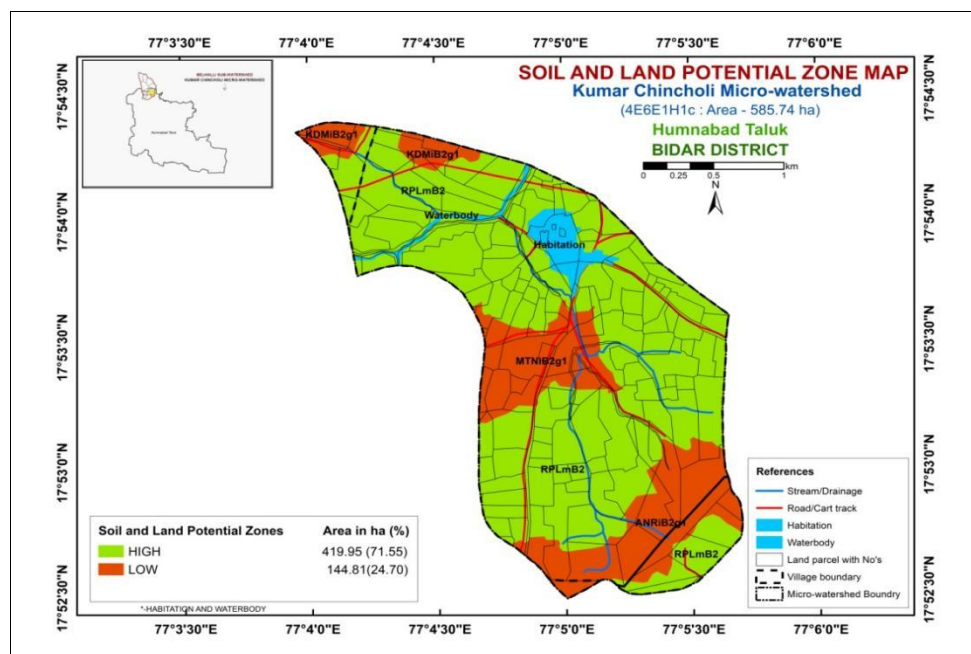


Fig 10: Soil and Land Potential Zone Map

After processing the LRI data through AHP and Weighted Overlay Analysis, Soil and Land Potential (SLP) Zones of Kumarchincholi micro watershed were identified as High SLP zone and Low SLP zone (Figure 10). Out of total cultivable area of micro watershed (564.76ha), 419.95ha (71.55%) was identified as High SLP zone, which includes Raipalli soil series

with RPLmB2 as soil mapping unit. Remaining area of 144.87 ha (24.72%) was found falling under Low SLP zone where Kodambal, Muttangi and Ainapur soil series were identified and mapped with KDMiB2g1(18.47 ha), MTNiB2g1 (53.11 ha) and ANRiB2g1 (73.29 ha) soil mapping units respectively (Table 8).

Table 8: Area Distribution of Soil and Land Potential Zones

Sl. No.	Soil and Land potential zones	Area of potential zones in ha	Area of potential zones in percentage	Mapping units	Area of mapping units in ha	Area of mapping units in percentage
1.	High potential zone	419.95	71.55%	RPLmB2	419.95	71.55%
2.	Low potential zone	144.87	24.72%	KDMiB2g1	18.47	3.15%
				MTNiB2g1	53.11	9.06%
				ANRiB2g1	73.29	12.51%
3.	Others*	20.96	3.75%	Others*	20.96	3.75%
	Total	585.72	100%		585.72	100%

*Habitation and Waterbody

SLP zones identified for the study area were confirmed with crop suitability assessment (FAO 1976, Naidu *et al.*, 2006, Everest *et al.*, 2021)^[45] for selected field and horticulture crops

recommended based on LRI data for different mapping units in the MWS. It was found that there is a strong relationship between SLP zones and crop suitability categories.

