Land Suitability Mapping for Paddy Production Using Remote Sensing and GIS Techniques

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ABSTRACT

Through the integration of GIS, RS, and the Ideal Vector Approach, this work presents a technique for assessing land suitability for paddy production in Raigad district. When it comes to storage, processing, and geographical analysis, GIS is the way to go. RS, on the other hand, offers extensive spatial datasets that include everything from topography to soil properties and drainage. A topographic database was created by combining SRTM data with DEMs produced from topographical maps; this allowed for the investigation of slope and aspect. To determine which crops thrive in each soil type, scientists measured factors like organic carbon content, pH, effective depth, and soil texture. We also factored in the availability of irrigation and patterns of rainfall. A performance index is generated using the Ideal Vector Approach, which determines land appropriateness by determining the degree to which qualities resemble positive and negative ideal solutions. A final land suitability map is produced by normalizing and weighting these variables using the Analytical Hierarchy Process (AHP). The Raigad district's agricultural land-use planning may be strengthened with the use of this integrated system.

Keywords: *Geospatial, Topography, Irrigation, Suitability, Agriculture.*

I. Introduction

Maintaining livelihoods and guaranteeing food security on a global scale are two of agriculture's most essential functions. Even while agriculture throughout the world is showing signs of being able to meet the increasing demand for food, Sub-Saharan Africa is still struggling with food insecurity. Over the last 30 years, agricultural output in Sub-Saharan Africa has declined, leading to a decline in export competitiveness and a failure to raise the daily calorie supply per capita above 2,100. Agricultural systems are under increasing challenges from factors such as fast population increase, shrinking arable land, and land degradation. One solution to these problems is to produce crops in conditions that are optimal for their development. So, to improve food production, optimize resource usage, and ensure long-term sustainability, land suitability study is essential. Land resources are non-renewable and limited, thus they must be distributed carefully to meet conflicting needs.

To encourage sustainable development in the face of land use conflict between preservation, urban growth, and agricultural, plans must take into account social, environmental, and economic aspects. Therefore, it is necessary to craft a land use policy that takes into consideration these conflicting needs and seeks a middle ground that encourages sustainable and fair growth in all areas. To achieve this goal of land use optimization that benefits both present and future generations, it is necessary to take into account a wide range of social, environmental, and economic factors.

In order to determine and plot the land's appropriateness for enset production, the research integrates GIS and MCDA. Soil physical and chemical qualities, elevation, slope, climate, and land use/cover are some of the important biophysical and environmental factors included in the study. An accurate geographical image of land suitable for enset farming is the goal of the study's thorough approach, which should lead to better decisions about sustainable agricultural planning and resource management.

Some academics argue that in order to increase food production globally and in Ethiopia specifically, land suitability studies are crucial. Land suitability analysis involves classifying and arranging parcels of land according to how well they work for certain purposes. To maximize output while protecting the environment for generations to come, land must be used with care and propriety. Because land is a non-renewable resource, accurate and efficient administration of land information is necessary for making these kinds of choices. Human actions both in the past and the present, as well as the land's physical and chemical characteristics, are considered when deciding on an acceptable usage. The goal of land evaluation is to determine the fair market value of property in relation to its intended use. A long-standing and mostly empirical topic is the difficulty of finding appropriate land for the growth of various agricultural crops. Poor land resource management and the inability to use land according to its optimum appropriateness continue to be major difficulties, particularly in developing nations, despite a great deal of study on agricultural production and food security on a worldwide scale.

II. Review of Literature

Sharma, Umang et al., (2025) In order to identify potential areas in District Aligarh (Uttar Pradesh), India, that are conducive to industrial growth, this article details a thorough Multi-Criteria Evaluation (MCE) methodology that is based on geographic information systems (GIS). The project aims to incorporate technical tools for strategic planning and concerns the rising demand of industrial growth on land resources. An efficient model for site selection is produced by combining GIS with the Analytical Hierarchy Process (AHP). The six important parameters that define the appropriateness of an industrial site were evaluated using expert surveys and AHP. These characteristics are as follows: land cover, railway accessibility, road accessibility, closeness to built-up regions, distance from water bodies, and soil type. A detailed suitability map was generated from the generated geographic layers by using weighted overlay analysis in a GIS. Particularly along important thoroughfares like Agra Road, Khair Road, and Delhi Road, the study finds excellent locations. In order to promote sustainable industrial growth while avoiding ecological and social damage, this integrated technique might be useful for policymakers and urban planners.

