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Land capability studies using GIS techniques in the northern dry zone of Karnataka (Sathihala sub-watershed, Vijayapura)

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Abstract
A study was conducted to assess land capability and develop a land suitability map based on soil characteristics and climatic factors in a sub-watershed area. A detailed soil survey was carried out in the Sathihala (4D5C5n) sub-watershed, located in Devara Hipparagi taluk of Vijayapura district, Karnataka, to obtain comprehensive land resource data. Based on soil-site characteristics, twenty-six soil series were identified in the study area: Algali (AGL), Atharga (ARG), Arthal (ATL), Baramkodi (BKD), Deginal (DGN), Dadamatti (DMT), Halahalli (HHL), Hunashyal (HSL), Hattararkihal (HTK), Jayawadagi (JYD), Kalgurki (KGR), Karjol (KRJ), Masabinal (MBL), Managoli (MGL), Nandihal (NDL), Naihalla (NHL), Kamanakeri (NRG), Rambapur (RMB), RPR, Sankanala (SKL), Tenihalli (THL), Tonsihal (TKL), Thalewada (TLD), Dadamatti (TNL), Tonsihal (TSL), and Yambatnal (YBT). These soil series were delineated into 74 mapping units using GIS techniques.

The Sathihala sub-watershed area was classified into four Land Capability Classes (LCC): I, II, III, and IV, with subclasses—Is, IIes, IIIs, and IVes. The subclass ‘e’ indicates major limitations related to erosion and slope (soil property group ‘e’), while ‘s’ denotes limitations associated with soil characteristics such as texture, depth, and gravelliness (soil property group ‘s’). Subclasses ‘se’ and ‘es’ represent combined limitations from both groups, with the order indicating the dominant constraint-either soil properties (‘s’) or erosion/slope (‘e’).

A land capability map developed using GIS techniques revealed that, out of the total study area of 3,810.81 ha, the majority (3,228 ha or 84.71%) falls under class IIIse, followed by class IVse, which covers 447 ha (11.73%).

The soil suitability assessment indicated that most of the land is moderately suitable for agriculture. Class IV soils, though reasonably fertile, are suited only for intermittent cultivation due to significant limitations that restrict crop choices. However, with appropriate management practices, these lands can still support agricultural use.

The application of a Land Use Planning (LUP) approach is crucial for developing site-specific land resource management strategies to improve land productivity, prevent degradation, and promote long-term sustainability.

Keywords: Crop suitability, geographic information system (GIS), land resource inventory (LRI), cropping pattern

Introduction

Land is a finite and invaluable resource that forms the foundation for all material production. When used rationally and judiciously, it has the potential to meet the needs of a growing population. However, in many parts of India, the current state of land use and management remains a serious concern, especially for those working at the grassroots level. Approximately 51% of the country’s total geographical area is available for agriculture, and more than 60% of the population continues to depend on agriculture for their livelihood. This limited agricultural land is increasingly under stress due to rising population pressure and competing demands from various land uses. Each year, significant portions of farmland and water resources are diverted to non-agricultural purposes (Sehgal *et al.*, 1990) [12]. Additionally, a growing disinterest in farming among rural communities has contributed to an alarming increase in fallow cultivable land across several regions.

Watershed management programs aim to address these challenges through comprehensive strategies such as soil and water conservation, enhancing the productivity of existing crops, promoting crop diversification with horticultural species, rehabilitating wastelands through multipurpose forestry, and improving livelihood options for landless households. Achieving these goals requires the preparation and implementation of a well-structured, site-specific Natural Resource Management (NRM) plan. The cornerstone of such a plan is the development of a Land Resource Inventory (LRI), which provides detailed insights into the resource potential and constraints of a given area.

An LRI involves the detailed characterization and mapping of land resources, including soil, climate, water availability, geological formations, vegetation types, cropping patterns, land use, socio-economic conditions, infrastructure, market access, and ongoing government programs (Naidu *et al*., 2006) [9]. Farm-level data collection enables the identification of location-specific problems and opportunities, supporting the scientific planning of conservation measures, assessment of land suitability for various uses, and the formulation of sustainable, site-specific land-use strategies tailored to individual landholdings (Katyal *et al.*, 2003) [4].

