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Land Evaluation of Tribal Talukas of Bharuch District in South Gujarat, India

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Climate change interrupts existing agriculture, emphasizing the need for land evaluation to assess current capacities and introduce climate-resilient alternative crops. A study was undertaken to evaluate soils of three tribal talukas *viz*. Jhagadia, Netrang and Valia of Bharuch district in South Gujarat during 2021-24. The total fifteen representative soil profiles were identified and excavated from various landforms based on GIS maps. Land evaluation was conducted using land capability classification, land irrigability classification and soil site suitability for existing crops and alternative crops for the study area. The study area is predominantly classified under Land Capability Class II,

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indicating minor limitations and covering the majority of the region. The study area also includes Class III with moderate limitations and Class IV in Netrang taluka, which faces severe limitations due to soil quality, wetness, and erosion. The study area soils were grouped under three irrigability classes with further divided into six sub-classes based on the limitation of soils and site characteristics. Soil suitability indicates high cotton potential in specific profiles, while pigeonpea and soybean shows broad suitability. Sugarcane thrives in Jhagadia and Valia, with marginal suitability in Netrang and banana is highly suitable in most of Jhagadia. Key alternative crops suitable for the study area are finger millet, castor, groundnut, green gram, cluster bean, mango, guava and *Kamalam*. The study advocates soil and water conservation for intensified, sustainable agriculture, proposing tree-based BAIF's *Wadi* model for hilly terrains.

Keywords: GIS; land capability class; soil-site suitability; wadi.

1. INTRODUCTION

The growing population and evolving dietary preferences have led to the conversion of substantial forest and grassland areas into agricultural lands. Projections indicate that the worldwide demand for food commodities is expected to surge by 75-100 percent from 2010 to 2050 [1]. While modern intensive agriculture has greatly increased crop production and contributed to food security, it has also led to the overexploitation and degradation of vital natural resources such as soil, water and air. Improper use of soil resources without appropriate management leads to degradation, raising concerns among planners, researchers and farmers [2]. Moreover, Climate change and increasing extreme weather events pose serious threats to crops yield and their stability worldwide [3]. The shifting weather patterns, unpredictable rainfall, increased frequency of extreme weather events and rising temperatures are all contributing factors that disrupt agricultural practices. This underscores the need for land evaluation to determine their suitability for various agricultural and allied practices and to introduce alternative crops that are better suited to the changing climate.

The significance of land evaluation for optimizing land use options has gained increasing importance, as an efficient and optimized land use plan is both agriculturally sustainable and economically viable. Land evaluation is the process of assessing land performance when used for a specified purpose [4]. This process involves the execution and interpretation of surveys and studies on landforms, soils, vegetation, climate and other related aspects of land. The goal is to compare potential land uses with specified land uses to determine the most promising options. Various interpretative groupings are used for land evaluation and the most common is land capability classification, land irrigability classification and land suitability classification.

With these considerations in mind, the present study was undertaken to evaluate land suitability for various purposes in the three tribal talukas of Bharuch district.

2. MATERIALS AND METHODS

The study area involves tribal talukas of Bharuch district namely, Jhagadia, Netrang and Valia. The location of the study areas falls under the South Gujarat region, which comprises South Gujarat agro-climatic Zone II. The study area is located between 21°29'05" to 21°55'21" N latitude and 73°03'40" to 73°29'51" E longitude in Bharuch district, Gujarat (Fig. 1). It has an elevation up to 414 m above mean sea level (MSL). It covers an area of 1.32 lakhs ha which is 20.23 per cent of the total geographical area (TGA) of Bharuch district and is comprised of 264 villages.

The semi-arid study area receives approximately 964.98 mm of annual rainfall. Temperatures range from a minimum of 13.73°C in January to a maximum of 39.35°C in May. Morning relative humidity data collected over the past 20 years (2004 to 2023) showed a range from 59.51 percent in February to 87.17 percent in July. Evening relative humidity also varied across months, ranging from 25.57 percent in March to 75.98 percent in July. Sunshine hours are lowest in July (2.78 hrs) and highest in April (9.23 hrs). Wind velocity varies from 2.99 to 10.98 $kmhr^{-1}$. The area has diverse vegetation; including *Butea monosperma*, *Bombax ceiba* and *Tectona grandis* in Jhagadia and Netrang, while *Azadirachta indica* and *Acacia nilotica* in Valia.