Table 9: Potential Zones Comparison with Crop Suitability

Selected Crops	Soil and land potential zones			
	High	Low		
	Soil Mapping units			
	RPLmB2	KDMiB2g1	MTNiB2g1	ANRiB2g1
	Crop suitability categories			
A. Field crops				
1.Redgram	S1	S3	S2	S2
2.Soybean	S1	S3	S2	S2
3.Sorghum	S1	S3	S2	S2
4.Bengal gram	S1	S3	S2	S2
5.Wheat	S1	S3	S2	S2
6.Sugarcane	S1	S3	S2	S2
B. Vegetables				
1.Solanaceous	S1	S2	S2	S2
2.Cruciferous	S1	S2	S2	S2
C. Fruit crops				
1.Guava	S2	N	S3	S2
2.Papava	S2	S2	S3	S2

3.Sapota	S2	S2	S3	S2
4.Banana	S2	N	S3	S2
5.Lime	S2	N	S2	S2
6.Tamarind	S2	S2	N	N
D. Flower crops				
1.Gallardia	S2	S3	S2	S2
2.Chrysanthemum	S2	S3	S2	S2
3. Marigold	S2	S3	S2	S2

High SLP zone (RPLmB2) of the study area was found S1 to major field and vegetable crops, S2 for fruits and vegetable crops were as Low SLP zone with KDMiB2g1 soil mapping unit was S3 for field crops, S2 for vegetable crops and S3 for flower crops. It was also recorded N suitability for fruit crops like Guava, Banana and lime under areas of said mapping unit. Similarly, low potential of MTNiB2g1 soil mapping unit was confirmed as the said area found S2 for all the field, vegetable, flower crops, S3 for fruit crops and N for Tamarind in particular. With respect to area belonging to ANRiB2g1 soil mapping unit found S2 for all the field, vegetable fruit and flower crops except being for Tamarind (Table 9).

5. Discussion

It is very important to establish and understand the relationship between properties of soil and land to find out their role in deciding potential of a given parcel of land. Accordingly, results of soil survey, and soil analytical data were processed through multi-criteria analysis of each component of mapping unit, to derive Soil and Land Potential (SLP) zones for Kumarchincholi MWS. Highest SLP of soils of Raipalli soils with the RPLmB2 mapping unit can be collaboratively confirmed through its properties such as; clay soil texture influences the soil potential with its role in the retention of more SOC, faster decomposition and transformation process (Gami *et al.*, 2009) [28]. In addition to that clay is known imparts good water holding capacity, reduced leaching loss, high nutrient retention, adsorption and exchange abilities due to its high surface area reflecting as higher fertility (Borchers *et al.*, 1992) [12], (Kome *et al.*, 2019) [37]. These roles also are in accordance with higher weightage value (11.67%). Moreover, land parcels on which very deep (>150 cm) Raipalli soil has been identified, are existing in lowland and midland physiographic position which will have a positive influence on soil development through deposition as well as through in-situ process (Karaca *et al.*, 2018) [35]. Deeper rooting depth makes these soils harbor and nurture many annual and perennial crops with tap root system (Yüksek *et al.*, 2009) [67]. This fact has been strongly endorsed by Raipalli soils being S1 to S2 for all the selected crops with minimal limitations that can hinder optimum crop growth in accordance with the weightage value of 15%.

Interpretation of the Low SLP status of Kodambal (KDM), Muttangi (MTN) and Ainapur (ANR) soil series, with mapping units namely KDMiB2g1, MTNiB2g1, ANRiB2g1 respectively, guides in understanding the influence of soil and land properties of the potential. The Sandy clay texture of these soils with the weightage value of 8.33% includes shallow soils which are at developing stage to moderately deep soils at partially developed stage, with a weightage value of 8.33% and 13.33% respectively. Light texture and presence up 35% of gravels are the indicator of susceptibility for excessive drainage, lower water holding capacity and nutrient loss through leaching as compared to clay textured soil where it supports soil aggregation, stability, water holding capacity, nutrient retention capabilities (Sainju *et al.*, 2022) [55]. Limitations for root development and penetration into deeper soil horizons due to

shallow to moderate depth of soil is one more lacuna makes these soils restrict to lower potential (Ayehu and Besufekad, 2015) [9]. These facts have been strongly endorsed by their status of S2, S3, and N, crop suitability, instead of S1 for all the selected crops of the region.