The district of Vijayapura, located in the northern part of Karnataka, lies within the Northern Dry Zone (Agro-climatic Zone 3) of the state. Spanning an area of 10,541 km², it is situated between 15°50′ and 17°28′ N latitude and 74°54′ and 76°28′ E longitude. Vijayapura is bordered by Yadgir district to the east, Kalaburagi district to the northeast, Bagalkot district to the southwest, and the state of Maharashtra to the northwest. The region’s geology comprises formations from the Deccan Traps, the Bhima Group, and the Peninsular Gneissic Complex. Agriculture in Vijayapura is predominantly rainfed, with cotton, maize, groundnut, chickpea, and various pulses as the principal crops. However, horticultural cultivation remains relatively limited in the area (Shivaprasad *et al.,* 1998) [14].

Methods

Description of the Study Area

The study was conducted in the Sathihala sub-watershed (4D5C5n), located in Devara Hipparagi taluk of Vijayapura district, Karnataka. Geographically, it lies between 16°28′20″ and 16°30′50″ North latitude and 75°51′50″ and 76°55′50″ East longitude, covering an area of approximately 9,531.65 hectares. The sub-watershed is bounded by the villages of Devara Hipparagi, Sathihala, Utthnala, Rabinala, Bommanahalli, Dindawar, Ingaleshwara, and Aralichandi.

The region falls under the hot, dry, semi-arid ecoregion (ESR) of the North Karnataka Plateau and southwestern Maharashtra. Soils are predominantly shallow to medium loamy black soils, with pockets of deep clayey black soils. The area exhibits moderate to high available water capacity (AWC), and the length of the growing period (LGP) ranges from 120 to 150 days.

This agro-ecological zone extends over the entire districts of Koppal, Vijayapura, and Bellary, as well as parts of several other districts, including five taluks of Belagavi, six of Bagalkot, two of Raichur, one of Dharwad, one of Davanagere, and four of Gadag. The total geographical area of this zone is approximately 8.94 million hectares. Most of the region lies at an elevation between 450 and 800 meters above mean sea level (MSL), with some areas reaching up to 900 meters.

Average annual rainfall in this zone ranges from 464.5 mm to 785.7 mm. The predominant soil types are medium and deep black clays in most areas, with sandy loams occurring in some parts. The main cropping season is rabi, and principal crops include maize, bajra, groundnut, cotton, wheat, sugarcane, and tobacco.

Soil Survey and Mapping

A comprehensive soil survey was conducted in the study area using high-resolution satellite imagery from IRS-LISS IV and Cartosat-1, at a scale of 1:8,000, supplemented by topographic sheets of Vijayapura district. The survey followed the methodology prescribed under the Land Resource Inventory (LRI) framework. Systematic field traverses were carried out to document surface characteristics such as soil texture, slope, erosion status, gravelliness, calcareousness, and stoniness. Surface soil samples were collected at 320-meter grid intervals and analyzed for key parameters including macro- and micronutrient status, electrical conductivity (EC), soil reaction (pH), and organic carbon content.

To assess subsurface variability, pedon sites were selected based on observed surface heterogeneity. Soil profiles were excavated at each site, and detailed morphological descriptions of individual horizons were recorded. Samples from each horizon were analyzed for essential physical and physicochemical properties using standard analytical procedures.

Based on correlation and interpretation of soil properties, the soils were classified into four distinct soil series according to the classification system outlined in the *Field Guide for Land Resource Inventory, Sujala-III Project*, developed by ICAR-NBSS&LUP. These soil series were further delineated into 74 unique mapping units, differentiated by variations in texture, depth, slope, and erosion characteristics.

Land Capability and Soil Suitability Assessment

Soil-site characteristics of the various soil units were determined by calculating the weighted average of each soil property, which was then interpreted to assess land capability. These properties were compared with criteria outlined for land capability classification (Table 1). The land capability classification is organized into three primary categories:

i) **Capability Unit:** Categorizes soils with similar responses to cultivated crops and pasture plants, often determined by their respective yields.
ii) **Capability Subclass:** Groups capability units sharing similar types of limitations and hazards.
iii) **Capability Class:** Groups soils based on the degree of limitations, escalating from Class I to VIII. Classes I to IV are suitable for cultivation, whereas Classes V to VIII are not suitable for cultivation but may be appropriate for grazing, forestry, wildlife maintenance, recreation, or watershed protection (ICAR, [6]).

