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Agricultural Land Suitability Categorization and Evaluation using GIS Assisted AHP in the Arid Western Plain Zone of Rajasthan, India

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ABSTRACT

Background: Agricultural Land Suitability Analysis is one of the dependable method through which crop specific land suitability can be analyzed. Agricultural land suitability analysis for the pearl millet in the Arid Western Plain Zone of Rajasthan was the major focus of the present study.

Methods: Nine criteria *viz*. mean temperature in the growing season (°C), total rainfall (mm), soil phosphorus (kg/h), soil texture, soil pH, soil organic carbon (%), salinity (dS/m), slope of the land (%) and landuse-landcover and their corresponding sub-criteria were selected. Analytic Hierarchical Process (AHP) was performed on the selected criteria through pair-wise comparison matrix and individual weights were determined and represented through Weighted Overlay Analysis (WOA).

Result: Temperature in the growing season (20.68%), total rainfall (15.90%) and landuse/ landcover (14.39%) depicted relatively higher weightage with consistency ratio of 0.087. Results obtained from WOA in GIS environment depicted four suitability category namely Highly suitable (S1), Moderately suitable (S2), Marginally suitable (S3) and Restricted (N). Significant percentage of area was categorized under S2 category while S3 category was associated with least area with limitations like relatively higher slope and higher salinity. The proposed model validation was performed with overall accuracy of 88.10% using confusion matrix.

Key words: Agricultural land suitability, AHP, MCDM, Weighted overlay analysis.

INTRODUCTION

Managing hunger and providing enough food for everyone are two of the most significant challenges that the modern world faces. Tuninetti *et al*. (2020) reported that the problem is caused by a variety of factors, including insufficiencies in the supply of both micronutrients and macronutrients, insufficiencies in the production of foods that lead to supply–demand imbalances and conflicts that destabilize various regions of the world. To fill the gap between need and supply, agricultural intensification as well as extensification is practiced throughout the world. Sulaiman *et al*. (2019) stated that Agricultural Land Suitability Analysis (LSA) is one of the effective ways to depict potentiality of land parcel. Multi criteria decision method (MCDM) is widely used to quantify the LSA. Criteria specific weight determination is an essential step in the entire process. According to Saaty (1980), analytic hierarchical process (AHP) is one of the most important methodologies for determining the significance or weights of various criteria. Geographical Information System (GIS) is an integral part of the entire process to handle diversified dataset. As per Moharana *et al*. (2016), the arid western plain zone is a distinct agro-climatic division in western Rajasthan. Pearl millet is one of the major summer crops of this region. According to the study of Krishnan *et al*. (2018), Pearl millet's nutritional value and adaptability to changing climates make it an ideal crop for harsh temperature and drought conditions since it has the potential to generate more economic returns under marginal conditions than other cereals would under similar circumstances. According to Srivastava *et al*. (2020), it also accounts for more than half of the world's millet production and can be used for both food and animal feed. As per the study of Nambiar *et al*. (2011), when compared to other cereals like wheat, maize, rice and barley, it excels due to its superior characteristics such as the C4 plant's high photosynthetic efficiency, greater dry matter production capability and resilience in the face of challenging agro-climatic conditions while requiring fewer resources and yielding greater financial returns. Satyavathi

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et al. (2021) reported that Pearl Millets are rich in omega-3 fatty acids including oleic acid (25%), linoleic acid (45%) and linolenic acid (4%), it has 74% polyunsaturated fatty acids and is nutritionally regarded as the best for health. In the recent years, the demand for pearl millet has increased manifold in food processing and other industrial uses. According to the findings of Saxena *et al*., (2018), it is expected that in the coming years the demand will increase further.

In the present study an attempt has been made to categorize and evaluate pearl millet specific agricultural land suitability in the arid western plain zone of Rajasthan, India, based on GIS assisted Analytical Hierarchal Process. To process and handle diverse kind of datasets, representation of results and its evaluation, GIS platforms like QGIS and ArcGIS were taken into consideration along with field verification.

MATERIALS AND METHODS

According to the District Census Handbook (2011), the study area covers entire Churu district of Rajasthan, India (Fig 1). It extends between 27°24′N to 29°00′N latitude and 73°40′E to 75°41′E longitude traversing an area of 13,835 km^2. In the east, it shares the state boundary with Haryana and in the west; it is bounded by Bikaner district, Rajasthan. In the north, it is surrounded by the district of Hanumangarh, while Jhunjhunu, Sikar and Nagaur district of Rajasthan are situated in south east, south and south west respectively. Climatically the arid western plain experiences wide range of temperature as high as 49°C in summer and as low as -1°C in winter and annual normal rainfall is as low as 350 mm.