However, all the mapping units of both the potential zones were found with high SOC in spite of gentle slope and moderate erosion with weightage values of 15%, 15% and 13% respectively which create favorable condition for optimum growth of crop plants conditioning physical and chemical properties of soil essential for proper growth of plants (Bandyopadhyay *et al.*, 2009) [10]. This may be attributed to the fact that the average annual rainfall of the region is more than 847mm distributed from June to October under which, cultivation of red gram as main crop and many leguminous crops (Black gram, Green gram, Soya bean, *etc.*) as inter crops or cover crops is a traditional cultivation practice leading to fix atmospheric nitrogen apart from adding a good amount of crop residue with narrow C:N ratio as well as sufficient SOC to the soil (Liu *et al.*, 2020; Gorooei *et al.*, 2023) [38, 29]. But the upholding coexistence of very deep and clay textured soils on gently sloping land with sufficient status of soil organic carbon in Raipalli soils were found decisive in confirming high SLP zone, found missing in remaining soils of the study area.

6. Conclusion

In the present investigation, an effort has been made to achieve higher accuracy the evaluation of the potentials of soil and land by integrating the findings of the detailed soil survey with using spatial analyst tools. Land evaluation can be narrowed down to site specific at 1:7920 scale where not only farm level but also to the extent of the limitations of individual parameter, its influence on other properties of soil and land can be addressed with site specific interventions to improve the productivity in a more sustainable approach. With wide applicability, the results obtained and interpretations in the above investigation provide an insight into the possibility of accessing the soil and land potentials with precision at mapping unit level in a micro watershed through the application of spatial analysis tools. This method of assessment for judging soil and land potential can be scaled up to a watershed having similar mapping units. Such methods can also be effectively utilized in the assessment of developmental projects which are aimed at improving potentials of land and their productivity.

7. Abbreviations

LRI: Land Resource Inventory, MWS: Micro watershed, GIS: Geographic information system, AHP: Analytic Hierarchy Process, S1: Highly suitable, S2: Moderately suitable, S3: Marginally suitable, N: Not suitable, SLP: Soil and Land Potential zones.

8. Conflict of interest

The authors declare that they have no conflict of interest.

9. Consent for publication

Not applicable

10. Ethical approval and consent to participate

Not applicable

11. Funding

Not applicable

12. Availability of data and materials

To be made available on request

13. Credit Author Statement

Praveen Kumar B. Naikodi - Conducting LRI, Characterization of classification of soils, conceptualization, AHP application, original draft editing. Praveen Jholgiker- Crop suitability assessment, editing. Ashok. S. Alur - Supervision and editing. Vijayshree- GIS application, AHP application, Generation of thematic layers. Ruben Ashirvadam- Lab analysis of soils. Aparna- GIS application, map generation.

14. Acknowledgements

All the authors are very much thankful to the members of LRI field, GIS and Soil water analysis lab, who have helped in generating essential data from their respective field to accomplish present study. Special thanks to Directorate of Research, University of Horticultural Science Bagalkot, Watershed Development Department, because of whom the research facilities were created and facilitated to research present findings. We are sincerely thankful to institutes like NBSS & LUP, Bengaluru, KSRSAC Bangalore, Karnataka, India, towards their guidance and support in performing LRI & GIS work. Many thanks to the anonymous reviewers through which processing and interpretation of data was done on the basis of which the present module has been constructed to assess it for wider applicability & its usefulness.

