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Land Suitability Assessment For Pomegranate Cultivation Using Multi-Criteria Analysis In GIS

ANIL S.YEDAGE[1] , R.S.GAVALI[2] , SAGAR MALI[3]

[1]Assistant Professor, Parvatibai Chowgule College of Arts and Science (Autonomous) Margao-Goa, India.

[2]Professor, Department of Environment, NIRD&PR, Hyderabad, India.

[3]Assistant Professor, Vidyaprabodhini College of Commerce, Education, Computer & Management, Parvari, Goa, India.

Corresponding Author email id anilyedage@gmail.com
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ABSTRACT

Pomegranate stands as one of the globally significant high-value agricultural crops, playing a pivotal role in the economic development of semi-arid regions. The selection of optimal sites for cultivating various agricultural crops, especially in diverse geographic regions, is a crucial aspect of agricultural research, leveraging the capabilities of Geographic Information Systems (GIS). This study aims to compare three distinct weighing methods—Ranking, Rating, and Analytical Hierarchical Process (AHP) pair-wise comparison—within the GIS framework, seeking to identify the most effective model. The initial step involves generating essential maps based on specific environmental conditions essential for pomegranate cultivation. These conditions encompass elevation, slope, land use, soil depth, soil properties, surface water availability, groundwater, and temperature threshold maps, all processed through GIS. Subsequently, the processed data layers undergo multi-criteria evaluation analysis using the three comparison methods. The resultant maps are then produced for each method within the GIS environment, facilitating a comprehensive comparison of the outcomes. The findings of the study reveal that the AHP comparison method outperforms the Ranking and Rating methods, showcasing the potential of GIS in selecting suitable land for pomegranate cultivation. The research concludes by identifying the central and southern parts of Sangola Taluka in the study area as highly suitable for establishing pomegranate orchards. In conclusion, this research underscores the significance of GIS and advanced analytical methods in agricultural studies, specifically in the context of site selection for high-value crops like pomegranates. The recommendation is to employ the AHP method in similar studies for its demonstrated superior performance.

Keywords: AHP, GIS, Multi-Criteria Analysis, Pomegranate, Site suitability.

1. Introduction

Land suitability analysis is a crucial step in the context of land planning, especially in situations where resources are limited. It involves assessing the fitness of specific soil parameters for defined land uses. The classification of land suitability entails the evaluation and categorization of distinct land areas based on their appropriateness for selected horticultural crops. In Maharashtra, horticulture farming has been a focal point since 1990-91, with government support and encouragement for farmers to develop land in semi-arid regions under employment guarantee schemes. This initiative encompasses the cultivation of fruits, flowers, and vegetables, with Pomegranate finding prominence in regions with low rainfall, particularly in drought-prone areas of Maharashtra. The Ganesh variety of Pomegranate is particularlypopular in this region. The integration of Multi-Criteria Decision Making (MCDM) techniqueswith Geographic Information Systems (GIS) has significantly advanced traditional map overlay approaches in land-use suitability analysis (Lyle and Stutz, 1983; Malczewski, 2004).The Food and Agriculture Organization (FAO) has established a system for evaluating lands' potential for crop cultivation based on soil and environmental characteristics, categorizing them into five classes: highly suitable, moderately suitable, marginally suitable, currently not suitable, and permanently not suitable (FAO, 1976, 1984, 1985). Site selection analysis aims to identify the optimal site for a given activity within a set of predetermined conditions. According to Malczewski (2004), this type of analysis assumes that all characteristics of the potential sites, including location, size, and relevant attributes, are known. The challenge lies in ranking or rating these alternative sites based on their characteristics to identify the best- suited site for the intended activity.

1.1 Importance of Pomegranate

Pomegranate (Punica granatum) is a beloved ancient fruit cultivated in arid and semi-arid regions across the globe. Renowned for its symbolic representation of abundance, the fruit is highly regarded for its cool, refreshing juice and esteemed for its medicinal properties. Through the examination of popularly available marketed products, it has been established that the fruit maintains its flavor and can be preserved for over a year when properly filtered, bottled, and treated with preservatives. The juice derived from pomegranate is believed to offer numerous health benefits and is used for therapeutic purposes in various cultures. Additionally, the seeds of the fruit are consumed fresh in many hot countries and are used as a condiment. Pomegranate is considered a high-value crop, and every part of the tree holds significant economic importance. The recognition of its health advantages has broadened its demand in the international market, expanding both trade and production opportunities. This versatile and valuable fruit continues to be cherished for its cultural significance, culinary uses, and potential health benefits.