Expert opinion

In the present study both secondary and primary data were incorporated. Entire research work was done during October 2021 to May 2022 in School of Liberal Arts and Sciences, Mody University of Science and Technology, Lakshmangarh, Sikar, Rajasthan, India. For the selection of the criteria, two-step process was adopted. In the first level, Soil Site Suitability Criteria for Major Crops Manual of National Bureau of Soil Survey anssd Land Use Planning (ICAR) was considered as base (Naidu 2006). According to Saaty (1980), the Expert opinion is an integral part of any land suitability analysis technique, hence four experts were selected in the next level. Two of them were farmers and two of them were Professors with expertise in the field of agriculture. Relative importance for each of the criteria was assigned based on the opinions obtained from the experts. A structured questionnaire was designed and sent to the Professors for their opinions while same questionnaire was filled during the filed survey from the farmers. Once all the results were obtained, the results were averaged for the final relative importance of each of the criteria.

Fields work and database

90 soil sampling locations were identified through random sampling considering maximum coverage of the study area (Fig 2) along with unique sampling location ID with corresponding GPS locations. Generalized workflow of the entire research is portrayed in Fig 3. The soil samples were collected during December 2021 from the depth of one foot from selected locations in the 500gm polyethylene zipped bag with their unique sampling IDs. Nine criteria *viz*. mean temperature in the growing season (°C), total rainfall (mm), Soil Phosphorus (kg/h), soil texture, soil pH, Soil Organic

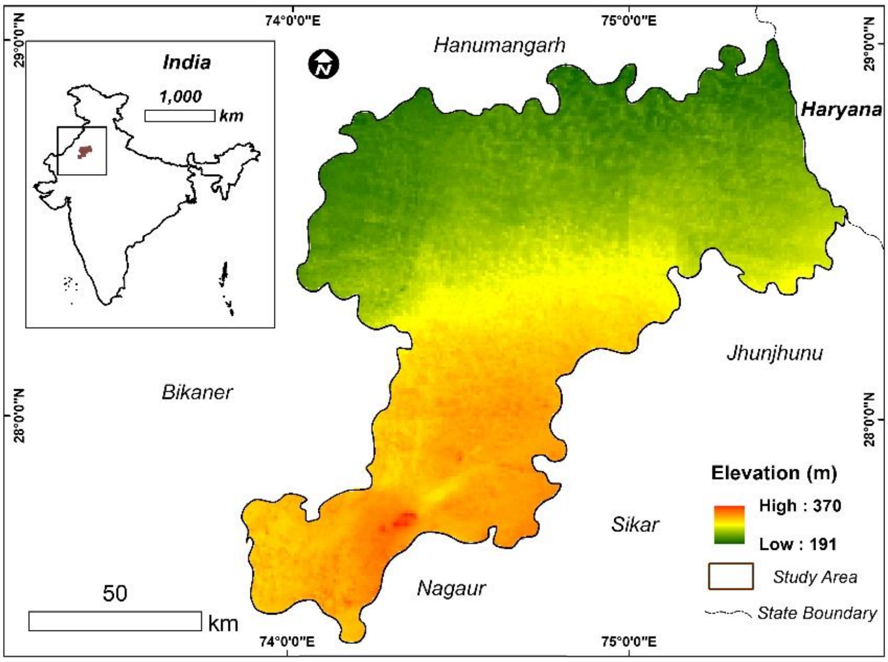

Fig 1: Location map.

Carbon (SOC) (%), salinity (EC) (dS/m), Slope of the Land (%) and Landuse and Landcover were selected along with their corresponding sub-criteria for the analysis. All of the soil related criteria were analyzed in the government approved soil testing laboratory, Department of Agriculture and Farmers Welfare, Haryana, by the professionals. Soil texture was analyzed according to Folk (1974) and Garcia M, (2008). Data was generated using standard wet sieving method as well as secondary sources in the consultation with the department of Chemistry and department of Biosciences, School of Liberal Arts and Sciences, Mody University of Science and Technology, Lakshmangarh, Sikar, Rajasthan during February 2022. Latest mean temperature (2021) during growing season and total rainfall data were collected from Indian Meteorological Department, Pune by Climate Monitoring and Prediction Group (2022). Elevation data was generated from ALOS palsar 12 m digital elevation model from ASF data search (2022).

