Soil-site suitability assessment for major fruit crops in Chikkumbi-3 micro-watershed (4D7C5O2f), Karnataka using remote sensing and GIS techniques

Abstract

A research project was conducted to assess the viability of three soil series (CLK, CKB, and HNL) in the Chikkumbi-3 micro-watershed of Dharwad district, located in the Northern dry zone (Zone-3) of Karnataka. Using criteria such as texture, depth, slope, erosion, graveliness, and stoniness, ArcGIS V 10.8 was employed to classify the soils into five mapping units. The suitability of these mapping units was then evaluated for cultivating major fruit crops, including mango, lime, guava, grape, pomegranate, and sapota. The analysis revealed that the soil series Chulki (CLK), Chikkumbi (CKB) and Hanchinal (HNL) are presently not suitable for growing mango and lime due to significant limitations in physical conditions, rooting, and moisture. However, the region is deemed moderately to marginally suitable for the cultivation of guava, grape, pomegranate, and sapota. These findings serve as foundational data for identifying specific soil constraints, aiding in the development of sustainable strategies for crop production in the study area.

Key words: Crop suitability classification, ArcGIS, Chikkumbi-3 micro-watershed.

Introduction

To assess the suitability and limitations of a specific piece of land for agricultural purposes, it is essential to employ a scientific method of land evaluation, as outlined by Rossiter (1996). The adverse environmental impacts of land use and the sustainability of agricultural production systems have become recent focal points. Developed nations have witnessed intensive agriculture leading to diminishing soil fertility, stagnant yields, and uncontrolled soil erosion, while developing nations face issues such as the overuse of natural resources and insufficient inputs like chemical fertilizers, as noted by Fresco (1990) and Lanen Van *et al.*, 1992. Given this context, there is an increased emphasis on land evaluation to determine optimal land use options. Maintaining the sustainability of agriculture hinges on efficient land utilization. According to FAO (1976), land evaluation is defined as "the process of assessment of land performance when used for specified purposes." This involves conducting and interpreting surveys and studies on landform, soils, vegetation, climate, and other relevant factors to compare potential land use with specific land use requirements. Wambeke and Rossiter (1987) describe land evaluation as the ranking of soil units based on their capacity to yield maximum returns per unit area while conserving natural resources for future use. Interpretive groupings aid in assessing the potential of various soils and making predictions about their behavior under different management strategies, with the Land Suitability Classification (FAO, 1976) being a widely used approach for land appraisal. The four steps in land evaluation involve: a) characterizing current soil, climate, and land use conditions; b) establishing soil-site criteria based on crop requirements; c) aligning crop requirements with existing soil and climate conditions; and d) ultimately selecting the most suitable crop for the situation as an alternative crop strategy. Therefore, the assessment of soil-site suitability plays a critical role in identifying potential crops for a given region and climate conditions.

Remote sensing (RS) data plays a crucial role in delineating different physiographic units and providing additional information on site characteristics, including slope, direction, and aspect of the study area. While RS data offer valuable insights, detailed knowledge of soil profile properties is essential for initiating crop suitability assessments. Therefore, soil survey data are indispensable for creating a comprehensive soil map of a given region, aiding in the evaluation of crop suitability and cropping system analysis. By integrating RS data with soil survey information into a geographical information system (GIS), it becomes possible to assess crop suitability under various soil and biophysical conditions. Previous research efforts by various scholars (such as Ravikumar *et al*., 2009; Walke *et al*., 2012; Gangopadhyay *et al*., 2018) have demonstrated the potential of this integrated approach using GIS and RS data for quantitative land evaluation. The current study aims to showcase the practical application of RS and GIS technologies in conjunction with soil data to evaluate soil-site suitability for specific horticultural crops in the Chikkumbi-3 micro-watershed.

2. Material and Methods

The research was carried out during the period 2022-2023 in the Chikkumbi-3 micro-watershed (4D7C5O2f) located in Belagavi district, Karnataka. The micro-watershed is situated between 16º 6′ – 16º 7′ North latitudes and 75º 12′ – 75º 14′ East longitudes, with its highest elevation reaching 900 m above mean sea level. The total geographical area of the micro-watershed is approximately 514.91 ha. The annual temperature in this region varies between 24.68 to 26.67 °C. The micro-watershed experiences an average annual rainfall ranging from 278 to 441 mm.

