International Journal on Science and Technology (IJSAT)
E-ISSN: 2229-7677 ● Website: www.ijsat.org ● Email: editor@ijsat.org

GIS-Based Agricultural Land Suitability Mapping in Waghur Basin

Dr. Rajesh Amrut More

Assistant Professor, SSVPS LK Dr. P. R. Ghogrey Science College, Dhule

Abstract

The Waghur Basin of Maharashtra is experiencing land degradation, water scarcity and unsustainable agricultural practices that have put pressures on the agricultural land and therefore proper land evaluation is necessary to ensure sustainable development. This paper uses a multi-criteria framework based on GIS to evaluate the suitability of agricultural land through the combination of spatial datasets. The data of soil characteristics, topography, climate, land use/land cover, and hydrological were obtained through NBSS&LUP, IMD, NRSC, Landsat imagery, and DEM products and preprocessed in ArcGIS Pro. Criteria were weighted with the Analytical Hierarchy Process (AHP) and then weighted overlay analysis was performed to produce a composite suitability index in categories of S1, S2, S3 and N. Findings indicate that the basin is highly suitable (S1), with the majority of it (41.02%) being concentrated in fertile valley plains, which have deep silty loam and clay loam soils; 37.08% is moderately suitable (S2); 18.32% is marginally suitable (S3); and 3.57% is unsuitable (S4) because of steep slopes, rock outcrops, or severe erosion. The discussion has emphasized the high agricultural potential of the basin but has pointed out the necessity to control upland degradation and enhance the nutrient content of the soil especially the nitrogen content. The research concludes that GIS based suitability mapping at high resolution is a powerful decision support system in optimization of crop distribution, conservation initiatives and sustainable agriculture in Waghur Basin and other semi-arid areas.

Keywords: GIS, Agricultural Land Suitability, Analytic Hierarchy Process (AHP), Spatial Analysis, Crop Suitability

Introduction

Mapping of agricultural land is important in ensuring that the land resources are optimally used and to advance sustainable agricultural practices due to the rising global demands of food and resources [1]. This is done by assessing the land qualities in order to establish the potential of that land to be used in a particular agricultural activity hence informing the land-use planning and management decisions. Geographic Information Systems (GIS) have transformed land evaluation by offering effective tools of managing, analyzing and visualizing spatial data. GIS allows combining various data, including soil characteristics, climatic data, topography, and land cover to produce detailed suitability maps [2].

This paper is based on the Waghur Basin, which is an area of high agricultural value and where informed land management policies are necessary to ensure food security and environmental sustainability [3]. Land degradation, water scarcity, and the necessity to achieve higher productivity are the problems in the agricultural sector of the Waghur Basin. This study will address these issues by coming up with a GIS-based agricultural land suitability map of the Waghur Basin. These goals are to determine the appropriate

location of different crops, evaluate the effects of various land management activities, and offer policy makers and farmers with decision support tools [5]. The research paper adds to the available literature by providing a spatially explicit evaluation of land suitability, which can be used to guide sustainable agricultural development in the area. The following parts of this paper will outline the methodology, data sources, results and discussion of the findings and finally give the practical implications and policy recommendation of the Waghur Basin.

Background of the research

The increasing population of the world and the evolving consumption patterns is putting strain on agricultural land. The consequent population growth demands sustainable land management to improve food security and decrease environmental degradation [6]. Informed decision-making of land use is significant in the balancing of agricultural production and conservation. In this respect, land suitability assessment (LSA) plays a vital role, as it provides a system of determining the suitability of land to be utilized in some agricultural operations [7].

Geographic Information Systems (GIS) have proved to be powerful tools in LSA, and the capability to store, analyze and visualize spatial data. Traditional methods of LSA might involve manual data collection and analysis that can be time consuming and resource intensive [8]. However, with GIS-based techniques, it is possible to integrate different data such as soil maps, climate data, and topography data to facilitate effective and comprehensive assessments [9]. The applicability of GIS in LSA has been demonstrated in several studies [10]. An example is the use of GIS to identify places where crops can be cultivated in various regions depending on the nature of the soil, slope, and water supply [11]. The articles reveal the potential of GIS to improve the accuracy and efficiency of LSA that may lead to the enhanced land-use planning and agricultural management decisions [12].