Ibrahim, Abdul et al., (2024) The need for sustainable agriculture techniques is growing in urgency due to the alarming rate of global population rise. Given its importance as a cereal crop, sorghum has great potential in this regard for achieving food security and reducing hunger. The importance of site suitability analysis in guaranteeing sustainable crop production in the face of global population expansion is highlighted in this research, which focuses on sorghum production in Niger State. Using geospatial tools, the research integrates varied factors to determine viable places for sorghum cultivation. Soil, topography, land use, geology, and water resources were each given a weighted value according to the Analytical Hierarchical Process (AHP) for Multi-Criteria Evaluation (MCE). After that, these criteria are combined using the Weight Overlay (WO) approach to provide a detailed suitability map. Among the results shown by the landscape distribution, 36.46 percent (697,972 hectares) are very suitable for sorghum production, 40.09 percent (766,055 hectares) are somewhat suitable, 17.88 percent (342,026 hectares) are somewhat suitable, 1.18 percent (22,857 hectares) are low suitability, and 4.36 percent (83,565 hectares) are extremely low suitability. Particularly conducive to sorghum cultivation are the regions of Gbako, Bida, Mokwa, Katcha, and Wushishi LGA. In order to promote sustainable agriculture and large-scale farming in appropriate areas using modern technology, the study suggests using this methodology to evaluate other cereal crops. It highlights how well it handles restriction factors, so it takes these criteria into account for future evaluations of a comprehensive approach to land suitability analysis.

Karakuş, C. & Yıldız, Sayiter. (2022) Using GIS in accordance with the Analytical Hierarchy Process (AHP) method—one of several multi-criteria decision-making (MCDM) approaches—this study identified the best locations within the Sivas/Turkey borders for potential dam construction. Dam sites were chosen based on nine factors: soil type, stream density, distance to roadways, elevation, slope, rainfall, lineament density, distance to residential areas, and land use/land cover. The criteria used to pick the dam location within the AHP approach had a CR (Consistency) rating of 0.054, indicating that the findings were consistent and satisfactory. The method's dam site selection suitability map showed five distinct categories of appropriateness: "very high" (12.70%), "high" (20.63%), "medium" (25.43%), "low" (25.11%), and "very low" (16.12%). The majority of the dams in Sivas province that are now operational (64.63%) fall into the "high" or "medium" appropriateness category, whilst the majority of the dams that are scheduled to be built (57.14%) are in the "low" category. The study's output, a suitability map for dam site selection, is a valuable resource for regional water resource management and sustainable development decision-makers.

Hussien, Kassaye et al., (2019) The continuous and unpredictable rainfall in Ethiopia throughout the primary growing seasons, along with the country's heavy reliance on rain-fed agriculture, is a major challenge to agricultural output and efficiency. In addition to helping with the sustainable use of limited resources, multi-criteria irrigation land suitability mapping may help with the worldwide issue of water shortages and agricultural productivity caused by unreliable and highly variable rainfall. Finding appropriate locations for surface irrigation in the Erer Watershed in Ethiopia's East Hararghe Zone was the primary goal of this research. Soil pH, type, drainage, depth, impermeable layer, ECE, CEC, phase, organic carbon, texture classes, root obstacle, slope, land use/land cover, and distance from river outlets were among the fifteen criteria used in the study's GIS-based multi criterion land suitability evaluation method. The findings are presented as a numerical range, with higher values indicating more acceptable traits and lower values indicating less suitable ones. This was achieved by standardizing each aspect to a common measuring scale. To determine the optimal irrigation site inside the ArcGIS environment, the values of each dataset were pooled and weighted using the Weighted Overlay tool. The research found that surface irrigation is acceptable for about 386,731ha (11.7%) of the watershed area, but is not appropriate for 140,308 ha (36.3%) of the watershed area. About 151,120 hectares (or 39.07%) of the watershed area fell into the marginally acceptable category, while 50,223 ha (12.98%) fell into the moderately suitable category. Looking at appropriate irrigable land in terms of the fifteen parameters outlined, the research's results may greatly contribute to increasing crop output in the study region and the amount of land that can be used for irrigation.

III. Research Methodology

In the Raigad district, a multi-criteria decision-making method involves utilizing GIS, RS, and the Ideal Vector Approach to translate geographically-based land data into a conclusion. Data input, storage, processing, and output of geographic data are all handled by GIS in this context. A great deal of geographical information, such as soil, drainage, slope data, etc., is provided by RS. Integrating RS with GIS provides a potent resource for building decision-making systems on the spatial of Earth and other planets. Using a number of factors, the Ideal Vector technique determines if a piece of land is suitable for growing paddy crops.

<u>Topographic Database</u>

The topographical maps of the Raigad district study area are created using Universal Transverse Mercator to produce DEM. The DEM is created using 3D surface analysis and then digitized using topographical maps. For the whole research region, an edge-to-edge DEM dataset is created using SRTM.

To determine the highest possible rate of change between every recorded cell, the Slope tool is used. With a greater slope value indicating a down area and a lower slope value indicating a flat region, each cell has a slope value. All the way from the north to the south of 360 degrees, the aspect is measured, and the value of each cell represents a particular area.

Soil Database

For plants to flourish, soil is an essential ingredient. Determining which crops do well in certain Raigad district soil types is a top priority. Before proceeding, it is necessary to conduct a study of the soil's physical and chemical properties. The soil's thickness is indicated by its effective depth. While the root systems of trees may reach depths of up to 150 cm, the average depth for annual crops is 50 cm. The 100 cm depth of roots is considered the highest limit, and it may provide a very excellent harvest.