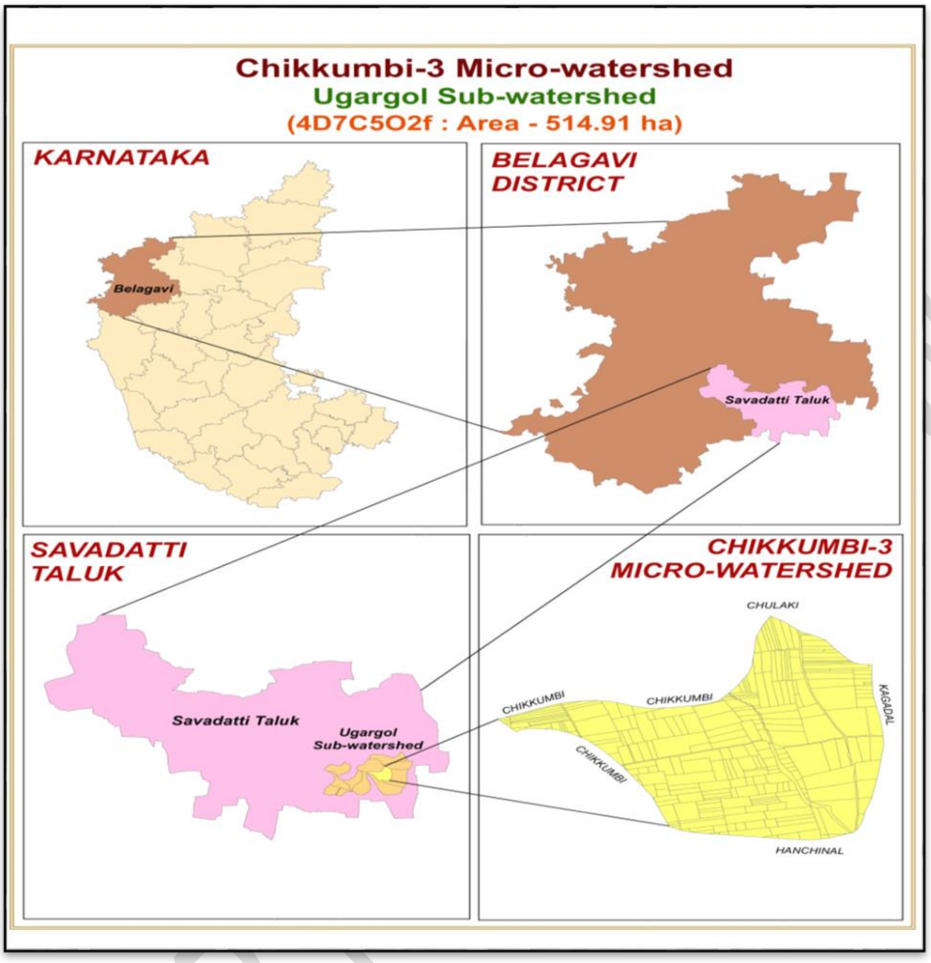

Figure 1 Location of the study area

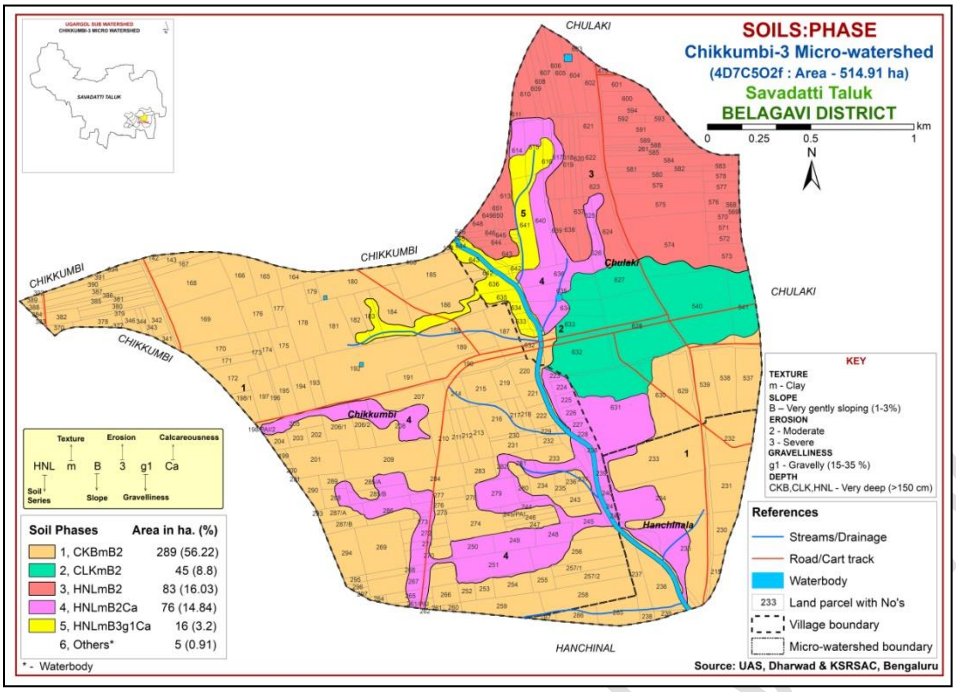

Figure 2 Mapping units of Chikkumbi-3 micro-watershed

2.1 Study method

Following an initial survey of the entire watershed, utilizing a 1:7,920 scale base map and satellite imagery, three specific soil profiles were chosen and examined. The selection was based on considerations such as geology, drainage patterns, surface features, slope characteristics, land use, landforms, and physiographic divisions. The morphometric characteristics of these chosen soil profiles were documented, and both physical and chemical properties were assessed through standard procedures (Soil Survey Staff, 2014). A comprehensive soil resource inventory for the Chikkumbi-3 micro-watershed was then conducted, leading to the identification of five distinct mapping units (Figure 2).

Subsequently, a detailed soil survey was carried out, and crop suitability maps for major fruit crops in the Chikkumbi-3 micro-watershed were generated at the soil phase level. This mapping process was executed using ArcGIS V 10.8. The assessment of crop suitability was conducted using the limitation method, taking into account the number and intensity of limitations, as outlined by Naidu *et al*. in 2006. This evaluation procedure encompasses three phases.

During the first phase, data collection focused on various characteristics outlined in Table 1. Landscape and soil attributes such as topography (% slope), wetness (flooding and drainage), and physical soil features (texture/structure, % coarse fragments by volume, soil depth in cm, $CaCO_3$%), as well as salinity (EC, dSm^{-1}), and alkalinity (ESP), were utilized for evaluating soil suitability. The study area exhibited very gentle slopes and had never experienced flooding (F0). Drainage conditions were identified as moderately well, and the soil had a clay texture following the guidelines provided by FAO (1976). Soil characteristics were assessed according to FAO recommendations (1976). Based on morphological, physical and chemical properties of soils, soils were classified up to family level as per "Keys to Soil Taxonomy". The soil pedons were classified as Fine smectitic isohyperthermic Typic Haplusterts, Fine smectitic isohyperthermic Calcic Haplusterts, Fine smectitic isohyperthermic Typic Calciusterts.