References

1. AbdelRahman MA, Natarajan A, Hegde R. Assessment of land suitability and capability by integrating remote sensing and GIS for agriculture in Chamarajanagar district, Karnataka, India. *The Egyptian Journal of Remote Sensing and Space Science*. 2016;19(1):125-141.
2. Aderonke DO, Gbadegesin GA. Spatial variability in soil properties of a continuously cultivated land. *African Journal of Agricultural Research*. 2013;8(5):475-483.
3. Agarwal E, Agarwal R, Garg RD, Garg PK. Delineation of groundwater potential zone: An AHP/ANP approach. *Journal of Earth System Science*. 2013;122(3):887-898.
4. Akbari M, Neamatollahi E, Neamatollahi P. Evaluating land suitability for spatial planning in arid regions of eastern Iran using fuzzy logic and multi-criteria analysis. *Ecological Indicators*. 2019;98:587-598.
5. Alemu MM. Sustainable land management. *Journal of Environmental Protection*. 2016;7(04):502-508.
6. Alexandratos N, Bruinsma J. World agriculture towards 2030/2050: the 2012 revision. *ESA Working Paper No. 12-03*. Rome: FAO; 2012.
7. Alonso JA, Lamata MT. Consistency in the analytic hierarchy process: a new approach. *International Journal of Uncertainty, Fuzziness and Knowledge-Based Systems*. 2006;14(04):445-459.
8. Antunes P, Santos R, Cosme I, Osann A, Calera A, De Ketelaere D, Nagarajan S. A holistic framework to assess the sustainability of irrigated agricultural systems. *Cogent Food & Agriculture*. 2017;3(1):1323542.
9. Ayehu GT, Besufekad SA. Land suitability analysis for rice production: A GIS based multi-criteria decision approach. *American Journal of Geographic Information System*. 2015;4(3):95-104.
10. Bandyopadhyay S, Jaiswal RK, Hegde VS, Jayaraman V. Assessment of land suitability potentials for agriculture using a remote sensing and GIS based approach. *International Journal of Remote Sensing*. 2009;30(4):879-895.
11. Bobade SV, Bhaskar BP, Gaikwad MS, Raja P, Gaikwad SS, Anantwar SG, Maji AK. A GIS-based land use suitability assessment in Seoni district, Madhya Pradesh, India. *Tropical Ecology*. 2010;51(1):41-54.
12. Borchers JG, Perry DA. The influence of soil texture and aggregation on carbon and nitrogen dynamics in southwest Oregon forests and clearcuts. *Canadian Journal of Forest Research*. 1992;22(3):298-305.
13. Burnham P, Kent R, Macartney J, Redfern V. *Sustainable Land Management*. London: Centre for Development, Environment and Policy, University of London; 2003.
14. Walkley A, Black IA. An examination of Degtjareff method of determining soil organic matter and proposed modification of the method of the chromic acid titration method. *Soil Science*. 1934;37(1):29-39.
15. Global Environment Facility. *Combating Land Degradation*. Washington, DC: GEF Secretariat; 2022.
16. Cowie AL, Orr BJ, Sanchez VMC, Chasek P, Crossman ND, Erlewein A, Welton S. Land in balance: The scientific conceptual framework for Land Degradation Neutrality. *Environmental Science & Policy*. 2018;79:25-35.
17. Dale DD. *Land Productivity Restoration and Strategies*. Addis Ababa: Ministry of Agriculture; 2020.
18. Delgado JA, Short NM Jr, Roberts DP, Vandenberg B. Big data analysis for sustainable agriculture on a geospatial cloud framework. *Frontiers in Sustainable Food Systems*. 2019;3:54.
19. El Baroudy AA. Mapping and evaluating land suitability using a GIS-based model. *Catena*. 2016;140:96-104.
20. El Behairy RA, El Baroudy AA, Ibrahim MM, Mohamed ES, Kucher DE, Shokr MS. Assessment of soil capability and crop suitability using integrated multivariate and GIS approaches toward agricultural sustainability. *Land*. 2022;11(7):1027.
21. Ennaji W, Barakat A, El Baghdadi M, Oumenskou H, Aadraoui M, Karroum LA, Hilali A. GIS-based multi-criteria land suitability analysis for sustainable agriculture in the northeast area of Tadla plain (Morocco). *Journal of Earth System Science*. 2018;127(6):1-14.
22. Environmental Systems Research Institute (ESRI). *User Guide ARC/INFO: The Geographic Information System Software*. Redlands, CA: ESRI Inc.; 1988.
23. Environmental Systems Research Institute (ESRI). *ARC/INFO Training Course Class Material*. Vol. 1. Redlands, CA: ESRI Inc.; 1989.
24. Everest Tİ, Sungur A, Özcan H. Determination of agricultural land suitability with a multiple-criteria decision-making method in Northwestern Turkey. *International Journal of Environmental Science and Technology*. 2021;18(5):1073-1088.