The Waghur Basin, like many other regions of agriculture, is facing the problem of land degradation, water scarcity, and unproductive agriculture [13]. The land use in this region should be streamlined to improve the agricultural production, natural resources and the living standards of the communities living in the region. The research is motivated by the fact that a GIS-based agricultural land suitability map of the Waghur Basin is required, which can be a valuable source of information to farmers, policymakers, and land-use planners. The research can assist in making agricultural activities more efficient and sustainable to reduce the impact on the environment and increase food security by determining the areas that are most conducive to different crops. It is in accordance with the broader goals of sustainable development and resources conservation, which emphasizes the practical significance of the research to other similar agricultural regions with the same issues.

Literature Review

The application of GIS-based agricultural land suitability mapping in the Waghur Basin can be informed with various methodologies and findings of studies conducted in other regions. GIS has been widely used together with multi-criteria decision analysis (MCDA) and the Analytic Hierarchy Process (AHP) to assess the suitability of land to agricultural activities as has been demonstrated in several studies. MCDA using GIS has been used to evaluate land in terms of wheat production, considering ecological factors, such as soil and topography, weighted with AHP to produce a land suitability map, as an example, in semi-arid areas [10]. Similarly, GIS and AHP were used on Faria agricultural catchment in Palestine to combine spatial weighted variables, including topography, soil, and climate to produce a map that identifies areas as highly, moderately, and marginally favorable to agriculture [14]. The Waghur Basin can be done with

the same methods taking into account the local conditions such as the soil properties, topography, and climatic conditions. Fuzzy set models and the geostatistical analysis can also be used to enhance the assessment as it is observed in the works of Central Anatolia and Ranchi District to take into account the variability of the soil and environmental data and uncertainty [15,16]. In addition, the integration of remote sensing (RS) and GIS, as applied in the Kadapa District, can also add to the accuracy of the land suitability analysis as it provides more specific spatial data of land cover and use [17]. All these approaches imply that a comprehensive GIS-based analysis, with the incorporation of local environmental and soil information, can be employed to map the appropriateness of agricultural land in Waghur Basin, which can be utilized to plan sustainable land use and develop agriculture in the region [18].

The available literature demonstrates that there are gaps in the research that this research aims to address. Integrated approaches demand the combination of biophysical and socioeconomic factors in order to provide a more holistic analysis of land suitability. Higher resolution data such as remote sensing images and soil surveys can be used to make the suitability maps accurate and more precise. In addition, more effective and transparent methods of weighting such as statistical analysis or elicitation of expert knowledge should be developed. Finally, the land suitability assessment can also be synchronized with climate change scenarios to help in determining the areas that would be vulnerable to environmental changes in future. The research paper aims to address these gaps by developing a GIS based land suitability model of the Waghur Basin which employs high resolution data, integrates biophysical and socioeconomic variables and considers the impact of climate change. The innovation lies in the fact that the flexible and adaptable framework is created and could be applied in other areas with the same data restriction and environmental concerns.

Study Area

The current research is based on the Waghur Basin which is a significant tributary of the Tapi River located in the Deccan Plateau of Maharashtra, India. It is located between 20°27′25.30″ N to 21°05′41.71″ N latitudes and 75°30′06.40″ E to 76°05′12.76″ E longitudes. The basin has an approximate area of 2,485 km^2 and a basin perimeter of 296.3 km, with parts of the basin being located in the Aurangabad, Buldana, Jalna, and Jalgaon districts. Waghur River is a river that forms in the Ajanta-Satmala hill ranges in the area of Ajanta Caves and drains into the Tapi River in the area of Bhusawal. Physiographically, the basin is composed of hilly terrain, pediments, and fertile valley plains which are covered by Deccan Trap basalts and alluvium patches. The climate is semi-arid monsoonal with an average rainfall of about 782 mm per annum, hot summer (up to 45°C) and mild winter. The soils differ between the silty loam and clay loam of the plains and rock outcrops on the slopes, which are the habitats of dry deciduous forests in the hills and intensive agriculture in the plains, whereby crops such as cotton, maize, wheat and sugarcane are grown.