1.3 Indian Scenario of Pomegranate

India holds a prominent position in pomegranate cultivation, with more than 1.20 lakh hectares dedicated to this fruit. Among the leading exporters of pomegranates, Thailand ranks first, followed by Spain, Iran, and India. Maharashtra state stands out as the leading producer of pomegranates within India, contributing significantly to the country's overall production (National Horticulture Board, 2011). Maharashtra is a key state for pomegranate cultivation, encompassing districts such as Solapur, Nasik, Ahemadnagar, Pune, Sangli, Latur, Osmanabad, Parbhani, Aurangabad, Beed, and Satara. The main varieties cultivated include Ganesh, Phule Arakta, Mridula, and Bhagwa. The availability of pomegranates for export primarily spans from July to September. The state has approximately 98,500 hectares under pomegranate cultivation, yielding a production of 6.00 lakh metric tons, accounting for around 70 percent of India's total pomegranate production (NHB Report, 2011). Solapur district, within Maharashtra,holds the highest production of pomegranates. It contributes to about 85 percent of the total pomegranate production in the state. Pomegranate cultivation in Solapur is particularly concentrated in talukas such as Sangola, Pandharpur, and Mohol. The region's significant contribution underscores its importance in the pomegranate industry within Maharashtra and the broader context of Indian pomegranate production.

2. Study area

The study area is situated in the Sangola taluka of Solapur district, located in the western part of Maharashtra. It spans latitudinal from 17°06'35" north to 17°40'35" north and longitudinally from 74°51'00" east to 75°20'25" east. Characterized by a semi-arid and warm climate, the region experiences average annual rainfall ranging from 50 cm to 70 cm, accompanied by temperatures varying between 9°C and 43.5°C. Encompassing an approximate area of 1031549.9 km^2, it is primarily situated in the Maan River basin, characterized by dry conditions for most of the year with seasonal flow.The predominant crops cultivated in the taluka includes Pomegranate, and among the cereals, Maize, Jowar, and Bajra are commonly grown. Agriculture in this region relies heavily on well and canal irrigation to support cultivation activities

2.1 Dataset

Remote sensing data utilized for digital analysis include multi-spectral digital information obtained from IRS Resourcesat-2 spanning the period from January 2008 to 2012. This dataset is complemented by LISS-III data featuring a spatial resolution of 23.5 meters, as well as Survey of India Toposheets at a 1:50,000 scale. To augment the satellite data, a comprehensive field survey of the Sangola taluka was conducted to gather detailed information on pomegranate field conditions, drainage patterns, and socio-economic aspects.

In the field survey, soil profiles were thoroughly examined, and samples were collected from sixty-five selected sites distributed across the study area. Ancillary or collateral data were consulted as needed, including administrative boundaries at the state, district, taluka, and village levels. Additionally, specific location information for villages in the field, area-wise production statistics of pomegranate, and data on other significant horticulture crops were incorporated. To provide historical context, the total pomegranate cultivation area over the past two decades was sourced from the taluka agriculture office. This comprehensive approach, combining remote sensing data, field surveys, and ancillary data, ensures a robust foundation for digital analysis and a thorough understanding of the conditions influencing pomegranate cultivation in the Sangola taluka