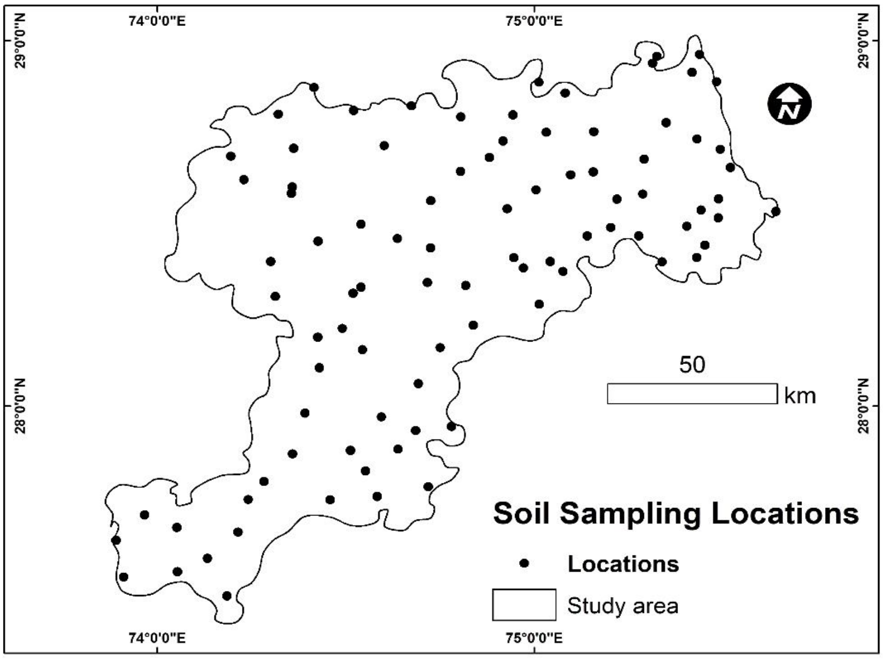

Fig 2: Soil sampling locations.

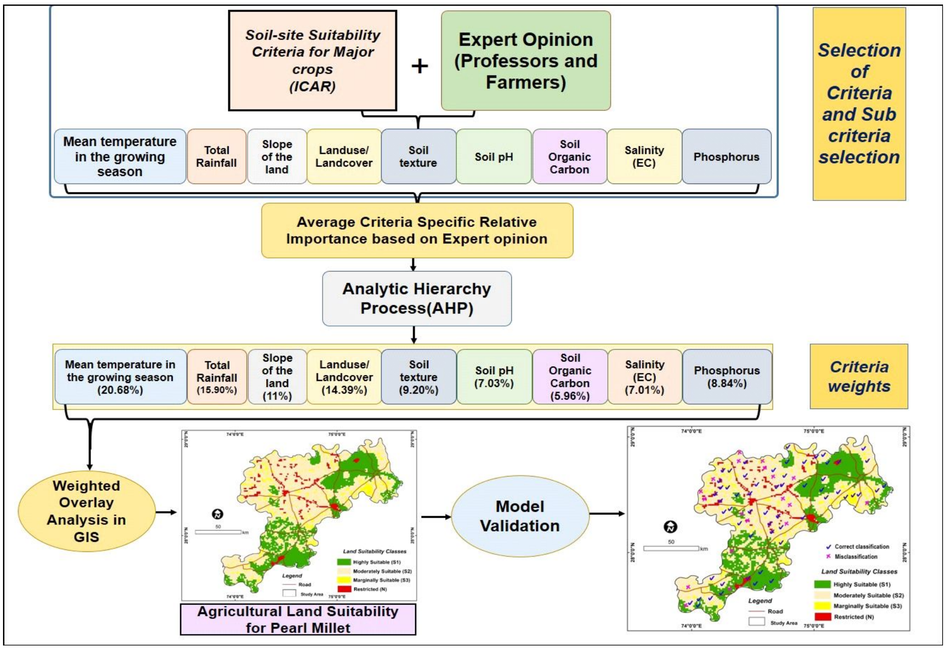

Fig 3: Generalized workflow.

Geospatial mapping of selected criteria

Landuse and landcover map was generated in QGIS software. The base map of the Rajasthan state with district boundary was downloaded from https://www.surveyofindia.gov.in/files/Raj_State_Map.pdf (accessed on 11/12/2021). After georeferencing of base map with WGS84 map projection, vector layer of the study area was prepared. Based on the generated vector layer Sentinel 2 satellite images were downloaded using Semi-automatic classification plugin of QGIS software. All the bands of the downloaded images were clipped according to the vector layer. For individual landuse and landcover components, training data sets were generated and classification was done. For the spatial representation of mean temperature in the growing season (°C), total rainfall (mm), Soil Phosphorus (kg/h), soil texture, soil pH, Soil Organic Carbon (SOC) (%), salinity (EC) (dS/m) layers were generated in ArcGIS. The sample locations along with their corresponding results were incorporated in ArcGIS and Inverse Distance Weighted (IDW) interpolation method was adopted for the generation of each of the thematic layers with predefined classes as per the expert opinion. The generated thematic layers were used in the further process.