In the second phase, the landscape and soil requirements for six crops were derived from Naidu *et al*. (2006) as detailed by Sehgal (2005). The third phase involved assessing land suitability under rainfed conditions by comparing landscape and soil characteristics with crop requirements, considering different limitation levels: no (0), slight (1), moderate (2), severe (3), and very severe (4). Limitations refer to deviations from optimal conditions of a land characteristic, impacting land use. If a land characteristic is optimal for plant growth, it incurs no limitation; however, unfavorable conditions lead to severe limitations for specific land evaluation types. The evaluation was conducted by aligning land characteristics with limitation levels of crop requirements outlined by Naidu *et al*. (2006), following Sehgal (2005) description. The number and severity of limitations determined the suitability class of each soil series for a particular crop, following FAO (1976).

3. Results and Discussion

The soil properties in the research area were compared against the soil-site suitability criteria for several significant fruit crops cultivated in North Karnataka. The table 2 illustrates the soil-site suitability for major horticultural crops.

3.1 Mango

Mango is well-adapted to tropical and subtropical climates and thrives up to 1500 metres above mean sea level, but it is not commercially viable above 600 metres. It is grown in nearly all Indian states and accounts for approximately 56% of global mango production.

Together, Andhra Pradesh, Uttar Pradesh, Bihar, Karnataka, Maharashtra, West Bengal, and Gujarat account for approximately 82% of India's total mango production. Andhra Pradesh ranks first in total production, while Uttar Pradesh ranks first in land area.

The suitability of the mapping units in the research region for mango cultivation was found to be not suitable (N). This was mostly due to the constraints imposed by climatic conditions.The mapping units HNLmB2, HNLmB2Ca, CKBmB2, CLKmB2, and HNLmB3Cag1 were deemed not suitable (Nc) due to significant constraints related to temperature, rainfall, length of growth period, and fertility limits.This was because of many things, such as the soil's physico-chemical qualities, its physical conditions, its moisture content, and a small amount of slope (Figure 3). The suitability sub-class Nc of the area demonstrated that it was not suitable for mango cultivation as a whole. Denis *et al*. (2014) also identified the depth restriction for mango in the Singhanhalli-Bogur micro-watershed.

3.2 Guava

The cultivation of guava has been shown to be viable in regions characterized by tropical and subtropical climates. In the Indian context, the cultivation of this crop is widespread in the states of Uttar Pradesh and Bihar, while it is practiced to a lesser degree in the other states. The mapping units within the research region exhibited marginal suitability for guava cultivation. The whole of the region exhibited moderate to severe constraints in terms of soil drainage, texture, pH, and organic carbon content, hence categorizing it as S3cs (Figure 4).