In the present study, land capability classification was undertaken primarily based on the third category (Class III) of the established classification system, which considers inherent soil properties, external landform characteristics, and relevant environmental factors. The delineation of land capability classes and subclasses was conducted following the methodological guidelines in the LRI Field Guide of the REWARD project, developed by ICAR-NBSS&LUP [7].

Using advanced Remote Sensing (RS) and Geographic Information System (GIS) technologies, various thematic layers were generated, overlaid, and subjected to spatial analysis to develop comprehensive land capability and soil-site suitability maps. This analysis was performed using the ArcView interface within the ArcGIS 10.8.2 software environment. Comparable approaches have been employed in previous studies by Suryawanshi *et al.* [8], Mishra *et al.* [9], Mishra and Babu [10], and Mary Silpa and Nowshaja [11].

Results and Discussion

Soil Map and Soil Mapping Units

A soil map visually represents the spatial distribution of different soil types and mapping units in relation to major physical and cultural features of the Earth's surface. In this study, soil mapping units were identified using input parameters such as soil series, texture, depth, slope, erosion status, and gravel content.

The study area was classified into 26 distinct soil series: Algali (AGL), Atharga (ARG), Arthal (ATL), Baramkodi (BKD), Deginal (DGN), Dadamatti (DMT), Halahalli (HHL), Hunashyal (HSL), Hattararkihal (HTK), Jayawadagi (JYD), Kalgurki (KGR), Karjol (KRJ), Masabinal (MBL), Managoli (MGL), Nandihal (NDL), Naihalla (NHL), Kamanakeri (NRG), Rambapur (RMB), RPR, Sankanala (SKL), Tenihalli (THL), Tonsihal (TKL), Thalewada (TLD), Dadamatti (TNL), Tonsihal (TSL), and Yambatnal (YBT) (Table 2).

Among these, the Tonsihal series occupies the largest area, covering 1,454 ha (38.16%). These soils are very deep (>150 cm), poorly drained, and range from sandy clay to clay in texture. They occur on gravelly, gently sloping uplands under cultivation. The Karjol series covers 485 ha (12.21%) and is characterized by very deep, poorly drained, non-gravelly soils of similar texture on gently sloping midlands. The Nandihal series, covering 445 ha (11.67%), consists of very deep, poorly drained, gravelly soils ranging from clay to sandy clay texture, located in gently sloping lowlands. The Baramkodi series, covering 255 ha (6.68%), comprises deep (100-150 cm), poorly drained, non-gravelly clay soils found in very gently sloping lowlands.

A total of 74 unique soil mapping units were delineated using the ArcView interface of ArcGIS 10.8.2 software (Fig. 1). These units were grouped into 14 mapping categories, derived during various stages of soil series delineation. The legend for the mapping units follows a structured nomenclature. For example:

DMTiB2g1

- **DMT:** Soil series (Dadamatti)
- **i:** Surface texture (sandy clay)
- **B:** Slope class (1-3%)
- **2:** Erosion status (moderately eroded)
- **g1:** Gravelliness class (gravelly)

This naming convention adheres to the guidelines provided in the *Field Guide for Land Resource Inventory*, REWARD Project (ICAR-NBSS&LUP).

Soil depth across the study area varied from shallow to very deep, with most locations exhibiting very gently sloping topography (1-3%), moderate erosion, and low gravelliness (<15%). Figures 2(a) and 2(b) illustrate the spatial variability of electrical conductivity (EC) and pH across the Sathihala sub-watershed.

Land Capability Classification

Based on the soil-site characteristics, the soils were classified into two Land Capability Classes (LCC), as summarized in Table 3.