Spatial distribution of criteria

Temperature during growing season ranged between 22.12°C to 41.32°C. Maximum temperature was observed in the south central portion (more than 38°C). In most of the portion of the study area, temperature ranges between 32°C to 38°C. In south-western segment, temperature ranges between 32°C to less than 28°C (Fig 4a). Total rainfall in the study area ranges between 316 mm to 580 mm. The intensity of rainfall was highest in the central segment of the region (more the 500 mm) and gradually it was decreased toward the periphery. Lowest rainfall (less than 300 mm) was observed in the north-east and south-west portion (Fig 4b). Percentage slope of the land ranges between less than 3% and 10.05%. Significant portion of the region is under slope less than 3% while in the northern segment the slope of the land was relatively higher (Fig 4c). Landuse and landcover map showed that majority of the segment of the study area was under agricultural land. Other than that, landuse/landcover category like settlement, roads, barren land, natural vegetation and water body can also be observed (Fig 4d). The entire study area was associated with three types of soil texture. Fine sand is mostly concentrated in the northern segment with few patched in the south. While loamy sand spanned the central segment, silty-sand was found in patches spread over the region (Fig 4e).Soil pH was more or less uniform throughout the region with a very small variation. Slightly higher soil pH was observed in the northern portion (Fig 4f). Concentration of Soil Organic Carbon (SOC) varied throughout the study area. North central portion was associated with lower soil organic carbon

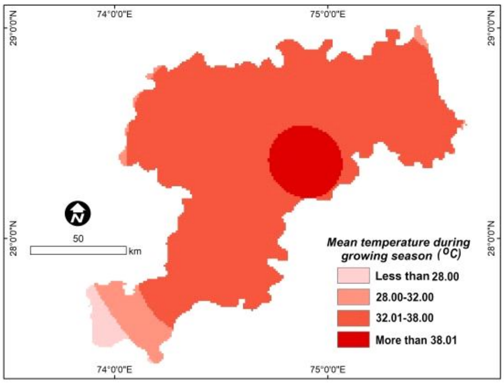

Fig 4a: Mean temperature in the growing season (°C).

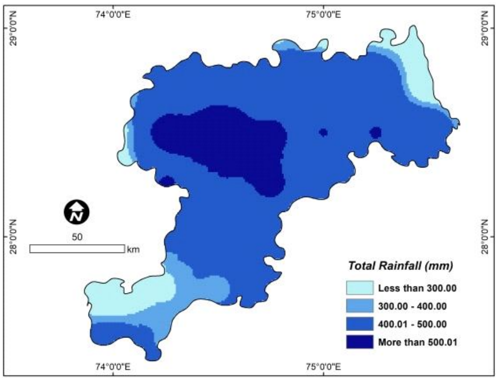

Fig 4b: Total rainfall (mm).

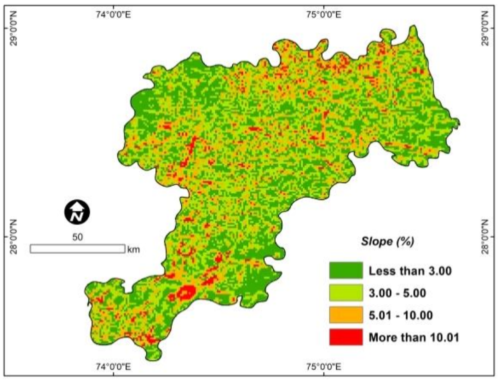

Fig 4c: Slope of the land (%).

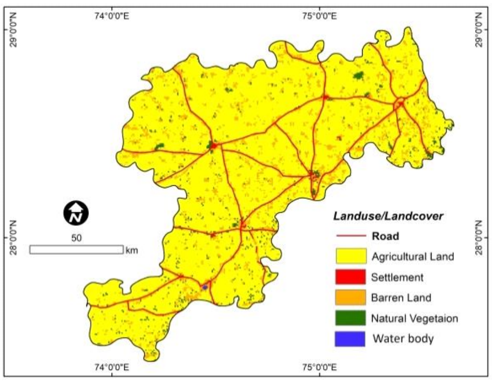

Fig 4d: Landuse/Landcover.

while in the peripheral portion, the concentration increased gradually (Fig 4g). Significant portion of the region was associated with lower Soil salinity (EC) (Less than 1dS/m). Only in the northeast and southern segment few patches with relatively higher salinity (1-3 dS/m) was detected (Fig 4h). The concentration of phosphorus in the soil was as low as 1.86 kg/h to 34.81kg/h. Considerable area was associated the phosphorus concentration ranged between 10 kg/h -20 kg/h (Fig 4i).