Methodology and Database

Data Preprocessing and Acquisition

The research employs diverse sources of data. The data on soil, such as soil maps and soil surveys are received in the National Bureau of Soil Survey and Land Use Planning (NBSS&LUP) with a scale of 1:250,000 and a resolution of 30 meters. The major properties of the soil that are taken into account are soil type, soil texture, soil depth, soil pH, soil organic matter, and nutrient availability. The data on climate, including rainfall, temperature, and evapotranspiration, is obtained at the Indian Meteorological Department (IMD) covering the years 2000-2024 and with the spatial resolution of 0.25 degrees. Data

reliability is achieved by data quality control processes, such as outlier detection and gap filling. Topographic information, in the form of a Digital Elevation Model (DEM), is based on the Shuttle Radar Topography Mission (SRTM) with a 30-meter resolution, which contains information about slope, aspect, and elevation. The data on land use and land cover is derived using Landsat satellite imagery with a spatial resolution of 30 meters and a classification scheme of land cover classification system created by the National Remote Sensing Centre (NRSC). The DEM is used to extract hydrological information such as stream networks and water bodies and this information is complemented by the Central Water Commission (CWC). Each dataset is preprocessed, such as data cleaning, georeferencing to the WGS 1984 UTM Zone 43N projection and conversion to a format that is compatible in the GIS environment. The main GIS software that is utilized in processing, analysis and mapping of data is ArcGIS Pro. Spatial interpolation, surface analysis and overlay operations are done with the help of the Spatial Analyst extension. Google Earth Engine is a remote sensing platform that is utilized in the acquisition and processing of satellite imagery to map land cover and monitor the environment.

Weighting and Ranking of Criteria

The weighting and ranking of the selected criteria are done through the use of the Analytical Hierarchy Process (AHP). AHP is selected due to its capability of integrating expert knowledge and preferences of stakeholders in a systematic decision-making process. The AHP technique entails the comparison of the criteria in pairs with respect to their relative significance in the suitability of agricultural land. Questionnaires and interviews are used to collect expert opinions of agricultural scientists, soil scientists and local farmers to determine the pairwise comparison matrix. The weights are then obtained based on the normalized major eigenvector of the comparison matrix. A weighted overlay analysis is used to combine the weighted criteria with ArcGIS Pro to create a composite suitability index.

Overlay Analysis and Suitability Mapping

The overlay analysis is a process that entails the integration of the weighted criteria in ArcGIS Pro to create a land suitability map. The weighted layers soil type, slope, rainfall, temperature and land cover are overlaid with the weighted sum tool of the Spatial Analyst extension. The resulting composite suitability index is categorized into four suitability classes namely, highly suitable, moderately suitable, marginally suitable and not suitable. The criteria of each suitability category depend on the needs of the crops and the nature of the land, which follows the FAO land evaluation recommendations. Field data in representative areas of the Waghur Basin and expert information on local agricultural extension officers are used to validate the suitability map.

Results

Land Suitability

Table 1 Distribution of Land Suitability of the Waghur basin

Suitability Class	Area (km^2)	Percentage (%)	Characteristics
Highly Suitable (S1)	1,020.32	41.02	Valley plains with fertile silty loam & clay loam soils, gentle slopes, good water availability
Moderately Suitable (S2)	922.58	37.08	Pediments & gently undulating lands with moderate soil depth and texture

Marginally Suitable (S3)	455.46	18.32	Dissected uplands, shallow soils, moderate slopes
Not Suitable (N)	88.82	3.57	Steep slopes, rocky outcrops, high erosion (Ajanta–Satmala hills)
Total	2,485.18	100.00	—

(Source: Calculated by researcher using ArcGIS Pro)