According to the Indian Council of Agricultural Research (ICAR, 2001), guava exhibits tolerance to high temperatures and drought conditions. However, it is also vulnerable to severe frost, which may result in the death of immature plants. The findings of the research suggest that the development and production of guava in the study region are mostly influenced by factors such as slope and coarse fragments. Denis *et al*. (2014) and Anilkumar *et al*. (2019) both documented comparable findings in the Singhanhalli-bogur micro-watershed and Haradanahalli micro-watershed, respectively. Due to the severe limitations, guava production could be restricted to a small portion of the area under study.

3.3 Pomegranate

Pomegranate adapts to a wide range of climatic conditions. It grows well in plains as well as on hills up to an elevation of 2000 M above MSL. It is a hardy plant that can withstand drought. The pomegranate fruit crop requires a soil depth of more than 100 cm, sandy loam, silt loam, clay loam, loam texture, soils free of salinity and alkalinity, and well-drained soils. The most suitable temperature for pomegranate cultivation is 30 °C to 34 °C. The length of the growing period for optimum crop production is more than 150 days.

The suitability of all the mapping units for pomegranate cultivation was found to be marginally suitable (S3), with moderate to severe constraints in terms of climate and physical condition of the soil.The mapping units HNLmB2, HNLmB2Ca, CKBmB2, and CLKmB2 were found to be marginally suitable (S3c) for the specified purposes. Additionally, the mapping unit HNLmB3Cag1 was classified as marginally suitable with severe limits (S3cs) in terms of temperature and length of growing period, while exhibiting none to mild constraints in relation to land form features.The suitability of the mapping units within the research region for pomegranate cultivation was found to be marginal. Figure 5 illustrates the presence of moderate to marginal limitations in terms of drainage, texture, and pH (S3cs). Manjunatha *et al*. (2017) reported comparable findings.

3.4 Sapota

India is regarded as the world's largest producer of sapota. In India, Maharashtra, Gujarat, Andhra Pradesh, Karnataka, Tamil Nadu, Kerala, Uttar Pradesh, West Bengal, and portions of Punjab and Haryana cultivate sapota on a commercial scale.

The suitability of all the mapping units for sapota cultivation was found to be marginally suitable (S3), with moderate to severe constraints in terms of climate. The mapping units HNLmB2, HNLmB2Ca, CKBmB2, and CLKmB2 were determined to be marginally suitable (S3c) based on their characteristics. Additionally, the mapping unit HNLmB3Cag1 was found to have severe limits in terms of temperature, pH, and length of growth period, while also exhibiting none to mild constraints in terms of land form features. The soil suitability for sapota cultivation in the Chikkumbi-3 micro-watershed was found to be marginally suitable, as shown in Figure 6. The whole region exhibited moderate to severe limitations in terms of soil drainage and rainfall and was classified as S3cs. The limiting parameters identified in this study were pH, organic carbon content, drainage, and soil texture. Madhusudan (2019) and Prathibha *et al*. (2019) have both reported comparable findings on the constraints imposed by rooting conditions and texture. Due to the severe limitations, sapota production could be restricted to a small portion of the area under study.

3.5 Lime

The lime fruit crop requires a soil depth of more than 150 cm, sandy loam, silt loam, clay loam, loam texture, soils free of salinity and alkalinity, and well-drained soils. The most suitable temperature for lime cultivation is 28 °C to 30 °C. The length of the growing period for optimum crop production is 240-265 days. The suitability of the mapping units in the research region for lime cultivation was found to be not suitable (N) owing to many factors, including restrictions in climatic conditions. The mapping units HNLmB2, HNLmB2Ca, CKBmB2, CLKmB2, and HNLmB3Cag1 were deemed not suitable (Nc) due to significant constraints related to temperature, rainfall, length of growth season, and fertility limits. The mapping units within the research area were not suitable for the cultivation of lime.

The unsuitability of the whole region for cultivation of citrus due to the severe limitations of $CaCO_3$, rainfall, and drainage was classified as suitability subclass Nc (Figure 7). The findings align with the study conducted by Rajesh *et al*. (2019), which indicated that the Adavibhavi micro-watershed is presently classified as not suitable (Nc) due to significant constraints related to slope, texture, and gravel. Similarly, Mahesh *et al*. (2019) reported that the Bharatnur-3 microwatershed is moderately suitable (S2lt) with limitations pertaining to texture and topography, while it is deemed not suitable due to constraints related to rooting depth and topography.