Analytical hierarchal process (AHP)

Analytic hierarchal process (AHP) is widely used method not only in the field of agriculture but also in other fields of studied by García *et al*. (2014) and Cengiz and Akbulak (2009). The analytical hierarchical process, also known as AHP, is one of the main methods that many researchers use in conjunction with the Geographic Information System (Feizizadeh and Blaschke, 2013; Ahamed *et al*. 2000). Research done in the Darjeeling district of West Bengal used AHP and GIS to locate agriculturally productive areas. A set of parameters was chosen on the advice of experts and their relative importance was determined using a pairwise comparison matrix followed by land suitability categorization and evaluation (Pramanik 2016). Zolekar and Bhagat, (2015) worked in the similar path focusing in the hilly terrain of Maharashtra, India.

Determination of ranks

In AHP, relative importance of selected criteria are assigned with relative ranks ranging from 1-9. The assigned ranks of the criteria indicated the relative importance of the criteria. Based on expert opinions, ranks were assigned to the criteria. Mean temperature during growing season, total rainfall, landuse and landcover and slope of the land were assigned with higher ranks (1-4) while soil texture vary according to the above said criteria and assigned with moderate rank (rank 5). Criteria like phosphorus, soil pH, salinity and soil organic matter were associated with least rank (6-9).

Pairwise comparison matrix and determination of weights

Further, pair wise comparison matrix was prepared using the relative importance of different criteria. For the criteria weights are calculated using the following equation:

$$\text{Eigen vector} = L_{ij} = \frac{P+Q}{\Sigma P+Q} \times 100 \qquad ......(1)$$

Where

P= m $\times$ r matrix.

Q= r $\times$ n matrix and both of the matrixes are positive and consistent.

Lij= record of i^{th} row and j^{th} column or in other words, criteria preferences.

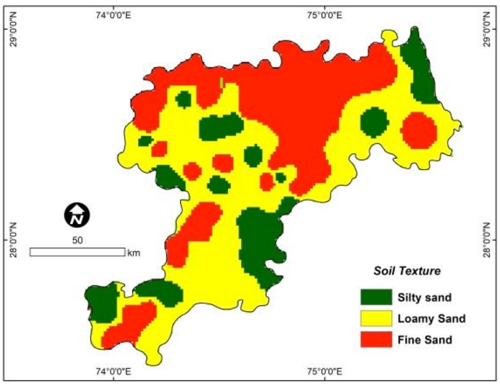

Fig 4e: Soil texture.

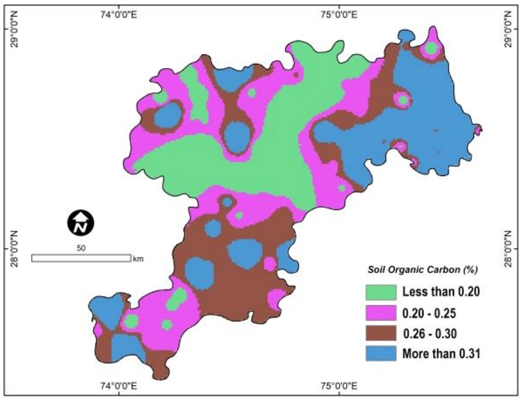

Fig 4g: Soil organic carbon (%).

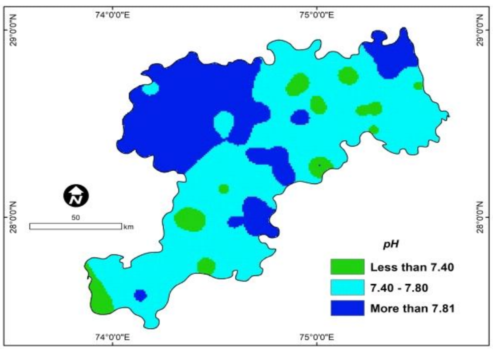

Fig 4f: Soil pH.

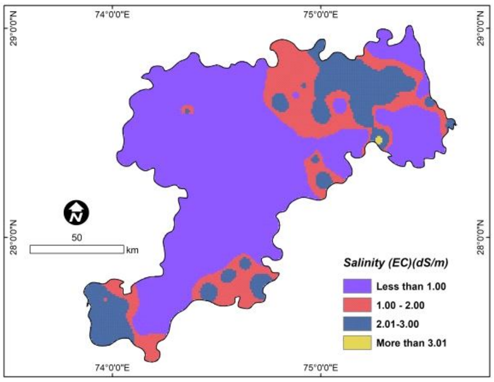

Fig 4h: Salinity (EC) (dS/m).

Results obtained from the AHP were further used to calculate Consistency ratio (CR). As per Saaty (1980), CR is one of the most important and integral aspects of the process to determine the rationality of the AHP model. The value of consistency ratio (CR) should be less than 0.10. Saaty (1980) suggested that if the calculated CR is more than the suggested value then the suggested relative importance by the experts are to be reassessed. For the calculation of CR, first, Consistency Index or CI is to be calculated. From the following calculation CI is calculated:

$$CI = \frac{(\lambda_{max} - n)}{(n-1)} \qquad ......(2)$$

Where

CI= Consistency Index.