Moderately Suitable Soils

Approximately 3,228 ha (84.71%) of the Sathihala sub-watershed falls under Land Capability Class III (Fig. 3). These soils are moderately suitable for cultivation but possess certain limitations that may restrict agricultural productivity. Key limiting factors include:

- Shallow soil depth
- High gravelliness
- Coarse or heavy soil texture
- Salinity or alkalinity
- Susceptibility to erosion and surface runoff

Recommended soil conservation measures to mitigate these constraints include contour ploughing, land levelling, ridges and furrows, and provision of adequate drainage (Sharma *et al.*, 2015) [13].

Marginally Suitable Soils

About 447 ha (11.74%) fall under Land Capability Class IV, which includes soils with severe limitations, primarily due to erosion, runoff, and shallow depth. These soils are fairly suitable for occasional cultivation or alternative land uses because of:

- Severe restrictions on crop selection
- High erosion susceptibility
- Steep slopes
- Low soil depth and water-holding capacity
- Poor drainage conditions
- Moderate to severe salinity/alkalinity

These soils typically exhibit moderate to rapid permeability, moderate drainage, poor profile development, low base saturation, and low organic carbon content. Moderate limitations also arise from coarse fragment content (Natarajan *et al.*, 2015) [10].

Sustainable management practices for Class IV soils include terracing, strip cropping, contour tillage, and integration of perennial vegetation or permanent cover crops. As noted by Amara *et al.* (2016) [1], cultivation on such soils should ideally be rotated with pasture, hay, or orchard systems to prevent degradation and reduce erosion risk.