3.6 Grapes

Regions that have an annual precipitation over 100 cm are considered very favourable for the cultivation of grapes. The yield of crops on soils with a depth exceeding 150 cm is often greater. Grapes may not thrive in soils that are too sandy or heavy in clay, as well as those with elevated levels of alkali metal salts or other hazardous compounds. The suitability of the studied region for grape growing was found to be marginal (Figure 8).

The suitability of all the mapping units for grape cultivation was found to be marginally suitable (S3) due to moderate to severe constraints in climate.The mapping units HNLmB2, HNLmB2Ca, CKBmB2, CLKmB2, and HNLmB3Cag1 exhibited marginal suitability (S3c) due to significant constraints related to temperature, texture, pH, duration of growth period, and fertility.The whole region exhibited a notable range of constraints in terms of precipitation, soil drainage, texture, pH, $CaCO_3$, and organic carbon content, leading to its classification under the suitability subclass S3c.The findings of Madhusadan (2019) and Manjunatha *et al*. (2017) indicate that the texture and pH constraints in the Kanaginahala sub-watershed, as described in the Chikamageri microwatershed, have resulted in outcomes ranging from moderately suitable to not suitable for grape cultivation.

Table 1. Soil-site suitability classification of mapping units for major fruit crops

Mapping unit	Lime	Grapes	Mango	Guava	Pomegranate	Sapota
HNLmB2	Nc	S3c	Nc	S3c	S3c	S3c
HNLmB2Ca	Nc	S3c	Nc	S3c	S3c	S3c
CKBmB2	Nc	S3c	Nc	S3c	S3c	S3c
CLKmB2	Nc	S3c	Nc	S3c	S3c	S3c
HNLmB3Cag1	Nc	S3c	Nc	S3cs	S3cs	S3cs

Table 2 Soil-site characteristics of soil mapping units of Chikkumbi-3 micro-watershed

S.No.	Soil Phases	Wetness (w)	Physical condition of soil (s)					Fertility (f)				Salinity/ alkalinity (n)		Erosion (e)
		Drainage	Texture	Depth (cm)	Stoniness	Gravel (%)	$CaCO_3$ (%)	pH	OC (g kg^{-1})	CEC [cmol (p^+) kg^{-1}]	BS (%)	EC (dS m^{-1})	ESP (%)	Slope (%)
1	HNLmB2	Moderately well drained	clay	Very deep (180+)	Nil	<15	11.61	8.46	10.67	45.52	85.84	0.43	3.62	1-3
2	HNLmB2Ca	Moderately well drained	clay	Very deep (180+)	Nil	<15	13.46	8.5	6.83	51.66	84.47	0.35	2.42	1-3
3	CKBmB2	Moderately well drained	clay	Very deep (180+)	Nil	<15	6.73	8.65	6.5	45.67	83.29	0.18	3.07	1-3
4	CLKmB2	Moderately well drained	clay	Very deep (180+)	Nil	<15	14.09	8.54	6.79	47.06	85.87	0.28	3.13	1-3
5	HNLmB3Cag1	Moderately well drained	clay	Very deep (180+)	Nil	15-35	14.85	8.55	6.67	51.22	91.77	0.27	2.90	1-3