λ_{max}= Principal Eigen vector obtained from comparison matrix.

n= Number of compared criteria (9 in the present work).

$$CR = \frac{CI}{RI} \qquad ......(3)$$

Where

CR= Consistency ratio,

CI= Consistency index.

RI= Random Index which is randomly produced consistency index of pair wise comparison matrix (Saaty 1980).

The weights of the criteria were determined through the following steps- i) Expert opinion, ii) determination of ranks, iii) preparation of pair wise comparison matrix using fundamental scale suggested by Saaty (1980) (Table 1) and iv) calculation of weights. Based on expert opinions, corresponding ranks were determined and compared in pairwise comparison matrix.

Weighted overlay analysis (WOA)

For the representation of the AHP results in the spatial dimension, entire process was done in ArcGIS software. Nine thematic layers, which were already generated, were incorporated in the Weighted Overlay Analysis (WOA) in ArcGIS. WOA is a widely used decision making parameter that take user defined relative weightage of different criteria and can reclassify the data as per the requirement followed by final classified map (Tiwari and Ajmera, 2021). In this process, the thematic layers were reclassified and respective weights, obtained from the AHP were assigned. The result of WOA was classified in to four categories namely- Highly Suitable (S1), Moderately Suitable (S2), Marginally Suitable (S3) and Not Suitable (N) (Fig 5).

Field verification and accuracy assessment

Validation of any model is one of the most important dimensions of any scientific study. The results obtained from the analysis was validated using field verification. On each of the category of land suitability, random points were generated in ArcGIS. In the present study 80 ground verification points were created (Fig 6) on the generated map and field verification was done with structured questionnaire. Based on the opinion of the farmers, suitability class was deducted. Results obtained from the land suitability map and results obtained from the opinions of the farmers were tabulated and accuracy assessment was done through confusion matrix in Python programming language (Fig 7).

RESULTS AND DISCUSSION

In addition to the direct consequences that the COVID-19 virus has had on people's health, the pandemic has caused disruptions in food supply chains in developing nations, caused food prices to become unstable and generated profoundly detrimental repercussions on food security (Kakaei *et al*., 2022). The implications of COVID-19 on India's food security are still being felt and they have a large territorial/spatial component because the short- and long-term effects have varied greatly by region (Padmaja *et al*., 2022). Sustainability and food security can be achieved in a number of ways. Evaluating a piece of land to determine whether or not it is suitable for agricultural use is a highly significant piece of information for the growth of agriculture and the long-term planning of food security and it does not compromise food safety (Viana *et al*., 2022). Focusing on the dry western plain zone of Rajasthan, India, this study uses GIS to conduct a pearl millet-specific agricultural land suitability analysis.

Agricultural land suitability for pearl millet

The consistency ratio (CR) obtained from the analysis was 0.087 and is lower than the value suggested (0.10) by Saaty

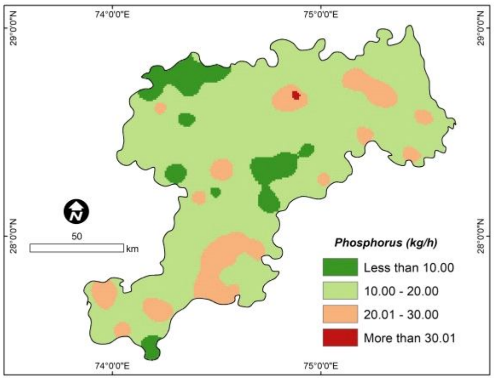

Fig 4i: Phosphorus (kg/h).

Table 1: Relative importance scale of AHP.

Linguistic scale	Intensity of importance
Equal Importance	1
Equal to moderate importance	2
Moderate importance	3
Moderate to Strong importance	4
Strong importance	5
Strong to very strong importance	6
Very strong importance	7
Very strong to absolute importance	8
Absolute importance	9

Source: Saaty 1980.

(1980). Pairwise comparison matrix of the nine criteria is depicted in the Table 2. Results of AHP showed that mean temperature in the growing season had the highest weightage (20.68%) followed by total rainfall (15.90%), landuse/landcover (14.39%) and slope of the land (11.00%) (Table 3). Four categories of land suitability was observed in the study area viz. highly suitable (S1), moderately suitable (S2), marginally suitable (S3) and Restricted (N) (Fig 5). 28.54% of the total area was under the S1 category while 52.47% area was under S2 category. In S3 and N category 11.51% and 7.48% area was depicted (Fig 8a).

Highly suitable

Highly suitable category covers an area of 3948.81 km^2 and spans over the north-eastern and south western segment of the study area. This segment showed minor limitations like relatively lesser percentage availability of soil nutrients like phosphorus and soil organic matter. For optimal production, inclusion of these external inputs are required.