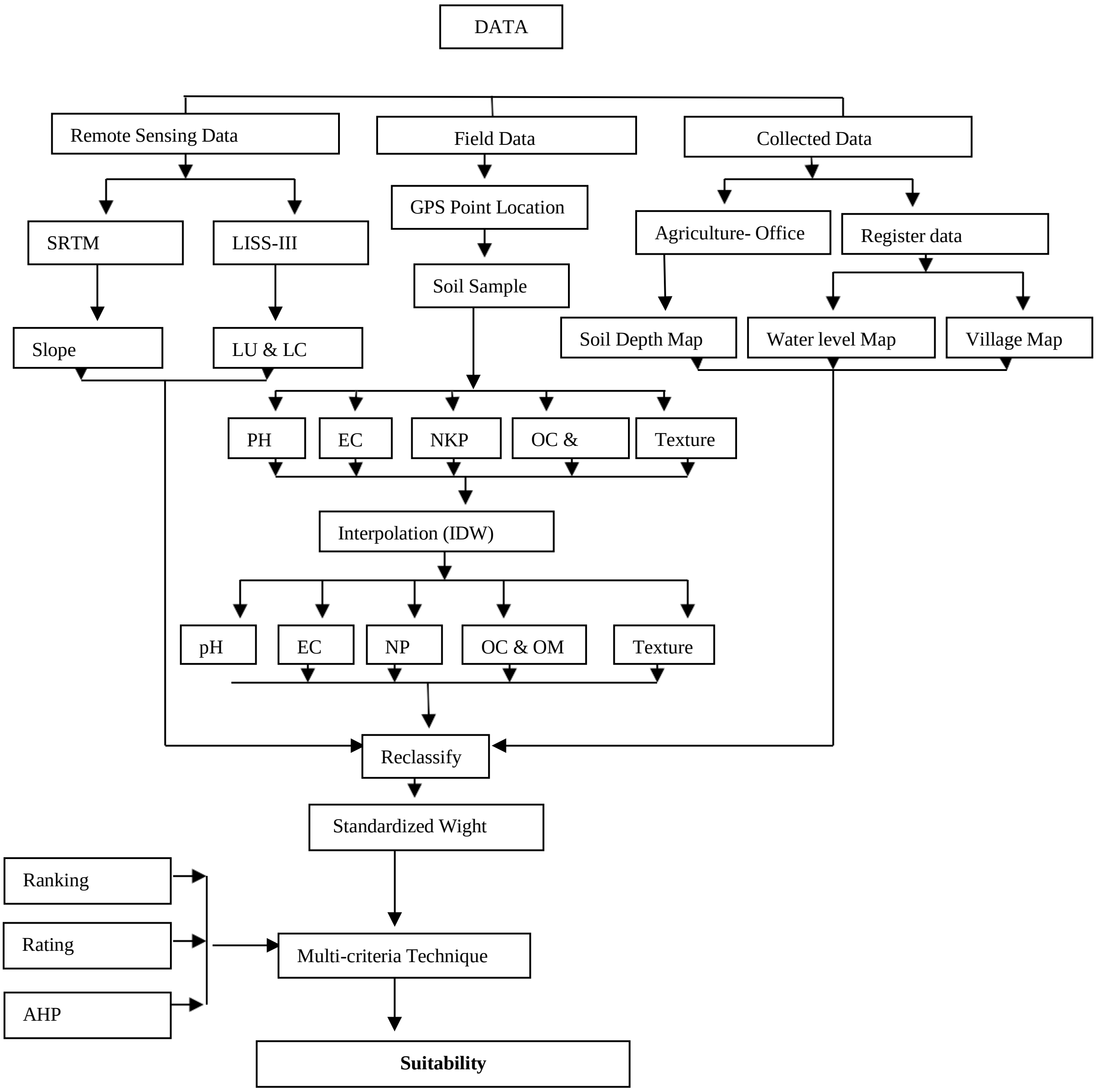
3. Method

The methodology employed for the physical land suitability analysis is based on a multi-criteria evaluation using the FAO land evaluation framework (FAO, 1976, 1985). This approach involves assessing soil or land qualities against the specific requirements of pomegranate cultivation and assigning a suitability rating to each land characteristic. To develop a suitability map, a set of evaluation themes and attributes related to horticulture crop production were utilized (refer to Fig.1). Mir et al. (2012) suggested in their review that Pomegranate could thrive in elevations ranging from plains up to 2000 m above mean sea level (amsl). While it behaves as deciduous in temperate climates, in sub-tropical and tropical climates, it exhibits characteristics of an evergreen or partially deciduous plant. Pomegranate thrives in regions with hot dry summers and cold winters, provided there is access to irrigation. The adaptabilityof the pomegranate plant allows it to grow in a range of climates, from temperate to tropical. Its deciduous or semi-deciduous nature depends on its specific location. While it prefers deep, loamy, well-drained soils, it also shows some tolerance to less-than-ideal drainage and mildly alkaline conditions (Johnson, 2002). Pomegranates can grow in various soil types, excluding saline or highly calcareous, alkaline soils. Although they tolerate mildly alkaline soils up to pH 7.5, they prefer slightly acidic soil with a pH range of 5.5-6.5. The plants respond best to deep, heavy loam, but medium to heavy soils are acceptable if good drainage is ensured. Some flooding is also tolerated. Since pomegranates are heavily irrigated in the fall to enhance fruit size, no irrigation is performed in the winter to prevent excessive vegetative spring growth. In heavy soils, planting on raised mounds known as berms can improve soil aeration and yields. According to Table 1, even light to sandy soils are utilized in pomegranate cultivation, as long as orchards are well-irrigated (Kitren and Louise, 2008).