The land suitability mapping that was developed using GIS produced detailed maps that identified the areas in the Waghur Basin based on their agricultural suitability. These maps classify land into different classes that include highly suitable, moderately suitable, marginally suitable, and not suitable. The maps are well marked with an elaborate legend and representative scale and a north arrow so that they can be easily oriented and interpreted. The spatial distribution depicts that the landscape is heterogeneous with highly suitable lands usually located in flatter areas where the soils are fertile and marginally suitable lands are usually located on steeper slopes or in poor drainage areas. Integrated GIS techniques were used to analyze the land suitability of Waghur Basin in terms of soil characteristics, slope, drainage, and land use. The findings showed that there was significant spatial difference in land suitability to agriculture.

The basin is mainly composed of highly suitable (S1) with about 41.02% (1,020.32 km^2) being located in the valley plains with fertile silty loam and clay loam soils, gentle slopes and favorable water availability. The proportion of moderately suitable (S2) is approximately 37.08% (922.58 km^2) and is mostly located in the pediment and the slightly undulating regions, with a moderate depth and texture of the soil. The marginally suitable land (S3) is approximately 18.32 per cent (455.46 km^2), mostly on the dissected uplands with shallow soils and moderate slopes. The basin is only 3.57% (88.82 km^2) (N) not suitable because of steep slopes, rocky outcrops or excessive erosion, with the Ajanta-Satmala hill ranges having the highest concentration of this category. The analysis shows that the basin has a great potential in agriculture, but land degradation in marginal and inappropriate areas should be managed carefully. The upland areas require sustainable agricultural practices and conservation whereas the valley plains are highly agricultural but when irrigation and soil fertility are well taken care of.

Factors Influencing Land Suitability

The combination of physical and chemical parameters affects the agricultural land suitability of the Waghur basin. The slope is a significant factor with gentle slope being very conducive to farming, moderate slope supporting a little farming and steep to precipitous slope subject to erosion and unsuitable. Suitability is also dependent on land use and land cover (LULC); approximately 55.9 percent of the land under agriculture is the most productive, whereas forest, barren, rocky, settlement, and water bodies are permanently unsuitable. Another important factor is soil depth where deep soils (70.3) in river valleys are very suitable in crop production, moderately productive soils (9.7) and shallow soils (20) limit cultivation. The soil texture in the basin differs with the gentle plains having clay loam which is good in agriculture whereas the steep slopes have silty loam which is not very productive. The moisture of the soil is also spatially varied; deep soils and forested land are well moistured and shallow and sloping land is comparatively dry. On the same note, the maximum water holding capacity (MWHC) is greater in deep and clay soils with gentle slopes and less in shallow or sandy soils with steep slopes.

The impact of soil erosion on fertility is great; even though approximately 90.7 percent of the land experiences very low soil erosion, steep and high-rainfall regions experience severe topsoil erosion. The average soil organic carbon (SOC) is 0.45 and thus the majority of the land is moderately suitable; it is greater in the northern basin and less in high and eroded areas. The pH of the soil is 6.75 to 8.04 with the

mean of 7.3, which is very favorable to crop production. Nevertheless, there is a variation in the nutrient availability: nitrogen is usually low, and more than half of the basin has extremely low suitability, which restricts crop production. The phosphorus content ranges between 2 and 135 kg/ha with most of the areas being marginally adequate and in need of external supplements. On the contrary, potassium occurs in large amounts (200-3276 kg/ha) in almost 90 percent of the basin, thus very suitable and useful in the strength of plants, resistance to diseases and yield.

Validation of Results

Various methods were used to verify the findings of this research. Accuracy was determined by comparing field data collected at representative sites in the Waghur Basin and suitability map classifications. The discussions with the local farmers and agricultural experts were useful in terms of feedback regarding the suitability maps and their relevance and feasibility. The overall agreement with the findings of the study was also determined using existing land use maps and agricultural statistics. These validation procedures guaranteed the reliability and applicability of the GIS-based land suitability mapping in the agricultural planning and management in the Waghur Basin.