Moderately suitable

Moderately suitable area (S2) was mainly observed in the central and northern portion with an area of 7259.12 km^2.

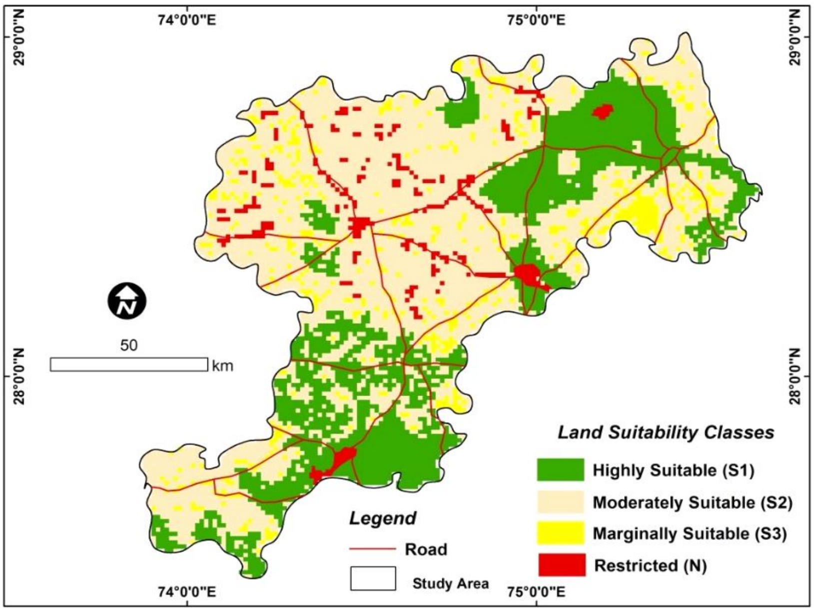

Fig 5: Agricultural land suitability map for pearl millet.

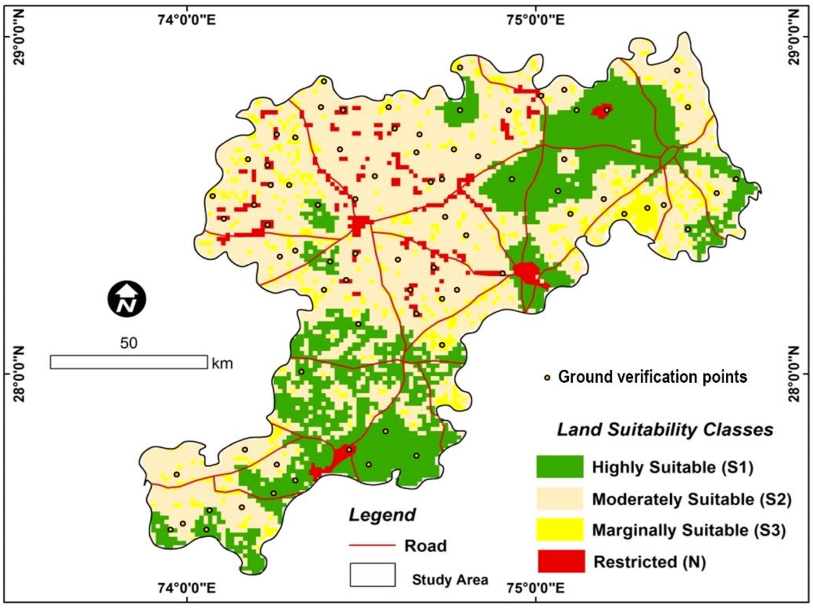

Fig 6: Ground verification points.

Table 2: Pairwise comparison matrix.

	Mean temperature in the growing season	Rainfall	Phosphorus	Soil texture	Soil pH	SOC	EC	Slope	LULC
Mean temperature in the growing season	1	1	1	4	4	3	4	2	2
Rainfall	1	1	5	1	3	2	1	2	1/2
Phosphorus	1	1/5	1	1/2	1	2	2	1	1/2
Soil texture	1/4	1	2	1	1	2	1	1	1/2
Soil pH	1/4	1/3	1	1	1	1	1/2	1	1
SOC	1/3	1/2	1/2	1/2	1	1	1	1	1/3
EC	1/4	1	1/2	1	2	1	1	1/3	1/3
Slope	1/2	1/2	1	1	1	1	3	1	2
LU/LC	1/2	2	2	2	1	3	3	1/2	1

Source: Computed.

Table 3: Weightage and % weightage of selected criteria.