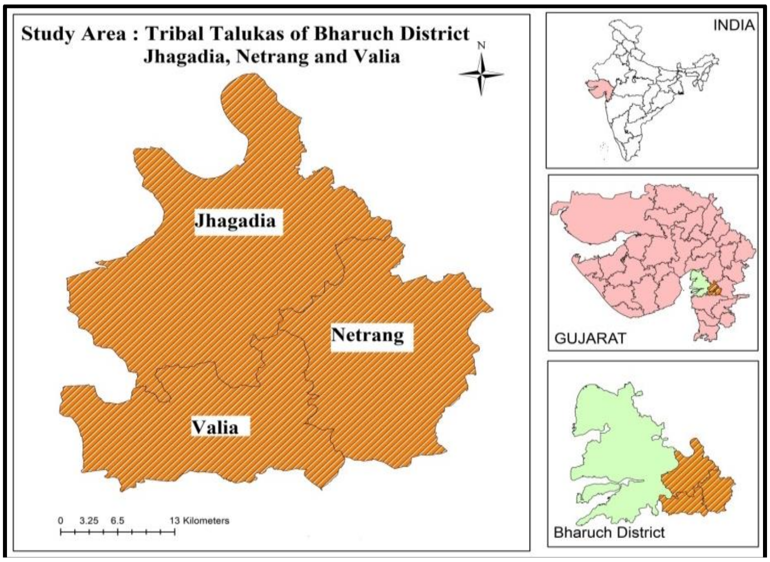

Fig. 1. Location map of study area

The detailed soil survey was carried out using Sentinel-2A satellite image (10 m spatial resolution), ALOS-DEM and toposheet of Survey of India (SOI) on 1:50,000 scale. To study the soil characteristics and evaluate the land suitability characteristics of the study area, fifteen representative soil profiles were dug out and were examined by following standard procedures (Soil Survey Staff, 2014). The horizon-wise samples were collected from these profiles and analyzed as per the standard procedure. Weighted mean of each property was calculated and soil-site characteristics of different soil profiles were obtained as shown in Table 1. These weighted average data have been used to evaluate the land capability classification, soil irrigability classification and soil-site suitability. Land capability, land irrigability and soil-site suitability maps were prepared using ArcGIS 10.8.2 software.

3. RESULTS AND DISCUSSION

3.1 Soil-site Characteristics of Tribal Talukas of Bharuch District

The eastern part of the study area features undulating terrain with slopes exceeding 3 percent, leading to moderate to severe soil erosion and somewhat excessive drainage. In contrast, the western part has gentler slopes of less than 3 percent. The soils of study area exhibit deep to very deep soil depths, with over 50 cm of soil depth present in all profile groups except P9 (Mungaj) in Netrang taluka. Predominantly, the upper layers of these soils contain a higher proportion of clay, exceeding 40 percent, thus classifying most soils into the clayey textural group. However, soils from P2 (Dhundha in Jhagadia) and P13 (Kesargam in Valia taluka) display slightly higher proportions of silt, categorizing them as clay loam soils. The higher clay content contributes to challenges in water permeability and infiltration within this area, although these soils demonstrate excellent water and nutrient retention capacities due to the high clay concentration. Notably, available moisture content appears lower in Netrang taluka, attributed to its undulating topography and sloped lands. The bulk density of different soil according to the profile and depth, ranged from 1.07 gcm^{-3} to 1.51 gcm^{-3}. The variation in BD of soils of different profiles might be attributed to the variation in clay along with coarse fractions/ gravels, partially decomposed rocks and intensity of plant roots/ organic matter in different horizons. The results are in good agreement with findings of Leelavathi et al. [5]. The available moisture content ranged from 6.00 per cent to 13.84 per cent. The mean cation exchange capacity (CEC) values, exceeding 30 across all profile groups, indicate that the soils in these talukas possess excellent water-holding and nutrient retention capacities. This elevated CEC further implies substantial clay content within the soils, underscoring their high nutrient retention potential. The exchangeable sodium percentage (ESP) ranged from the lowest 2.63 in P9 to the highest 8.94 per cent in P15. The soils of Valia taluka manifest a relatively higher degree of slight sodicity, which is subsequently followed by the soils of Jhagadia.