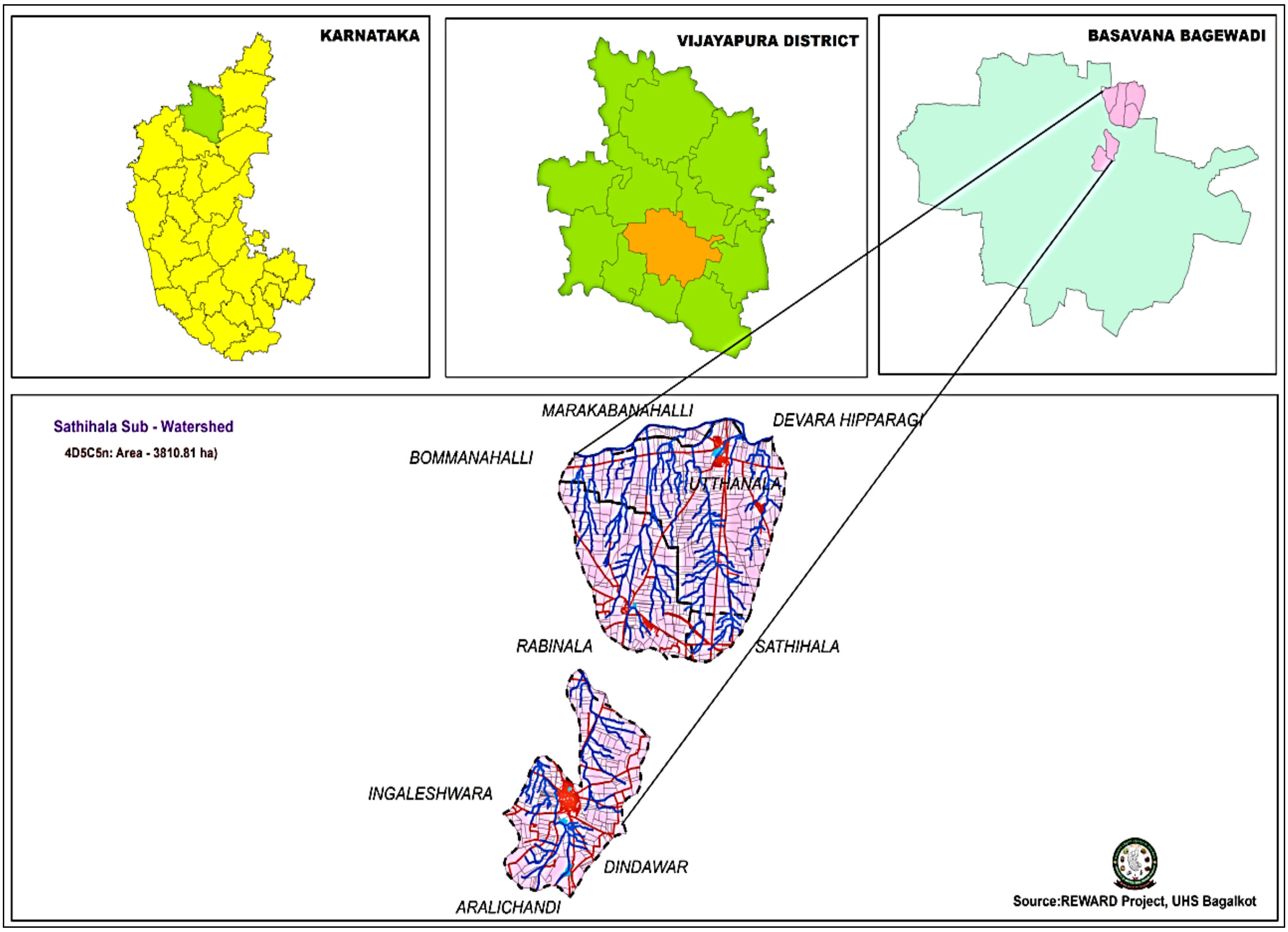

Fig 1: Location map of Sathihala sub-watershed

Table 1: Parameters and their rating to be used for grouping parcels into land capability classification (LCC) units/classes

Characteristics	LCC classes							
	I	II	III	IV	V	VI	VII	VIII
Climate	Humid with well distributed rainfall	Humid with occasional dry spells/sub humid yield frequently reduced by droughts	-	Semi-arid/Arid	-	-	-	-
Slope (%)	<1%	1-5% (Red soils), 1-3% (Black soil)	5-10%	10-25%	-	25-50%	>50%	-
Erosion	Slight	Moderate	-	Severe	-	Very severe	-	-
Drainage	Well to moderate drained	Imperfect to poor	Very poor	-	-	-	-	-
Soil depth	>100 cm	50-100 cm	25-50 cm	10-25 cm	-	<10 cm	-	-
Texture	sl, scl, cl, l	sc, si, c	c	ls	s	-	-	-
Gravels (%)	<15	15-35	35-60	>60	-	-	-	-
Rock out crops (%)	<2	2-10	10-50	50-90	50-90	-	-	>90
Salinity (EC)	<2	2-4	4-8	8-16	-	-	-	-
pH	6.5	-	5.5-6.5 & 7.5-8.5	<4.5, 4.5-5.54 & 8.5-9.5	-	-	-	-
Permeability	Very slow	Moderately slow	Slow	Very slow	-	-	-	-

Source: Ref. 6: Texture classes denoted in the table indicate: sl: sandy loam, scl: sandy clay loam, cl: clay loam, l: loam, sc: sandy clay, si: silt, c- clay, ls: loamy sand and s: sand