25. Falasca SL, Ulberich AC, Ulberich E. Developing an agro-climatic zoning model to determine potential production areas for castor bean (*Ricinus communis* L.). *Industrial Crops and Products*. 2012;40:185-191.
26. Fallah-Alipour S, Mehrabi Boshrahadi H, Zare Mehrjerdi MR, Hayati D. A framework for empirical assessment of agricultural sustainability: The case of Iran. *Sustainability*. 2018;10(12):4823.
27. Food and Agriculture Organization (FAO). A framework for land evaluation. *FAO Soils Bulletin* 32. Rome: FAO; 1976.
28. Gami SK, Lauren JG, Duxbury JM. Influence of soil texture and cultivation on carbon and nitrogen levels in soils of the eastern Indo-Gangetic Plains. *Geoderma*. 2009;153(3-4):304-311.
29. Gorooei A, Aynehband A, Rahnama A, Gaiser T, Kamali B. Cropping systems and agricultural management strategies affect soil organic carbon dynamics in semi-arid regions. *Frontiers in Sustainable Food Systems*. 2023;6:1016000.
30. Greenland DJ, Gregory PJ, Nye PH, editors. *Land resources: on the edge of the Malthusian precipice*. New York: CAB International; 1998.
31. Halder JC. Land suitability assessment for crop cultivation by using remote sensing and GIS. *Journal of Geography and Geology*. 2013;5(3):65-77.
32. Hossain A, Bhatt R, Arora S, Latef AAHA, Islam T. Arbuscular mycorrhizal fungi: The natural biotechnological tools for sustainable crop production under saline soils in the modern era of climate change. In: *Plant Growth Regulators: Signalling under Stress Conditions*. Cham: Springer International Publishing; 2021. p. 373-401.
33. Ikerd J. Two related but distinctly different concepts: organic farming and sustainable agriculture. *Small Farm Today*. 1993;10(1):30-31.
34. Incardona JP, Collier TK, Scholz NL. Edaphic factors in environmental health. *Environmental Health Perspectives*. 2002;110(3):285-292.
35. Karaca S, Gülser F, Selçuk R. Relationships between soil properties, topography and land use in the Van Lake Basin, Turkey. *Eurasian Journal of Soil Science*. 2018;7(2):115-120.
36. Karlen DL. Soil productivity. In: Hillel D, editor. *Encyclopedia of Soils in the Environment*. Oxford: Elsevier; 2005. p. 430-437.
37. Kome GK, Enang RK, Tabi FO, Yerima BPK. Influence of clay minerals on some soil fertility attributes: a review. *Open Journal of Soil Science*. 2019;9(9):155-188.
38. Liu K, Bandara M, Hamel C, Knight JD, Gan Y. Intensifying crop rotations with pulse crops enhances system productivity and soil organic carbon in semi-arid environments. *Field Crops Research*. 2020;248:107657.
39. Lorenz K, Lal R. The depth distribution of soil organic carbon in relation to land use and management and the potential of carbon sequestration in subsoil horizons. *Advances in Agronomy*. 2005;88:35-66.
40. Mandal D, Chandrakala M, Alam NM, Roy T, Mandal U. Assessment of soil quality and productivity in different phases of soil erosion with the focus on land degradation neutrality in tropical humid region of India. *Catena*. 2021;204:105440.
41. McKenzie FC, Williams J. Sustainable food production: constraints, challenges and choices by 2050. *Food Security*. 2015;7(2):221-233.
42. Motuma M, Suryabhadgavan KV, Balakrishnan M. Land suitability analysis for wheat and sorghum crops in Wogdie District, South Wollo, Ethiopia, using geospatial tools. *Applied Geomatics*. 2016;8(1):57-66.
43. Mueller L, Schindler U, Mirschel W, Shepherd TG, Ball B, Helming K, Wiggering H. Assessing the productivity function of soils: a review. *Agronomy for Sustainable Development*. 2010;30(3):601-614.
44. Novak P, Vopravil J, Lagova J. Assessment of the soil quality as a complex of productive and environmental soil function potentials. *Soil and Water Research*. 2010;5(3):113-119.
45. Naidu LGK, Ramamurthy V, Challa O, Hegde R. *Manual: Soil-site criteria for major crops*. NBSS Publication No. 129. Nagpur: National Bureau of Soil Survey and Land Use Planning; 2006. p. 118.
46. Nhamo L, Magidi J, Nyamugama A, Clulow AD, Sibanda M, Chimonyo VG, Mabhaudhi T. Prospects of improving agricultural and water productivity through unmanned aerial vehicles. *Agriculture*. 2020;10(7):256.
47. O'Geen AT. A revised Storie index for use with digital soils information. Publication 8335. Oakland: University of California Division of Agriculture and Natural Resources; 2008.
48. Parikh SJ, James BR. Soil: The foundation of agriculture. *Nature Education Knowledge*. 2012;3(10):2.
49. Pramanik MK. Site suitability analysis for agricultural land use of Darjeeling district using AHP and GIS techniques. *Modeling Earth Systems and Environment*. 2016;2(2):1-22.
50. Richardson GS, Ruark MD, Radatz T, Radatz A, Cooley E, Silva EM, Ziegler CH. The influence of inherent soil factors and agricultural management on soil organic matter. *Ecosphere*. 2023;14(3):e4459.
51. Roy R, Chan NW. An assessment of agricultural sustainability indicators in Bangladesh: review and synthesis. *The Environmentalist*. 2012;32(1):99-110.
52. Saaty TL. A scaling method for priorities in hierarchical structures. *Journal of Mathematical Psychology*. 1977;15(3):234-281.
53. Saaty TL. Fundamentals of the analytic network process—multiple networks with benefits, costs, opportunities and risks. *Journal of Systems Science and Systems Engineering*. 2004;13(3):348-379.
54. Saaty TL. Decision making with the analytic hierarchy process. *International Journal of Services Sciences*. 2008;1(1):83-98.
55. Sainju UM, Liptzin D, Jabro JD. Relating soil physical properties to other soil properties and crop yields. *Scientific Reports*. 2022;12(1):22025.
56. Sarkar A. Soil geomorphology of Garpanchkot hill area and its influence on land use and land cover. *Journal of Geoscience and Environment Protection*. 2019;7(07):108-124.
57. Sarkar A, Ghosh A, Banik P. Multi-criteria land evaluation for suitability analysis of wheat: a case study of a watershed in eastern plateau region, India. *Geo-Spatial Information Science*. 2014;17(2):119-128.
58. Shalaby A, Ouma YO, Tateishi R. Land suitability assessment for perennial crops using remote sensing and Geographic Information Systems: A case study in northwestern Egypt. *Archives of Agronomy and Soil Science*. 2006;52(3):243-261.
59. Shennan C, Krupnik TJ, Baird G, Cohen H, Forbush K, Lovell RJ, Olimpi EM. Organic and conventional agriculture: a useful framing?. *Annual Review of*