Table 1. Soil-site characteristics of tribal talukas of Bharuch district

Profile	Land form characteristics			Physiochemical characteristics (f)							
	Slope (%)	Erosion	Drainage	Depth (cm)	Texture	BD (gcm^{-3})	AMC (%)	$pH_{1:2.5}$	CaCO3 (%)	CEC ($me100g^{-1}$)	ESP (%)
Jhagadia taluka											
P1 (Amalzar)	3-8	Moderate	Well	107	c	1.46	8.21	7.10	6.46	49.05	3.17
P2 (Dhundha)	0-1	None	Well	120	cl	1.44	6.00	7.82	6.35	48.33	7.26
P3 (Jarsad)	1-3	V. slight	M. Well	115	c	1.36	12.19	8.00	5.18	49.98	6.66
P4 (Selod)	1-3	V. slight	M. Well	91	c	1.51	13.84	7.00	6.37	49.90	6.06
P5 (Shir)	1-3	V. slight	Well	129	c	1.46	9.56	6.92	5.73	50.08	4.97
Netrang taluka											
P6 (Chaswad)	0-1	None	Well	54	c	1.38	9.49	6.81	7.05	49.45	4.33
P7 (Kadwali)	1-3	Moderate	Well	90	c	1.41	10.03	6.10	5.72	41.25	3.55
P8 (Kavchiya)	1-3	V. slight	M. Well	122	c	1.41	7.10	7.28	6.43	49.63	3.41
P9 (Mungaj)	3-8	Severe	SW excess	41	c	1.07	9.39	6.53	5.23	46.12	2.63
P10 (Shankoi)	3-8	Severe	SW excess	93	c	1.41	7.65	5.81	5.02	51.38	3.24
Valia taluka											
P11 (Daheli)	0-1	V. slight	M. Well	95	c	1.35	12.06	7.87	4.83	49.45	8.48
P12 (Jamniya)	1-3	Moderate	Well	110	c	1.38	8.70	7.52	5.84	43.26	4.96
P13 (Kesargam)	0-1	None	Well	114	cl	1.48	8.39	7.35	4.84	42.35	6.09
P14 (Naldhari)	3-8	Moderate	Well	120	c	1.51	10.49	7.52	5.44	48.10	8.17
P15 (Pansoli)	0-1	None	M. Well	110	c	1.40	12.70	7.88	6.68	46.97	8.94

(V. slight = Very slight; M. Well = Moderately Well; SW excess = Some What excess; c= clayey; cl= clay loam, BD= Bulk Density; AMC= Available Moisture Content; CEC= Cation Exchange Capacity; ESP= Exchangeable Sodium Percentage)

3.2 Land Capability Classification (LCC)

The land capability classification groups the soils into eight classes from I to VIII, with each higher class having greater degree of a single or a combination of various limitations to crop production. Each class is further sub divided into sub classes depending upon the type and severity of limitation *viz*., erosion (e), wetness (w), soil root zone limitation (s) and climate (c). The results pertaining to land capability classes and subclasses with their extent and distribution in the study area are given in Table 2. As per land capability classification criteria, land of the tribal talukas of Bharuch district are grouped into three capability classes *viz*. II, III, and IV. The dominant LCC class covering largest area of 75907 ha is II with the minor limitation of soil, wetness and erosion. It is followed by land capability class III (34476 ha) with the moderate limitation of soil, wetness, erosion and comprised of P1, P6, P7 and P14. The class IV covers P9 and P10 with severe to very severe limitation of soil, wetness and erosion. Mungaj and Shankoi series occur on slopes (3-8%), prone to severe erosion and have shallow depth (0-50 cm) hence classified into LCC VI. Shallow soil depth and severe soil erosion as a consequence of moderate slope leading to washing out of top soil over period of time.

The sub-classes IIe, IIew, IIes, and IIw are categorized based on slope, erosion, and drainage limitations. Class IIe, covering profiles P2 across 3907 ha, exhibits slight erosion and is suitable for most crops with simple management. Class IIew spans 21921 ha, with slight erosion and drainage issues, necessitating drainage management. Class IIes, extending over 22699 ha, has minor soil issues and can support all climatically adapted crops with irrigation. Class IIw, affected by drainage limitations, also requires drainage management. The soil data interpretation reveals that the land capability classes and subclasses reflect the combined effects of climate and inherent soil characteristics. Similar LCC class characteristics with comparable limitations were observed by Sharma et al*.* [6] in cultivated soils of Jhagadia taluka of Bharuch district.