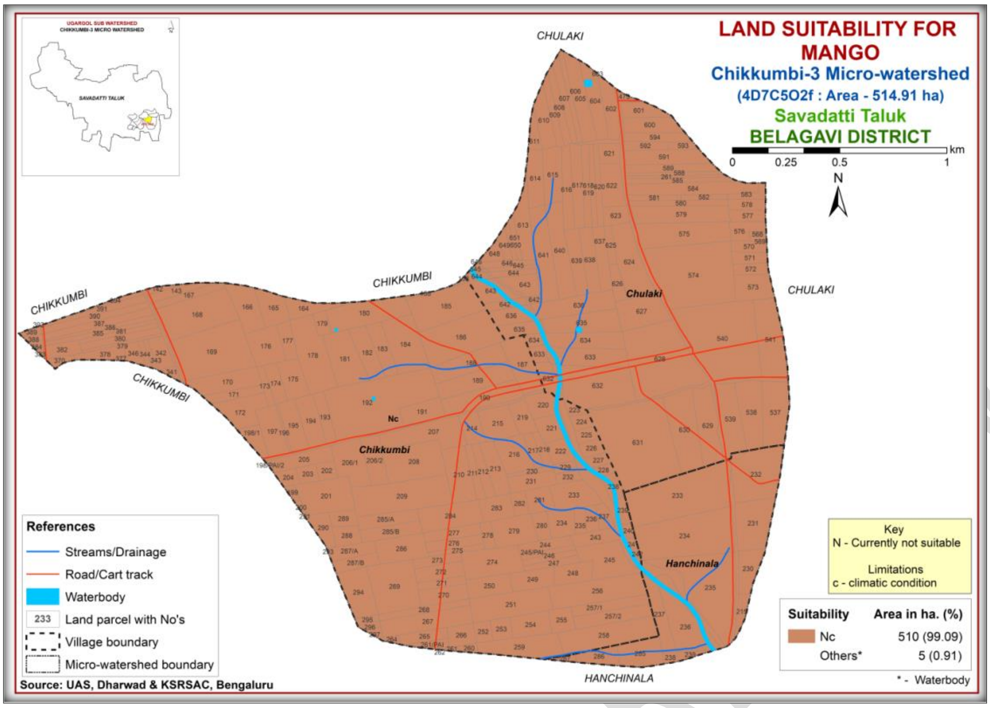

Figure 3 Soil-site suitability map for mango crop in Chikkumbi-3 micro-watershed

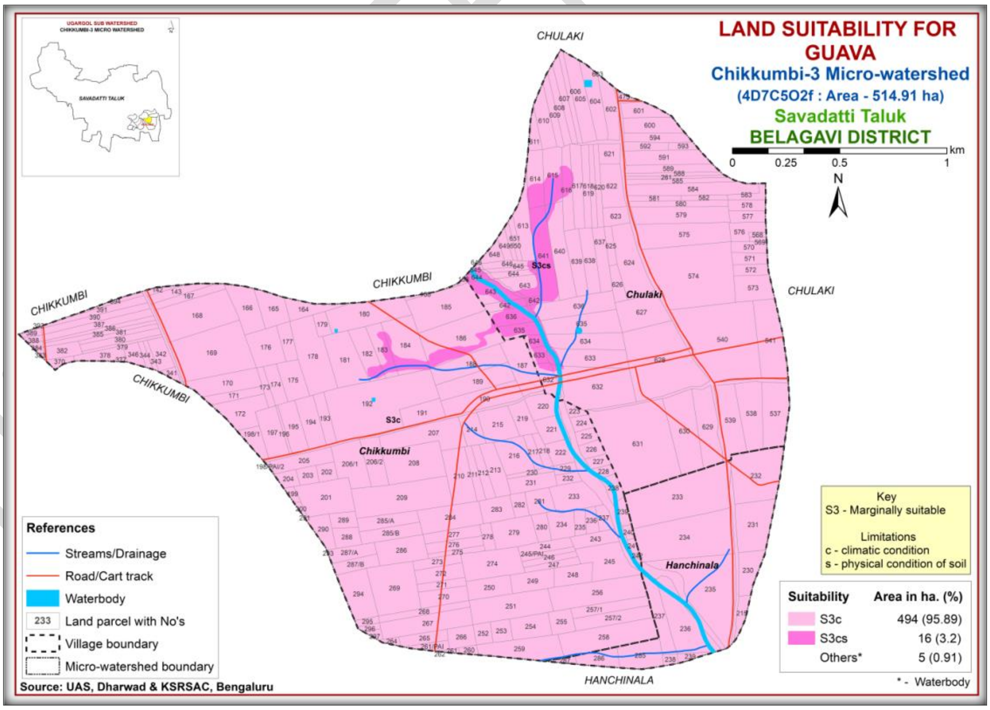

Figure 4 Soil-site suitability map for guava crop in Chikkumbi-3 micro-watershed