Table 2: Mapping unit description of Sathihala sub-watershed

Soil. No.	Mapping unit	Mapping Unit Description
1	AGLmD3g2	Clay surface, Moderately sloping (5-10%), Severe erosion, Very gravelly (35-60 %)
2	ARGmB2g1	Clay surface, Very gently sloping (1-3%), Moderate erosion, Gravelly (15-35 %)
3	ATLmC3g1	Clay surface, Gently sloping (3-5%), Severe erosion, Gravelly (15-35 %)
4	BKDmA2	Clay surface, Nearly Level (0-1%), Moderate erosion
5	BKDmA2g2	Clay surface, Nearly Level (0-1%), Moderate erosion, Very gravelly (35-60 %)
6	BKDmB2	Clay surface, Very gently sloping (1-3%), Moderate erosion
7	BKDmB2g1	Clay surface, Very gently sloping (1-3%), Moderate erosion, Gravelly (15-35 %)
8	BKDmC2	Clay surface, Gently sloping (3-5%), Moderate erosion
9	BKDmC2g1	Clay surface, Gently sloping (3-5%), Moderate erosion, Gravelly (15-35 %)
10	BKDmD3g1	Sandy Clay surface, Moderately sloping (5-10%), Severe erosion, Gravelly (15-35 %)
11	BKDmF3	Clay surface, Very strongly sloping (15-25%), severe erosion
12	BKDmF3g1	Clay surface, Very strongly sloping (15-25%), severe erosion, Gravelly (15-35 %)
13	DGNmB2	Clay surface, Very gently sloping (1-3%), Moderate erosion
14	DGNmB2g1	Clay surface, Very gently sloping (1-3%), Moderate erosion, Gravelly (15-35 %)
15	DGNmB2g2	Clay surface, Very gently sloping (1-3%), Moderate erosion, Very gravelly (%)
16	DGNmD3g1	Clay surface, Moderately sloping (5-10%), Severe erosion, Gravelly (15-35 %)
17	DMTmC3	Clay surface, Gently sloping (3-5%), Severe erosion
18	HHLmB2g1	Clay surface, Very gently sloping (1-3%), Moderate erosion, Gravelly (15-35 %)
19	HSLmB2	Clay surface, Very gently sloping (1-3%), Moderate erosion
20	HSLmC2	Clay surface, Gently sloping (3-5%), Moderate erosion.
21	HSLmC2g1	Clay surface, Very gently sloping (1-3%), Moderate erosion, Gravelly (15-35 %)
22	HTKmA2	Clay surface, Nearly Level (0-1%), Moderate erosion.
23	HTKmB2	Clay surface, Very gently sloping (1-3%), Moderate erosion
24	HTKmB2g1	Clay surface, Very gently sloping (1-3%), Moderate erosion, Gravelly (15-35 %)
25	HTKmD3	Clay surface, Moderately sloping 5-10%), Severe erosion
26	HTKmD3g1	Clay surface, Moderately sloping 5-10%), Severe erosion, Gravelly (15-35%)
27	HTKmD3g2	Clay surface, Moderately sloping 5-10%), Severe erosion, Very gravelly (35-60%)
28	JYDmB2g1	Clay surface, Very gently sloping (1-3%), Moderate erosion, Gravelly (15-35%)
29	KGRmB2	Clay surface, Very gently sloping (1-3%), Moderate erosion
30	KGRmB2g1	Clay surface, Very gently sloping (1-3%), Moderate erosion, Gravelly (15-35 %)
31	KRJmA2	Clay surface, Nearly Level (0-1%), Moderate erosion
32	KRJmA2g1	Clay surface, Nearly Level (0-1%), Moderate erosion, Gravelly (15-35 %)
33	KRJmB2	Clay surface, Very gently sloping (1-3%), Moderate erosion
34	KRJmB2g2	Clay surface, Very gently sloping (1-3%), Moderate erosion, Very gravelly (35-60 %)
35	KRJmC2	Clay surface, Gently sloping (3-5%), Moderate
36	KRJmD2	Clay surface, Moderately sloping(5-10%), Moderate
37	MBLmA2	Clay surface, Nearly Level (0-1%), Moderate erosion
38	MBLmB2	Clay surface, Very gently sloping (1-3%), Moderate erosion
39	MGLmB2	Clay surface, Very gently sloping (1-3%), Moderate erosion
40	MGLmB2g1	Clay surface, Very gently sloping (1-3%), Moderate erosion, Gravelly (15-35 %)
41	MGLmC2g1	Clay surface, Very gently sloping (1-3%), Moderate erosion, Gravelly (15-35 %)
42	NDLfC2g2	Clay loam, Gently sloping (3-5%), Moderate erosion Very gravelly (35-60%)
43	NDLmA2	Clay surface, Nearly Level (0-1%), Moderate erosion
44	NDLmB2	Clay surface, Very gently sloping (1-3%), Moderate erosion
45	NDLmB2g1	Clay surface, Very gently sloping (1-3%), Moderate erosion, Gravelly (15-35 %)
46	NDLmB2g2	Clay surface, Very gently sloping (1-3%), Moderate erosion, Very gravelly (35-60 %)