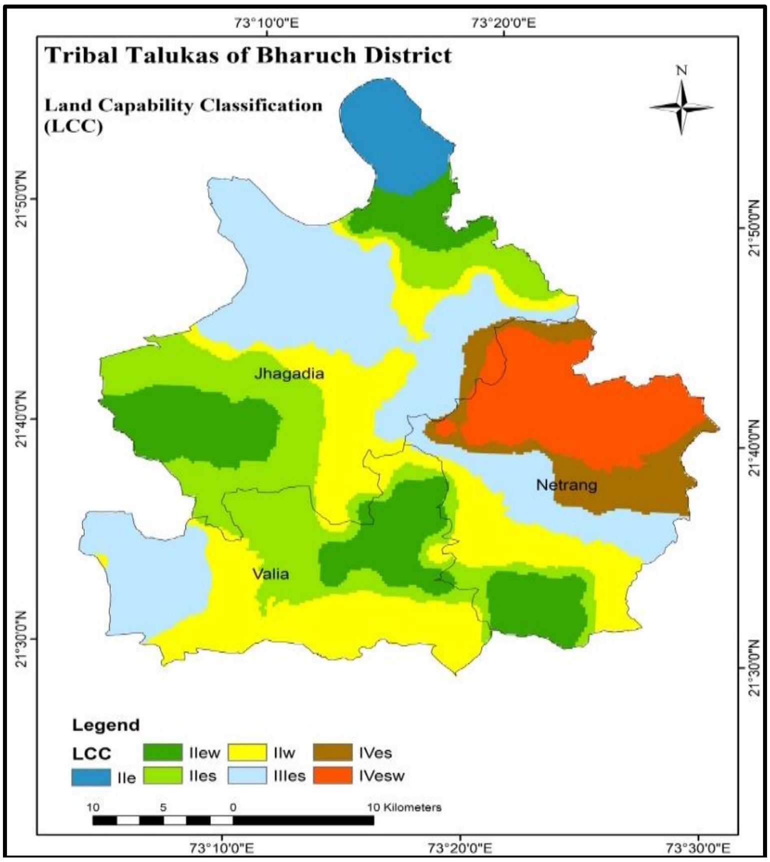

Fig. 2. Spatial distribution of land capability classes

Table 2. Land capability classification of tribal talukas of Bharuch district

Sub-classes	Description	Profile Area	Area (ha)
IIe	The good cultivable lands on very gentle slope that have slight limitation of erosion, which reduce the choice of crops. The soils are recommended to cultivate majority of climatically suitable crops with precautions; need simple management practices to protect soil erosion	P2	3907
IIew	The cultivable lands with very gentle slope that have slight limitation of erosion and drainage. The soils are recommended to cultivate majority of climatically suitable crops with precautions; need modest management practices to protect soil erosion and surface or subsurface drainage.	P8, P13	21921
IIes	These are the good cultivable lands with minor soil problem such as satisfactory texture, minor soil and erosion limitations. All climatically adapted crops can be grown with lifesaving irrigation.	P4, P5, P11	22699
IIw	The good cultivable lands on very gentle to gentle slope that have slight limitation of drainage, which reduce the choice of crops. The soils are recommended to cultivate majority of climatically suitable crops with precautions; need simple management practices of surface or subsurface drainage.	P3, P12 P15	27380
IIIes	Moderately good cultivable lands on very gentle to gentle slope with moderate limitations of erosion and texture. These areas have varying suitability for different crops. Unsuitable for growing vegetable crops. Recommended to cultivate with careful management practices; need intensive care for soil and erosion.	P1, P6, P7 P14	34476
IVes	Fairly good land on gentle slope, suitable for occasional or limited cultivation. Unsuitable for growing variety of crops because of severe limitations of soil texture, depth, erosion and AWC. If soils are economical to cultivate, then need intensive care of soil conservation and management practices	P10	5467
IVesw	Fairly good land on gentle slope, suitable for occasional or limited cultivation. Unsuitable for growing variety of crops because of very severe limitations of soil texture, depth, erosion and AWC. Soils may be cultivated for agroforestry (Wadi), silvipastoral system and need intensive care of soil conservation and management practices.	P9	9862