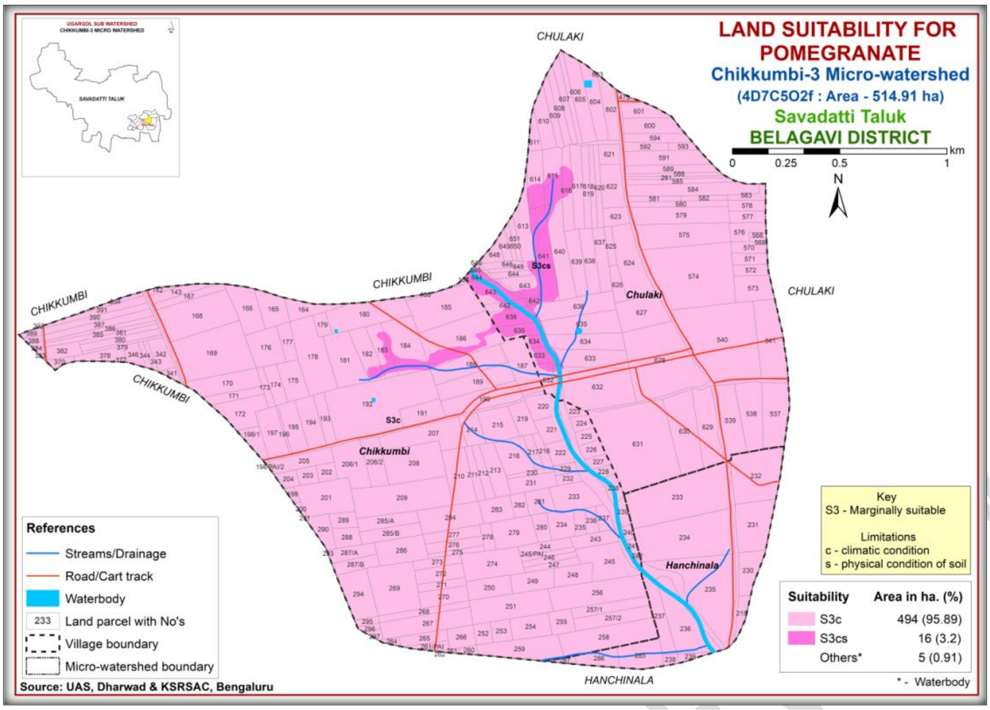

Figure 5 Soil-site suitability map for pomegranate crop in Chikkumbi-3 micro-watershed

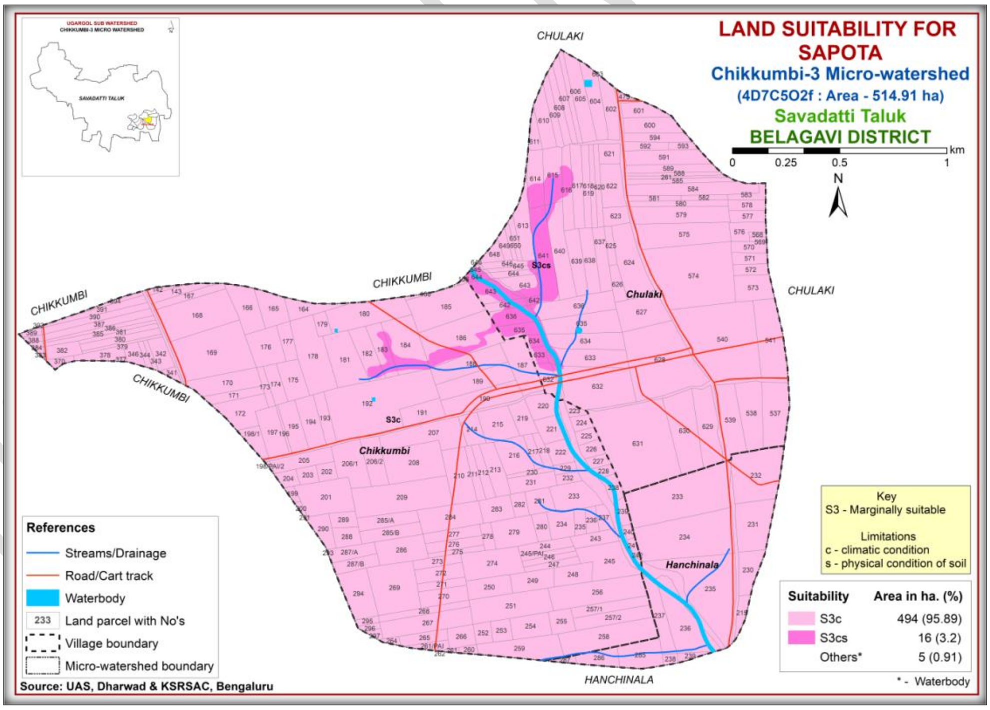

Figure 6 Soil-site suitability map for sapota crop in Chikkumbi-3 micro-watershed