- Environment and Resources. 2017;42:317-346.
60. Soil Survey Staff. Soil Survey Manual. USDA Handbook No. 18. Washington, DC: U.S. Department of Agriculture; 1993.
 61. Steiner F, McSherry L, Cohen J. Land suitability analysis for the upper Gila River watershed. Landscape and Urban Planning. 2000;50(4):199-214.
 62. Stuart AM, Devkota KP, Sato T, Pame ARP, Balingbing C, Phung NTM, Singleton GR. On-farm assessment of different rice crop management practices in the Mekong Delta, Vietnam, using sustainability performance indicators. Field Crops Research. 2018;229:103-114.
 63. USDA Agricultural Research Service. Draft Science Documentation: Revised Universal Soil Loss Equation Version 2 (RUSLE2). Washington, DC: USDA-ARS; 2008.
 64. Soil Conservation Service. Procedures for collecting soil samples and methods of analysis for soil survey. Soil Survey Investigations Report No. 1. Washington, DC: USDA; 1984.
 65. Wang G, Mang S, Cai H, Liu S, Zhang Z, Wang L, Innes JL. Integrated watershed management: evolution, development and emerging trends. Journal of Forestry Research. 2016;27(5):967-994.
 66. Food and Agriculture Organization (FAO). Palau Climate Change and Land Use Report. Rome: FAO; 2015.
 67. Yüksek T, Göl C, Yüksek F, Erdoğan Yüksel E. The effects of land-use changes on soil properties: The conversion of alder coppice to tea plantations in the Humid Northern Blacksea Region. African Journal of Agricultural Research. 2009;4(3):192-200.
 68. Zolekar RB, Bhagat VS. Multi-criteria land suitability analysis for agriculture in hilly zone: Remote sensing and GIS approach. Computers and Electronics in Agriculture. 2015;118:300-321.