47	NHLmA1	Clay surface, Nearly Level (0-1%), Slight erosion
48	NHLmA2	.Clay surface, Nearly Level (0-1%), Moderate erosion
49	NHLmB2	Clay surface, Very gently sloping (1-3%), Moderate erosion
50	NHLmB2g1	Clay surface, Very gently sloping (1-3%), Moderate erosion, Gravelly (15-35 %)
51	NHLmC2g1	Clay surface, Gently sloping (3-5%), Moderate erosion, Gravelly (15-35 %)
52	NRGfC2g1	Clay loam, Gently sloping (3-5%), Moderate erosion, Gravelly (15-35 %)
53	NRGfD2g1	Clay loam, Moderately sloping (5-10%), Moderate erosion, Gravelly (15-35 %)
54	NRGfE3g1	Clay loam, Strongly sloping (10-15%), Severe erosion, Gravelly (15-35 %)
55	RMBmB2	Clay surface, Very gently sloping (1-3%), Moderate erosion
56	RPRmA2	Clay surface, Nearly Level (0-1%), Moderate erosion
57	RPRmC2	Clay surface, Very gently sloping (1-3%), Moderate erosion
58	SKLmA2g1	Clay surface, Nearly Level (0-1%), Moderate erosion, Gravelly (15-35 %)
59	SKLmB2g1	Clay surface, Very gently sloping (1-3%), Moderate erosion, Gravelly (15-35 %)
60	THLmB2	Clay surface, Very gently sloping (1-3%), Moderate erosion
61	TKLmC3g2	Clay surface, Gently sloping (3-5%), Severe erosion, Very gravelly (35-60%)
62	TLDdD3g2	Loam, Moderately sloping (5-10%), Severe erosion, Very gravelly (35-60%)
63	TNLmB2g1	Clay surface, Very gently sloping (1-3%), Moderate erosion, Gravelly (15-35%)
64	TNLmB2g2	Clay surface, Very gently sloping (1-3%), Moderate erosion, Very Gravelly (35-60 %)
65	TSLmA2	Clay surface, Nearly Level (0-1%), Moderate erosion
66	TSLmA2g1	Clay surface, Very gently sloping (1-3%), Moderate erosion
67	TSLmB2	Clay surface, Very gently sloping (1-3%), Moderate erosion
68	TSLmB2g1	Clay surface, Very gently sloping (1-3%), Moderate erosion, Gravelly (15-35%)
69	TSLmB2g1	Clay surface, Very gently sloping (1-3%), Moderate erosion, Very gravelly (35-60%)
70	TSLmC3	Clay surface, Gently sloping (3-5%), Severe erosion
71	YBTmB2	Clay surface, Very gently sloping (1-3%), Moderate erosion
72	YBTmB2g1	Clay surface, Very gently sloping (1-3%), Moderate erosion, Gravelly (15-35 %)
73	YBTmD2g1	Clay surface, Moderately sloping (5-10%), Moderate erosion, Gravelly (15-35%)
74	YBTmD3g1	Clay surface, Moderately sloping (5-10%), Severe erosion, Gravelly (15-35%).

Source: WDPD project, UHS, Bagalkot

Conclusion
The land capability maps developed for the Sathihala sub-watershed, based on Land Resource Inventory (LRI) data, indicate that the entire area consists of arable land suitable for cultivation. However, none of the land qualifies as Capability Class I (very good cultivable land). The majority (~84.71%) falls under Class III, indicating moderately suitable soils that require moderate conservation practices such as contour ploughing, land levelling, ridge and furrow systems, and adequate drainage to improve productivity.

Class IV soils (~11.74%) face more severe limitations like erosion, shallow depth, and poor drainage, restricting their cultivation potential. Nonetheless, with intensive soil conservation measures such as graded bunds, terracing, strip cropping, and contour tillage, these lands can be sustainably utilized.

This site-specific Land Capability Classification (LCC) provides critical insights for sustainable land management. The maps generated, based on detailed field surveys and topographic analysis, serve as practical tools for assessing crop suitability and guiding farmers and policymakers in designing effective, location-specific agricultural management strategies.

Furthermore, the findings encourage the promotion of horticultural cropping systems as viable, income-enhancing land use alternatives, potentially improving livelihoods and ensuring long-term sustainability in the region.

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