Table 3. Land irrigability classifications of tribal talukas of Bharuch district

Irrigab. Classes	Definition	Profile No	Area (ha)
2d	These are the lands having moderate limitations for sustained use under irrigation. These soils have moderate limitations of soil drainage	15	246
2s	These are the lands having moderate limitations for sustained use under irrigation. These soils have moderate limitations of soil characteristics	2, 4, 11	21314
2td	These are the lands having moderate limitations for sustained use under irrigation. These soils have moderate limitations of topography and drainage.	3, 8, 13	29080
3s	These lands have severe limitations for sustained use under irrigation. Lands of this class have severe limitation of soil characetristics.	5, 12	22354
3st	These lands have severe limitations for sustained use under irrigation. Lands of this class have severe limitation of soil and topography.	1, 6, 7, 14	26499
4st	These are the marginal lands for sustained use under irrigation because of very severe limitations of soils. Lands of this class have very severe limitation of topography	9, 10	26226

3.3 Land Irrigability Classification

The irrigability classification evaluates soil and land characteristics, including slope, erosion, texture, depth, drainage, salinity, alkalinity, graveliness, infiltration capacity and permeability. Based on these factors, land is categorized into six irrigability classes, with each soil type qualifying for only one class. The suitability for irrigation is determined by first grouping the soils into a) soil irrigability classes according to their sustained use under irrigation and b) then grouping the irrigable soils into land irrigability sub-classes.

Land is grouped into six land irrigability classes. Land belonging to class 1 to 4 is irrigable but limitations in their use for sustained irrigation increases from 1 to 4. Class 5 land is non-irrigable and special investigations are required to assign this class. Class 6 land is not suitable to sustained use under irrigation. The irrigability subclass is assigned according to the limitations of soils (s), topography (t) and drainage (d). The study area soils were grouped under three irrigability classes *viz*. 2, 3 and 4 and further divided into six sub-groups, the groupings are presented in Table 3.

The data in Table 3 reveals that soil series *viz*. Mungaj and Shankoi occupies 26226 ha area have very severed soil and topographic limitations occurring on moderately steep sloping hills and hence classified in 4st subclass of irrigability classification. Soil series Amalzar, Chaswad, Kadwali and Naldhari with 26499 ha area were grouped under 3st subclass having limitations of erosion and shallow soil depth. Soil series Dhundha, Selod and Daheli (21314 ha) are classified in 2s irrigability sub-class because of limitations in surface texture.

It is observed that soils of hilly terrain are rendered non irrigable due to serious topographic soil limitations prevailing on these landform units. The soils of older flood plains and pediments have slight to moderate soil and topographic limitations and are most suitable soils in the study area for their sustained use under irrigation. Soils developed over lower and middle alluvial plains are irrigable with some limitations of drainage and shallow ground water table. The results are in close agreement with the findings reported by Patil et al. [7]; Nasre et al. [8].