Discussion

This paper presents new methods of GIS-based agricultural land suitability mapping in the Waghur Basin, beyond the conventional methods to provide more detailed and practical information. One of the main innovations is the incorporation of the advanced techniques of spatial analysis, which may include machine learning algorithms to simulate the complex interdependence between the environmental factors and the crop suitability. This enables a more data-driven and adaptive evaluation than those studies that are based on only the rule-based methods. Moreover, the methodology can include new criteria, like socioeconomic (e.g. market access, farmer income) or environmental (e.g. soil erosion risk, water availability trends) to give a wider perspective of land suitability beyond purely biophysical. The appropriateness assessment is made to be based on local knowledge and priorities by a unique method of weighting and ranking criteria, including the participatory methods with local farmers or the methods of multi-criteria decision analysis (MCDA).

The importance of this research is that it may change the agricultural planning and decision-making in the Waghur Basin and other areas with the problem of sustainable land use. In contrast to the previous research that might have concentrated on the suitability assessment at a large-scale level, this study offers high-resolution suitability maps that are specific to crops and other farming methods, which can make more targeted interventions. These maps can be used to make land allocation decisions, which can optimize the choice of crops according to

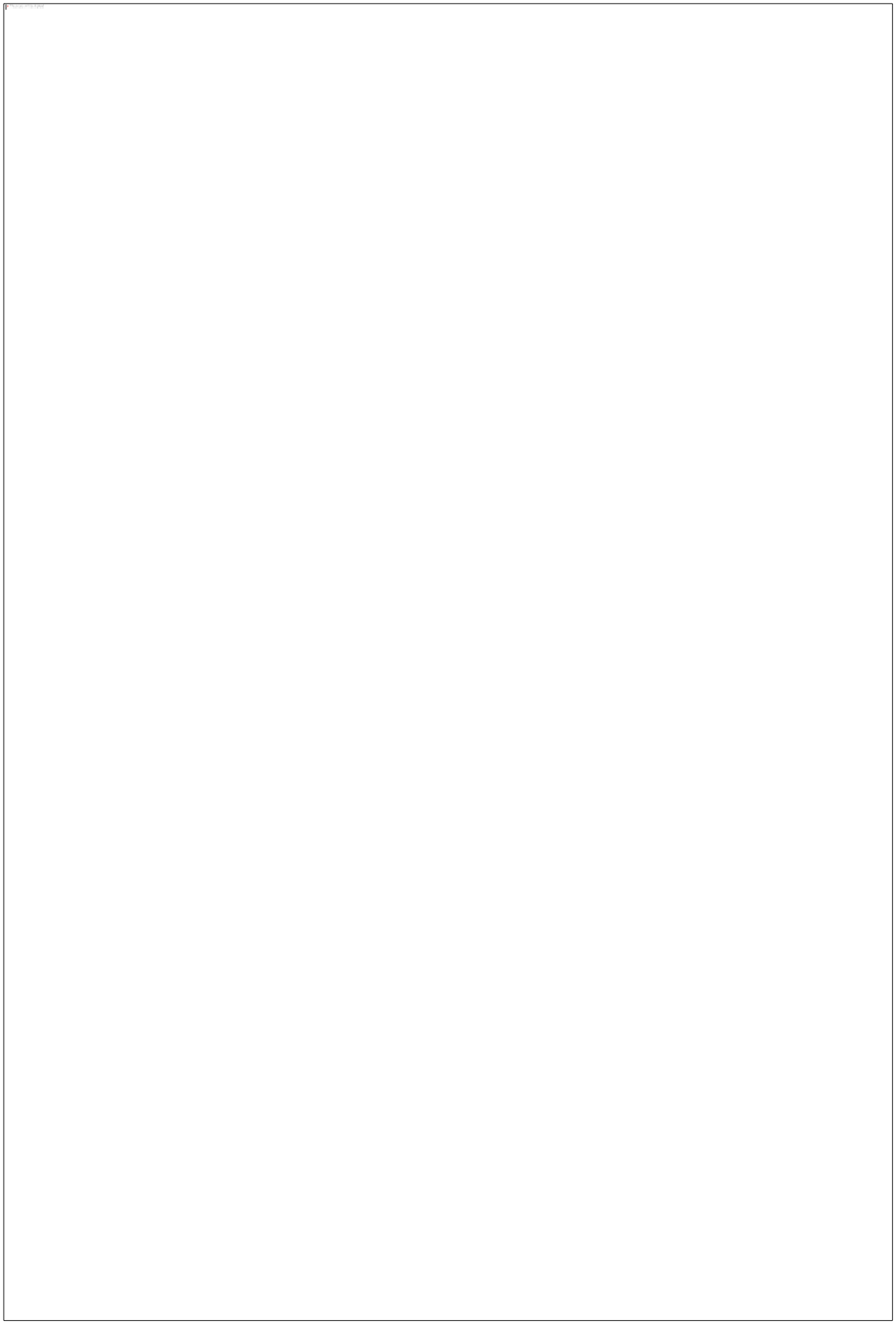

Figure 1 Land suitability for agriculture area of the Waghur basin

the conditions of the site and reduce land degradation. In addition, the suitability maps may be used to prioritize agricultural extension services and support programs to the regions with the highest potential to be improved so that the limited resources may be used to the fullest. The study encourages the environmentally friendly management of land and reduces the adverse effects on the water resources and biodiversity by identifying the areas where sustainable agricultural activities can be practiced, e.g., conservation tillage or agroforestry. The novel method of land suitability mapping used in the study offers a useful instrument in the promotion of sustainable and resilient agricultural systems in the Waghur Basin and elsewhere.

Conclusion