Table 1. Suitable land and soil in pomegranate growth (Johnson 2002, Kitren and Louise 2008, Zekri 2104).

Factor	Parameter
Soil Type	Light to sandy loam
Soil depth	Medium to heavy (1m.)
Drainage	Well-drain
Ph	7.5
Climate	Hot summer and medium to cold winter
NPK	1.0,0.5,1.0
Slope	Slightly moderate

Figure 1. Flowchart of the methodology



3.1 Interpolation techniques

Spatial interpolation is a process used to estimate the values of properties at unsampled sites within a given area. In an ideal scenario, it involves deriving empirical values at every spatial location based on the coverage provided by observations in a spatial dataset. The primary purpose of interpolation in Geographic Information Systems (GIS) is to extrapolate values between observed data points. Regardless of the interpolation technique applied in soil surveys, the resulting data are essentially estimates of what the actual values might be at specific locations. In the study region, Global Positioning System (GPS) survey data was employed to generate surface maps. This involves collecting precise location information through GPS technology, contributing to the creation of detailed maps that reflect the spatial distribution of various properties or features in the study area. The integration of GPS survey data enhances the accuracy and reliability of the interpolated surface maps, allowing for a more comprehensive understanding of the spatial variations within the region.

3.2 Reclassification

Reclassification stands out as a pivotal analytical technique within Geographic Information Systems (GIS), particularly in raster-based analyses. According to Heywood (2009), in the context of land use data layers, reclassification involves transforming the original image into a new one where areas under agriculture cover might be assigned a coded value of 1, while all other areas not under agriculture could be coded with a value of 0. This essentially creates a Boolean image. Such reclassification from a complex original image to a simplified two-code image is highly valuable because it facilitates subsequent analyses with clear distinctions between relevant categories. This technique allows for the creation of images that are specifically tailored for further analysis, providing a simplified representation of the landscape or features of interest. Moreover, reclassification can extend beyond land use data to include various maps, where weights are assigned based on specific parameters. This adaptability allows analysts to derive meaningful insights from the reclassified images, enhancing the utility of GIS in a wide range of applications.

3.3 Multi-criteria Decision Analysis-

The application of a Multi-Criteria Evaluation (MCE) approach was employed to pinpoint suitable areas for maize and potato crop production in Central Mexico, as highlighted by Alejandro (2003). In this context, MCE serves as the focal point for Multi-Criteria Decision Making (MCDM), emphasizing the importance of method selection due to its profound impact on the final results. According to Florent (2001), MCDM problems involve assessing a set of alternatives based on conflicting and incommensurate criteria. Spatial multi-criteria decision problems typically entail evaluating geographically defined alternatives, choosing one or more alternatives based on a set of criteria. GIS-based MCDM can be conceptualized as a process that integrates spatial and non-spatial data, transforming them into a final decision. The MCDM procedures or decision rules establish the relationship between input and output maps, incorporating geographical data, decision maker preferences, and manipulating these elements according to specified decision rules. Two crucial considerations for spatial MCDM are the GIS capabilities for data acquisition, storage, retrieval, manipulation, and analysis, and the MCDM capabilities for amalgamating geographical data and decision maker preferences into unidimensional values for alternative decisions. Various multi-criteria decision rules have been implemented in GIS environments to address land-use suitability problems. These decision rules can be categorized into multi-objective and multi-attribute decision-making methods, as outlined by Malczewski (1999). In a similar context, Van (1996) utilized multi-criteria analysis for assessing the performance of rubber plantations. The synergy between GIS and MCDM provides a robust framework for decision-making processes in complex spatial scenarios.