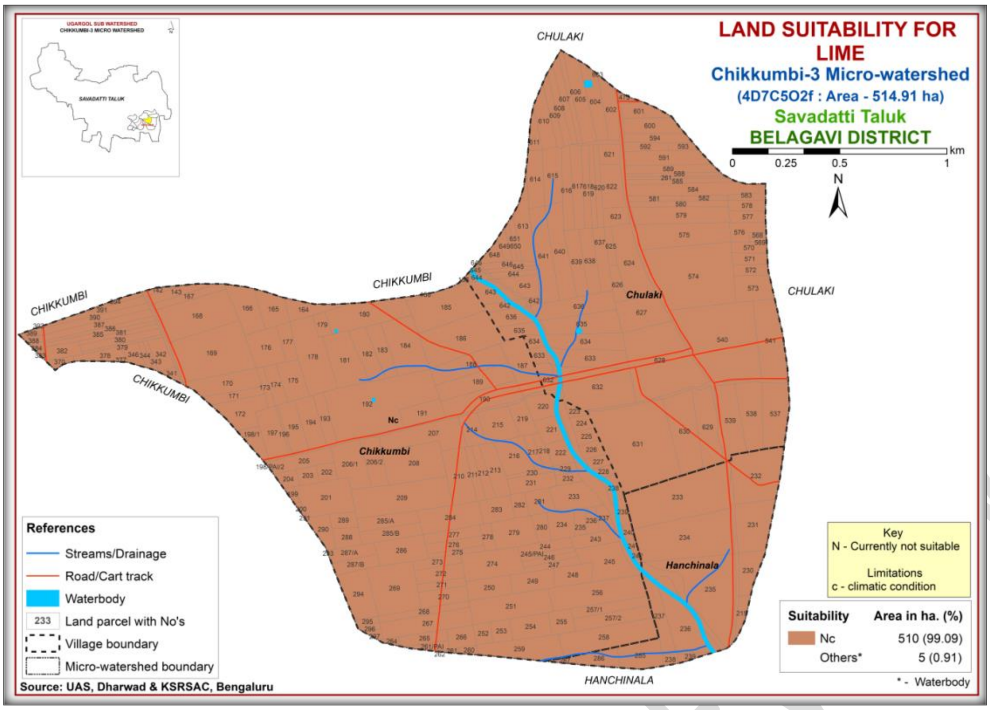

Figure 7 Soil-site suitability map for lime crop in Chikkumbi-3 micro-watershed

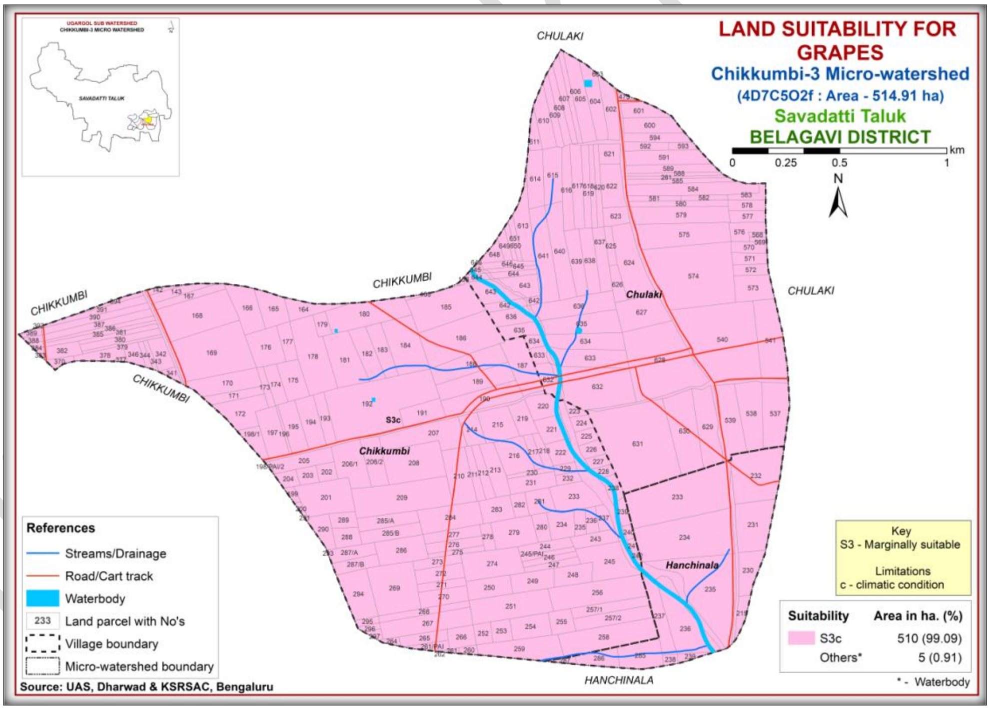

Figure 8 Soil-site suitability map for grape crop in Chikkumbi-3 micro-watershed

Conclusion

It is concluded that the soils of the Chikkumbi-3 micro-watershed showed different degrees of suitability for growing mango, guava, pomegranate, sapota, lime and grapes. The soil series CLK, HNL and CKB are currently not suitable for the production of mango and lime and marginally suitable for the production of guava, pomegranate, sapota and grapes. The main limitations in all the soil series found to be degree of texture, $CaCO_3$ contentand climate factors. However the degree of these limitations in all these soil series varies from slight to very severe. Further integrated use of organic manures and inorganic fertilizers not only paves the way to achieve sustainable yields of crops but also sustains the soil health for future generations undergoing deterioration and also helps in doubling the farmer's income.

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