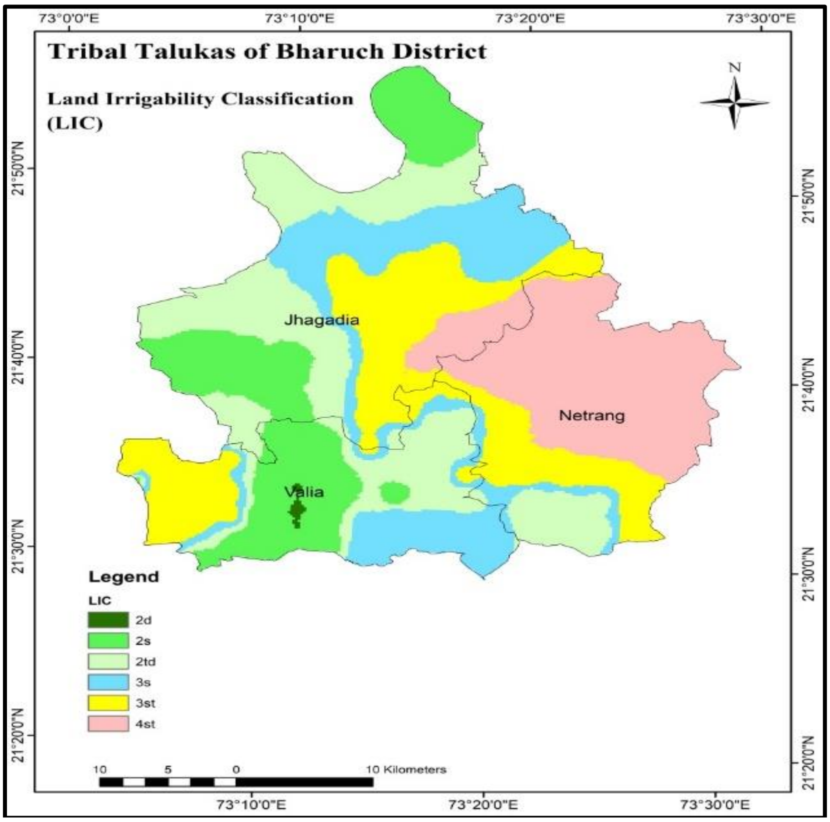

Fig. 3. Spatial distribution of Land Irrigability Classes

Table 4. Soil-site suitability rating for existing and alternative crops

Crops	Jhagadia					Netrang					Valia				
	P1	**P2**	**P3**	**P4**	**P5**	**P6**	**P7**	**P8**	**P9**	**P10**	**P11**	**P12**	**P13**	**P14**	**P15**
Existing Crops															
Cotton	S3*fle*	S2	S2	S1	S1	S2	S3*f*	S2	S3*lfe*	S3*lfe*	S1	S2	S2	S2	S1
Pigeonpea	S2	S1	S1	S2	S2	S1	S2	S1	S2	S2	S2	S2	S1	S1	S2
Sugarcane	S3*lf*	S1	S1	S1	S1	S2	S3*f*	S1	N*rle*	S3*rle*	S1	S1	S1	S2	S1
Wheat	S2	S1	S2	S2	S2	S2	S2	S2	S3*lf*	S3*lf*	S1	S1	S1	S1	S1
Soybean	S2	S2	S2	S2	S2	S1	S1	S1	S2	S2	S1	S1	S1	S1	S2
Banana	S3*lf*	S1	S2	S2	S1	S3*f*	S2	S2	N*rle*	S3*rle*	S2	S2	S1	S2	S2
Alternative Crops															
Finger Millet	S1	S1	S2	S2	S2	S2	S1	S1	S2	S1	S2	S1	S1	S2	S2
Chickpea	S2	S1	S2	S1	S1	S1	S1	S1	S2	S2	S1	S1	S1	S2	S2
Black gram & Green gram	S2	S1	S2	S1	S1	S1	S1	S1	S2	S2	S1	S1	S1	S2	S2
Groundnut	S2	S1	S1	S1	S2	S2	S2	S2	S3*lf*	S1	S1	S1	S1	S2	S1
Castor	S2	S1	S2	S1	S1	S2	S2	S1	S3*lfe*	S2	S1	S1	S1	S1	S1
Chilli	S2	S2	S2	S2	S2	S3*f*	S2	S2	S3*lfe*	S2	S2	S2	S2	S2	S2
Cluster bean	S2	S1	S1	S1	S1	S2	S2	S2	S2	S1	S1	S1	S1	S2	S1
Mango	S2	S1	S1	S1	S1	S2	S2	S2	S2	S1	S1	S1	S1	S2	S1
Sapota	S2	S2	S2	S2	S2	S2	S2	S2	S3*lf*	S2	S2	S2	S2	S2	S2
Guava	S2	S1	S1	S1	S1	S2	S2	S2	S3*lf*	S2	S2	S2	S2	S2	S2

Note: S1: highly suitable, S2: moderately suitable, S3: marginally suitable, N: Not suitable, r: rooting depth, t: texture, l: slope. f: physicochemical characteristics, e: erosion

3.4 Land Suitability/ Soil-Site Suitability Classification

The suitability of a given piece of land refers to its natural ability to support a specific purpose. The optimum requirements of a crop are always region specific. Climate and soil-site parameters play significant role in maximizing the crop yields. In the present study, information was analyzed using models described by Naidu et al. [9] to determine soil suitability criteria. These models were applied to assess the overall sustainability and suitability of soils in different profile areas of the tribal talukas of Bharuch district for the cultivation of major crops. The findings are presented in Table 4.