The paper suggests that land suitability mapping with the help of GIS is a significant tool of sustainable farming in the Waghur Basin. The study provides practical data on how to distribute land resources to different crops through integration of alternative spatial data layers and multi-criteria decision analysis. The suitability maps developed can be utilized to advise farmers and land managers in order to make sound decisions on the type of crops and land management practices that would ultimately result in increased agricultural productivity and environmental sustainability.

Future research should also consider a number of areas to enhance the accuracy and applicability of land suitability assessments. In order to increase the suitability map accuracy, input data i.e. soil maps and climate data accuracy and resolution should be improved. Other factors such as water availability, market access and socioeconomic factors would provide a more detailed assessment of the land suitability. One of the methods to assist farmers and land managers in adopting them would be to come up with easy-to-use decision support systems that integrate suitability maps with other relevant information to enable them make decisions using data.

This study has certain limitations. The dependence on some assumptions and simplifications introduces the subjectivity and potential bias in the process of selection and weighting of the criteria. Uncertainty in the input data particularly on the soil properties and climate projections may also compromise the accuracy of the suitability maps. Moreover, the analysis is limited by the fact that the socioeconomic factors such as land tenure and access to credit are not given a lot of attention. However, the research provides a practical model on land suitability analysis in Waghur Basin and is useful in subsequent studies.

Authors' Biography

Dr. Rajesh Amrut More is an experienced academician with over 15 years of teaching and research experience in the Department of Geography at SSVPS L. K. Dr. P. R. Ghogrey Science College, Dhule. He holds a Ph.D. in Geography and has been actively involved in teaching undergraduate and postgraduate students. His academic interests include geographical analysis, regional studies, and the application of geographical concepts to socio-environmental issues. Dr. More has contributed to academic research through publications and has participated in seminars, conferences, and academic activities, reflecting his sustained commitment to geography education and research.