3.3.1 Analytical Hierarchical Process:

The Analytical Hierarchy Process (AHP) method, pioneered by Saaty in 1980, is grounded in three fundamental principles: decomposition of comparative judgment, assessment of priorities, and synthesis of these priorities. In the realm of Multi-Criteria Decision Making (MCDM), determining weights for a set of activities based on their importance is a common challenge. Location decisions, such as ranking alternative communities, exemplify MCDM scenarios that necessitate prioritizing multiple criteria. The AHP procedure initiates by decomposing the decision problem into a hierarchy, comprising the most critical elements of the decision scenario. The top level of this hierarchy represents the ultimate goal of the decision. Notably, the attribute concept creates a linkage between the AHP method and GIS-based procedures. In AHP applied to GIS, criterion maps are standardized and contain ordinal values such as high, medium, and low, reflecting the degree of land suitability concerning a specific criterion. These maps are made consistent using the pair-wise comparison method within the ArcGIS Spatial Analysis extension. Additionally, AHP is employed to rank various suitability factors, and the resulting weights are utilized to generate suitability map layers. Bakhtiar (2012) utilized this approach to assess the general suitability of land for agriculture. This integration of AHP with GIS provides a systematic and quantitative means of evaluating and prioritizing criteria in complex decision-making processes related to land-use suitability.

3.3.2 Ranking Methods:

The simplest method for assigning weights to criteria involves arranging them in rank order based on the decision maker's preference. In this approach, each criterion is ranked according to priority, with the highest priority criterion placed first and the lowest priority criterion positioned last (Ozturk, 2011). This method allows decision makers to establish a clear hierarchy of importance among the criteria, simplifying the weight assignment process.

3.3.3 Rating Methods:

Rating methods in decision-making involve the decision maker estimating weights based on a predetermined scale, such as a scale ranging from 0 to 100. A straightforward rating method is the point allocation approach. In this method, the decision maker assigns points to each criterion to reflect their perceived importance. For example, the decision maker might allocate 30 points to the criterion of accessibility to the transportation system, 50 points to the cost of establishing the plant, and 20 points to the availability of water. Subsequently, these point allocations are converted into weights by dividing each point value by the total points assigned. In the given example, weights of 0.3, 0.5, and 0.2 would be assigned to the three criteria, respectively (Malczewski & Liu, 2014). This rating method provides a numericalrepresentation of the decision maker's preferences, allowing for a quantitative assessment of the criteria's relative importance in the decision-making process.

3.4 Weighted Overlay:

In this analysis, eight map layers were utilized, involving overlays of various raster datasets that share a common measurement scale. Each layer was weighted according to its perceived importance in the analysis. It's important to note that all input raster datasets must be in integer format. If a raster is in floating-point format, it needs to be converted to an integer raster before being used in Weighted Overlay (Bevand et al., 2013). The Reclassification tools are employed for this conversion, providing an effective means to assign new values to each class in the input raster based on an evaluation scale. The Reclassification process involves assigning new values to the original input raster values based on a specified evaluation scale. This allows for the transformation of the original raster into a format suitable for subsequent analyses. A restricted value can be designated for areas to be excluded from the analysis.In the Weighted Overlay analysis, each input raster is assigned a weight according to its importance or percent influence. The weight is expressed as a relative percentage, and it is crucial that the sum of the percent influence weights equals 100. Altering the evaluation scales or percentage influences can lead to variations in the results of the weighted overlay analysis. Careful consideration of these factors is essential for ensuring the accuracy and reliability of the analysis outcomes.

4. Results and Discussion

In the study focusing on the horticulture crop of Pomegranate and utilizing three multi-criteria evaluation techniques, eight major parameters were selected for the investigation. The selection process involved close collaboration with agriculture experts, literature surveys, and fieldwork. These key tools played a significant role in determining the parameters for the evaluation criteria and structuring the hierarchy. The evaluation criteria were established based on a comprehensive understanding derived from expert insights, existing literature, and on-the-ground observations. Each criterion was then categorized into five suitability classes (S1, S2, S3, N1, and N2). These classes were determined in accordance with the specific requirements of horticulture crops, particularly Pomegranate. The subsequent step involved the application of the three multi-criteria evaluation techniques to assess land suitability. This systematic approach aimed to explore and compare the suitability of the study area for Pomegranate cultivation based on the identified criteria and their respective classes. The use of these techniques provides a robust framework for decision-making in land-use planning, leveraging the combined expertise of agriculture specialists and empirical data from the field.