Soil-site suitability of existing crops: Cotton and Pigeonpea are long duration crop with deep rooted system. Hence, soils which are very deep and have high clay content are suitable for cotton and pigeonpea. Based on the soil suitability evaluation for cotton cultivation, profiles P4 and P5 in Jhagadia, as well as P11 and P15 in Valia, were found to be highly suitable (S1). In contrast, profile P1 in Jhagadia and profiles P7, P9 and P10 in Netrang were deemed marginally suitable for cotton cultivation due to limitations related to soil drainage and slope. The remaining profiles were evaluated as moderately suitable (S2). Soil suitability for Pigeonpea was found to be moderately to highly suitable across all talukas. Similar results of suitability of crops in Bharuch district was reported by Jangir et al. [10]. The best rooting medium for sugarcane should at least have more than 100 cm depth, stable well-structured loam to clay loam soils. Inadequate aeration decreases the intake of water by sugarcane through its effect on absorption and indirectly by reduced root growth, which lead to reduce cane growth. The majority of soils in Jhagadia (P2, P3, P4 and P5) and Valia (P12, P13 and P15) were found to be highly suitable to moderately suitable (P11 and P14) for sugarcane cultivation, while the soils in Netrang were marginally suitable (S3) for sugarcane. Mungaj (P9) profile area in Netrang taluka is not suitable for sugarcane due to severe limitation of soil depth, topography and moderate limitation of stoniness. For wheat cultivation, profiles No. 2, 11, 12, 13, 14 and 15 were rated highly suitable (S1). Profiles No. 1, 3, 4, 5, 7 and 8 were considered moderately suitable (S2). In Netrang, profiles P6, P9 and P10 were found marginally suitable (S3) due to constraints in soil drainage and slope. In the relation to the soybean cultivation soil site evaluated as all profiles evaluated as moderately suitable (S2) to highly suitable (S1).