References

1. Lyle, J., & Stutz, F. P., “Computerised Land Use Suitability Mapping”, Cartographic Journal, 1983. https://doi.org/10.1179/CAJ.1983.20.1.39

2. Saremi, H., Kumar, L., Sarmadian, F., Heidari, A., & Shabani, F., "GIS based evaluation of land suitability: A case study for major crops in Zanjan University region", Journal of Food Agriculture & Environment, 2011.
3. Akbulak, C., "Land use suitability analysis of the Upper Basin of the Kara Menderes River using analytical hierarchy process and geographical information systems", Journal of New Results in Science, 2010.
4. Agone, V., "Hydrogeomorphic analysis of Tittur drainage basin", LAP LAMBERT Academic Publishing, 2014.
5. Hoffmann, E. M., Schareika, N., Dittrich, C., Schlecht, E., Sauer, D., & Buerkert, A., "Rurbanity: a concept for the interdisciplinary study of rural-urban transformation", 2023. https://doi.org/10.1007/s11625-023-01331-2
6. Singha, C., & Swain, K. C., "Land suitability evaluation criteria for agricultural crop selection: A review"' Agricultural Reviews, 2016. https://doi.org/10.18805/AR.V37I2.10737
7. Mendas, A., & Delali, A., "Integration of Multi Criteria Decision Analysis in GIS to develop land suitability for agriculture: Application to durum wheat cultivation in the region of Mleta in Algeria", Computers and Electronics in Agriculture, 2012. https://doi.org/10.1016/J.COMPAG.2012.02.003
8. Agone, V., & Bhamare, S. M., "Change detection of vegetation cover using remote sensing and GIS", Journal of research and development, 2012, 2(4).
9. Tugaç, M. G., Tercan, A. E., Torunlar, H., Karakurt, E., & Usul, M., "Agricultural land suitability assessment with GIS-based multi-criteria 2 decision analysis and geostatistical approach in semi-arid regions", Soil Studies, 2023. https://doi.org/10.21657/soilst.1328637
10. Wati, S. F. A., Fitri, A. S., Kartika, D. S. Y., Wulansari, A., & Safitri, E. M., "GIS Land Suitability to Increasing Agricultural Production for the Agriculture Supply Chain: A Systematic Literature Review", 2022. https://doi.org/10.33005/ijconsist.v3i2.67
11. Pilehforooshha, P., Karimi, M., & Taleai, M., "A GIS-based agricultural land-use allocation model coupling increase and decrease in land demand", Agricultural Systems, 2014. https://doi.org/10.1016/J.AGSY.2014.07.001
12. Akhavan, S., Jalalian, A., Toomanian, N., & Honarjo, N., "Use of a GIS-Based Multicriteria Decision-Making Approach, to Increase Accuracy in Determining Soil Suitability" Communications in Soil Science and Plant Analysis, 2022. https://doi.org/10.1080/00103624.2022.2118312
13. Shadeed, S., Abboushi, A. M. E., & Almasri, M. N., "Developing a GIS-based agro-land suitability map for the Faria agricultural catchment, Palestine", International Journal of Global Environmental Issues, 2017. https://doi.org/10.1504/IJGENVI.2017.10004145
14. Özkan, B., Dengiz, O., & Turan, İ. D., "Site suitability analysis for potential agricultural land with spatial fuzzy multi-criteria decision analysis in regional scale under semi-arid terrestrial ecosystem", Scientific Reports, 2020. https://doi.org/10.1038/S41598-020-79105-4
15. Sengupta, S., Mohinuddin, S. K., Arif, M., Sengupta, B., & Zhang, W., "Assessment of agricultural land suitability using GIS and fuzzy analytical hierarchy process approach in Ranchi District, India", Geocarto International, 2022. https://doi.org/10.1080/10106049.2022.2076925
16. Rajasekhar, M., Raju, G. S., Kudnar, N., Ramachandra, M., & Kumar, B. P., "Multi-criteria Land Suitability Analysis for Agriculture in Semi-Arid Region of Kadapa District, Southern India: Geospatial Approaches", 2021. https://doi.org/10.21523/GCJ1.2021050201

17. Raikwar, V., Pagare, P., Abdulwahab, A., Agone, V., Patel, P.P., "A Comparison of Different Artificial Intelligence and Machine Learning Methods for Gully Erosion Susceptibility Mapping in the Upper Narmada Basin", In: Das, J., Halder, S. (eds) New Advancements in Geomorphological Research, Geography of the Physical Environment. Springer, Cham, 2024. https://doi.org/10.1007/978-3-031-64163-3_7