4.1 Standardization of the criteria map

In land suitability analysis, each evaluation criterion is represented on a map using ordinal values (such as S1, S2, S3, N1, N2, etc.), indicating the degree of suitability with respect to that criterion based on crop requirements (refer to Table 2). These suitability classes must be rated to determine their relative importance in contributing to the final goal or objective. This process of assigning relative importance to the classes of criteria is referred to as standardization. Criterion standardization is typically carried out on a scale of 0 to 1, 0 to 10, 0 to 100, etc. The pair-wise comparison technique is a method used for rating or standardizing these ordinal values (see Table 2, 3, and 4). This technique is applied to establish the suitability index for each criterion in the land suitability analysis. The pair-wise comparison method is employed within the context of three multi-criteria evaluation techniques: 1) Ranking, 2) Rating, and 3) Analytical Hierarchical Process (Malczewski, 2003). It provides a systematic way to quantify the relative importance of different suitability classes for each criterion, contributing to a more objective and structured decision-making process in land suitability assessments.

Table 2: Ranking calculation

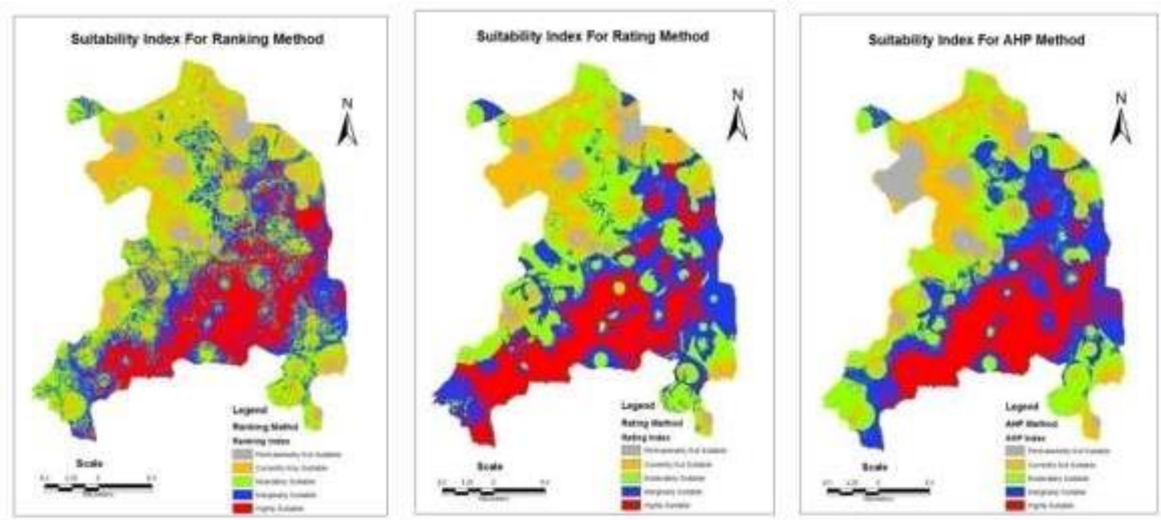
Table 3: Rating

Parameter	Rank	Weight	Normalize
pH	4	8-4+1=5	5/38=0.166
EC	7	8-7+1=2	2/38=0.52
OM/OC	5	8-5+1=4	4/38=0.10
LU/LC	6	8-6+1=3	3/38=0.078
Slope	2	8-2+1=7	7/38=0.184
NPK	3	8-3+1=6	6/38=0.157
Soil type	8	8-8+1=1	1/38=0.026
Texture	1	8-1+1=8	8/38=0.210

Parameter	Rating	Weight	Normalize
pH	65	65/10=6.5	6.5/43=0.151
EC	50	50/10=5.0	5.0/43=0.162
OM/OC	80	80/10=8.0	8.0/43=0.186
LU/LC	10	10/10=1.0	1.0/43=0.023
Slope	20	20/10=2.0	2.0/43=0.046
NPK	75	75/10=7.5	7.5/43=1.74
Soil type	30	30/10=3.0	3.0/43=0.069
Texture	100	100/10=10	10.0/43=0.235