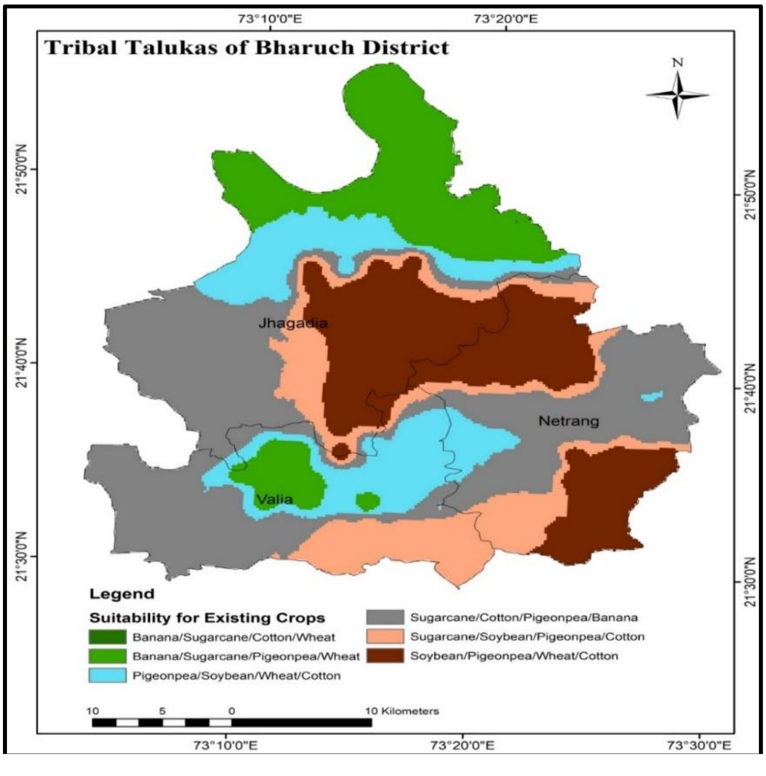

Fig. 4. Soil- suitability for existing crops in tribal talukas of Bharuch

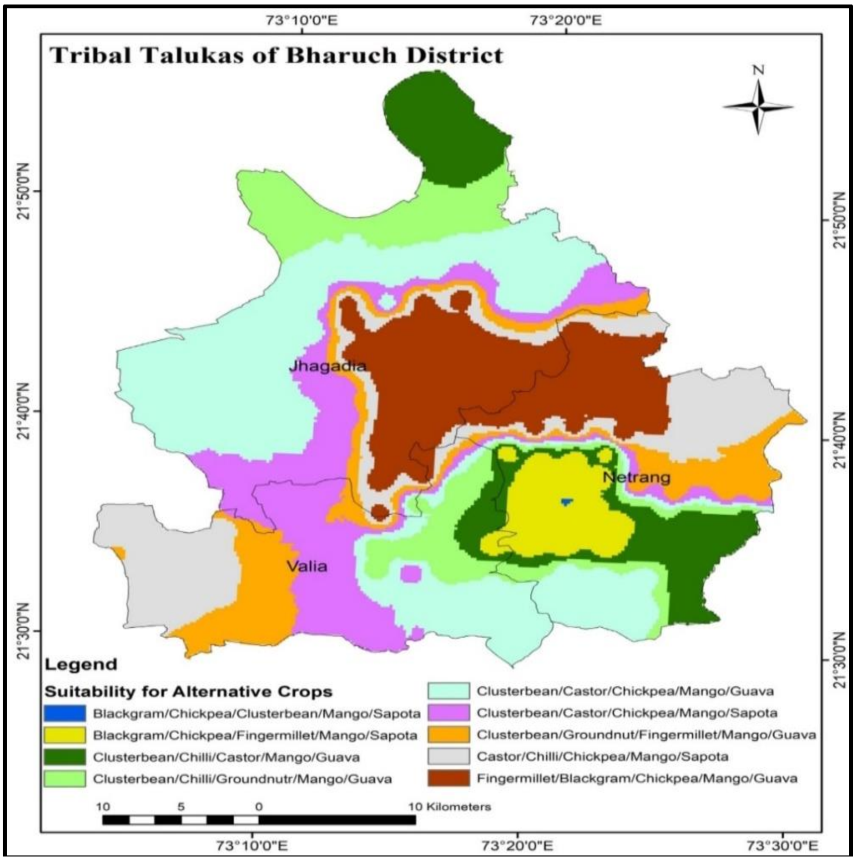

Fig. 5. Soil- suitability for alternative crops in tribal talukas of Bharuch

Soil-site suitability of potential alternative crops: The assessment identified finger millet as highly suitable for nearly 50% of the area and moderately suitable in other areas due to alkaline pH and sodicity. Short-duration pulses like black gram and green gram are the favoured crops of the tribal farmers of a Netrang, Valia and Jhagadia block of Bharuch district particularly for less fertile hilly upland and marginal soil [11]. Groundnut is generally suitable except in P9 due to soil depth and slope issues, and can be intercropped with pigeonpea. Castor is highly suitable for sugarcane-dominated areas, offering a diversification option. Vegetables like cluster bean and chilli, along with fruit species such as mango, guava, and sapota, show potential for introduction and expansion based on soil suitability. *Kamalam* (Dragon fruit) is well-suited for the light, well-draining soils found in the hilly areas of Jhagadia and Netrang, which typically have a pH range of 6.0-7.0. The Wadi model introduced by BAIF typically involves planting of fruit trees species along with forestry along the borders, with pulses and vegetables as intercrops can also be promoted in these talukas. The studies on carbon sequestration in soils revealed a general trend of increasing soil carbon sequestration in agroforestry as compared to other land-use practices [12,13].

4. CONCLUSIONS

The tribal talukas of Bharuch district primarily fall under Class II of the Land Capability Classification, covering 75907 ha and indicating minor limitations. This is followed by Class III, covering 34476 ha with moderate limitations, and Class IV, covering 9862 ha in Netrang taluka, which has severe limitations. According to land irrigability classes, the study area is classified with 50640 ha under Class 2, 48853 ha under Class 3, and 26226 ha under Class 4. The crop suitability evaluation finds that pigeon pea, soybean, and wheat are mostly suitable for cultivation across the study area. Finger millet, castor, groundnut, green gram, cluster bean, mango and guava are the potential alternative crops identified. The study emphasizes the need soil and water conservation to support intensified agriculture and sustainable land use. It also suggests tree-based farming "*Wadi*" model for undulating and hilly areas.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of manuscripts.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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