The identification of the soil type, as indicated by its texture, is also important for root penetration. As the negative logarithm of the hydrogen ion concentration in the soil solution, the pH value of the soil is a crucial factor. Paddy grows best on soils with a pH of 6-7. One further critical factor for paddy crop improvement is organic carbon.

Irrigation Data

The irrigation of rice fields in Raigad district is mostly accomplished via the use of canals and groundwater. Tropical and subtropical regions with an average yearly rainfall of 1250 mm to 2000 mm are ideal for growing rice since the crop flourishes in these settings.

Ideal Vector Analysis

With an ideal vector, you may get the performance index of the appropriateness classes for any parameter you employ. The foundation of it is the optimal solutions, both positive and negative, that may be obtained from the various sets of qualities. In terms of distances from them, both provide the shortest and longest options. To find out how similar two qualities are in Raigad district, Maharashtra, we measure their distance to the Soil Physical, Soil Chemical, Topographic, and Irrigation groups. To find out how similar two attributes are in the positive and negative ideal solutions, we employ vector-matching algorithms.

The following equation measures the degree to which actual results resemble the positive ideal of success.

$$R_{ij}^{+} = \frac{X_{ij}X_j^{+}}{\max\left(X_{ij}X_{ij}, X_j^{+}X_j^{+}\right)} \tag{1}$$

Similarly, the provided formula may be used to compute the Degree of Resemblance to the negative ideal success.

$$R_{ij}^{-} = \frac{X_{ij}X_j^{-}}{\max\left(X_{ij}X_{ij}, X_j^{-}X_j^{-}\right)} \tag{2}$$

Where, $X_{ij} = (x_{i1}, x_{i2}, x_{im})$ is the overall success matrix of number of classes of the groups such as Soil Physical, Soil Chemical, Topographic and I.

The group's success index is calculated as:

$$P_j = \frac{R_j^{+}}{R_j^{+} + R_j^{-}} \tag{3}$$

In this case, j=1, 2,..., n. These success indices alter the previous values of the group (Ranking) used in this calculation. The following formula determines the weight utilized as a normalizing factor in order to get the final suitability utilizing the AHP mechanism:

Soil Physical -WEIGHT = Soil Physical (SUCCESS)*(Soil Chemical (Ranking) + Topographic (Ranking)+ Irrigation (Ranking))/3

IV. Results and Discussions

We used Erdas-11 and ArcGIS to research and create topographical maps of the Raigad district in Maharashtra. Our work also included analyzing the soil's physical, chemical, and land access rating layers. In order to cultivate rice on land that is physically and topographically appropriate in the Raigad area of Maharashtra, all of the factors that go into building the index model that determines physical land suitability are kept in temporary memory files.

Forest cover density plots in the research region are found using optical bands with suitable false color combinations (SFCC) of LANDSAT 7 TM satellite images. Using the Ideal Vector Analysis approach, datasets on vegetation canopy cover are created from satellite pictures. For the Raigad district in Maharashtra, Table 1 shows the various parameter values produced by the suggested method.

Table 1: Quantitative Values Obtained from The Land Images

Parameter	pH	Ranking	+ve Resemblance	-ve Resemblance	Success	Weight
Soil Physical	1.05	1.02	0.0692	0.9123	0.0221	0.021
Soil Chemical	0.371	0.399	0.164	0.6980	0.182	0.180
Topographic	0.178	0.177	0.3990	0.2930	0.0088	0.0085
Irrigation	0.0681	0.0689	0.5740	0.1455	0.0045	0.0043

Lands in Raigad district, Maharashtra, that are ideal for growing rice crops are quantitatively analysed in Table 2. S1 encompasses over 63% of the district's land, suggesting that much of it is ideal for growing rice. The non-suitable region takes up much less space than the appropriate area, indicating that there aren't many places in Raigad district, Maharashtra, where paddy crops may be grown.

Table 2: Suitable Areas

Index	Area (KM^2)	Area (%)
S1	64.50	28.40
S2	22.95	42.70
S3	13.60	13.50
N1	7.90	6.30
N2	10.85	9.50

V. Conclusion

In order to conduct a multi-criteria land suitability analysis in the Raigad area, this research shows that combining GIS, RS, and the Ideal Vector Approach is successful. A thorough evaluation of the land's suitability for paddy production was accomplished by merging spatial information including topography, soil properties, drainage, and irrigation infrastructure. RS provided current and precise information on environmental factors such as slope, aspect, and soil texture, while GIS offered a strong foundation for managing, analyzing, and visualizing spatial data. By determining how closely each parameter matched the positive and negative ideal solutions, the Ideal Vector Approach could quantify land suitability and provide performance indices for each suitability criteria. The Analytical Hierarchy Process (AHP) was used to further standardize and weight these criteria, thereby producing an objective and dependable land suitability map. Not only does the approach show you where it's best to grow paddy, but it also shows you where you're facing problems, so you can fix those specific areas to make the most efficient use of your property. All things considered, the Raigad district now has a robust, data-driven framework for agricultural planning, sustainable land management, and resource allocation thanks to the combination of GIS, RS, and multi-criteria decision-making methodologies. This framework should work just as well for other locations and crop varieties.

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