Table 4: Analytical Hierarchical Processes

	Texture	**OC/OM**	**NPK**	**pH**	**EC**	**Soil type**	**Slope**	**LU/LC**	**Weight**	**Normalize**
Texture	1	2	3	2	4	7	8	9	0.289	1.0
OC/OM	0.5	1	2	3	3	6	8	8	0.227	0.786
NPK	0.3	0.5	1	2	3	5	6	7	0.162	0.561
pH	0.5	0.3	0.5	1	3	4	6	8	0.135	0.468
EC	0.25	0.3	0.3	0.3	1	5	3	8	0.090	0.312
Soil type	0.14	0.2	0.2	0.25	0.2	1	6	4	0.051	0.175
Slope	0.12	0.12	0.16	0.16	0.3	0.16	1	5	0.029	0.101
LU/LC	0.11	0.12	0.14	0.12	0.12	0.25	0.2	1	0.016	0.56



A **B** **C**

Figure 2: Suitability index (A) Ranking, (B) Rating(C) AHP

4.2 Land Suitability for Multi criteria analyses

In the land suitability analysis for horticulture crops, three different approaches—Ranking, Rating, and Analytical Hierarchical Process (AHP)—were applied to assess the suitability of various areas in Sangola Taluka. Here are the key findings for each method:

Ranking: - Figure 2 (A) illustrates the suitability map for horticulture in Sangola Taluka. The southern part of the taluka is identified as highly suitable, while the northern part is deemed not suitable The highly suitable area covers 365,190.84 ha, marginally suitable area is 41,614.04 ha, and moderately suitable area is 44,765.63 ha. Other areas are classified as currently or permanently not suitable. Specific villages identified as highly suitable for horticulture include Rajapur, Akola, Sonand, Goudewadi, Javala, Alegoan, and Nijampur.

Rating: The output map (Figure 2 B) from the Rating approach indicates that the south part of Sangola Taluka is highly and marginally suitable, while the north part is not suitable for horticulture. According to Table 3, the highly suitable area covers 36,522.03 ha, marginally suitable areas cover 42,508.8 ha, and moderately suitable area is 45,266.69 ha. The currently not suitable area is 30,108.1 ha, and the permanently not suitable area is 6,527.866 ha.

Analytical Hierarchical Process (AHP): The AHP method was used to determine land suitability for horticulture crops. The results indicate that the southern part of the taluka is better suited than the north for horticulture crops. The highly suitable area is estimated at 34,781.93 ha, marginally suitable area is 42,888.5 ha, and moderately suitable area is 43,651.76 ha. The area not clearly fit and currently not suitable accounts for 27,455.5 ha. Additionally, the permanently not suitable area is 12,155.79 ha (Table 4). Villages such as Sonand, Goudwadi, Javala, Alegaon, Hanmantgaon, Nijampur, and Wadegaon are identified as highly suitable for horticulture crops, specifically for Pomegranate cultivation. These analyses provide a comprehensive understanding of land suitability for horticulture crops in Sangola Taluka, facilitating informed decision-making for agricultural planning and cultivation..

5. Conclusions

The utilization of IRS Resourcesat-2 LISS-III sensor data proves to be optimal for mapping Pomegranate fields, especially given the larger field sizes of more than 2 hectares. Pomegranate cultivation is predominantly undertaken in two seasons, locally known as Ambai and Hast. The northern part of Sangola Taluka, which is supplied with canal irrigation, faces a high incidence of bacterial blight disease. Pomegranate cultivation activities are primarily concentrated in the central part of Sangola Taluka. This concentration is attributed to factors such as water scarcity, availability of barren land, well-drained soil with a coarse texture, and the socio-economic conditions of the region. Notably, the rise of the horticultural economy involves small and poor farmers, and even though land is relatively equally allocated across all communities, certain attributes may play a role in explaining the specific contribution of these farmers. Supervised classification proves to be the most effective method for identifying and mapping horticultural crops, achieving an accuracy rate above 90%. Among interpolation techniques, Inverse Distance Weighting (IDW) stands out as suitable for generating thematic maps with surface features. In the comparison of various techniques, the Multi-Criteria Analysis using the Analytical Hierarchical Process (AHP) yields superior results, a conclusion supported by ground-based surveys. The southern part of the study region exhibits a highly suitable class, followed by the central, southwest, and south parts that are highly and moderately suitable. In the northwest part, only a few patches exhibit a permanently not suitable class. This comprehensive analysis provides valuable insights into the suitability and factors influencing Pomegranate cultivation in the Sangola Taluka region..

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