Criteria	Weightage	Weightage (%)	Sub-criteria
Mean temperature in the growing season (°C)	0.2068	20.68	Less than 28.00 28.00-32.00 32.01-38.00 More than 38.01
Total rainfall (mm)	0.159	15.90	Less than 300.00 300.00-400.00 400.01-500.00 More than 500.01
Landuse/Landcover	0.1439	14.39	Agricultural Land Barren Land Natural Vegetation Water Body Settlement Roads
Slope of the land (%)	0.11	11.00	Less than 3.00 3.00-5.00 5.01-10.00 More than 10.01
Soil texture	0.092	9.20	Fine Sand Loamy Sand Silty Sand
Phosphorus (kg/h)	0.0884	8.84	Less than 10.00 10.00-20.00 20.01-30.00 More than 30.01
Soil pH	0.0703	7.03	Less than 7.40 7.40-7.80 More than 7.81
Salinity (EC) (dS/m)	0.07	7.00	Less than 1.00 1.00-2.00 2.01-3.00 More than 3.01
Soil Organic Carbon (SOC) (%)	0.0596	5.96	Less than 0.20 0.20-0.25 0.26-0.30 More than 0.31

Source: Computed.

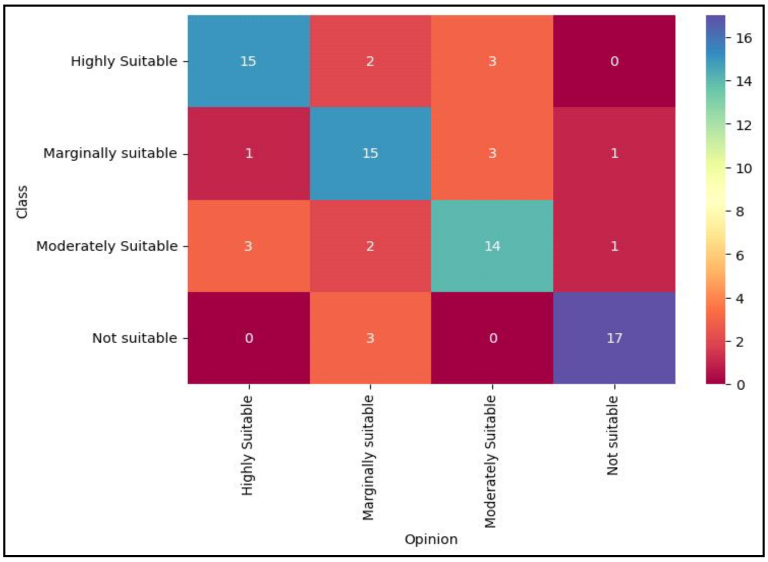

Fig 7: Confusion matrix heat map.

Few segments of the S2 category were also observed in the northeastern segment as well as southwestern portion. It was observed during the filed survey that significant percentage of barren land were present in this category with higher potential and can be used for agricultural activity.

Marginally suitable

In comparison to S1 and S2 category, S3 category was found in relatively smaller percentage. S3 category or marginally suitable category spades over the study area in discrete manner and covers 1592.14 km^2 area. Although the availability of rainfall and temperature was favourable for the growth but major controlling factors were relatively higher slope of the land and higher salinity. Better farmland management can be the probable way to tackle the issue.

Restricted

N category covers the region which cannot be used the agricultural activity and spans over an area of 1034.93 km^2 (Fig 8b) (Table 4). This category is mostly associated with landuse and landcover category like roads and permanent settlement hence extension of agricultural activity in these areas are remotely possible.

From the confusion matrix, accuracy of the proposed model was assessed. Among total of 19 sampling locations related to Highly suitable category (S1), 15 were correctly classified while 1 location was misclassified as marginally suitable (S2) and 3 locations were wrongly classified as moderately suitable (S3). None of the locations were misclassified in Not Suitable category (N). In the similar way, among 22 validation points for S2 category (Marginally suitable), majority (15) were classified correctly while in S1, S3 and N category 2, 2 and 3 locations were misclassified respectively (Fig 9). In marginally suitable class (S3), 20 validation points were considered and among them, 3 locations were misclassified in both S1 as well as S2 category. The overall accuracy achieved from the analysis was 88.10%.

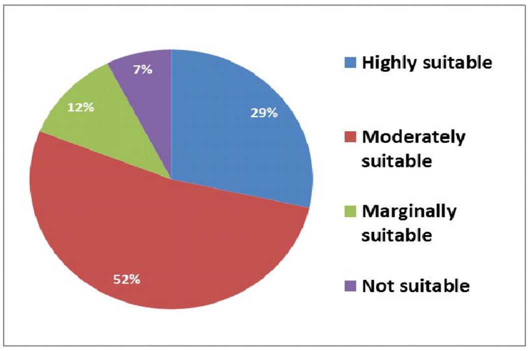

Fig 8a: % Area to total area under different land suitability category.

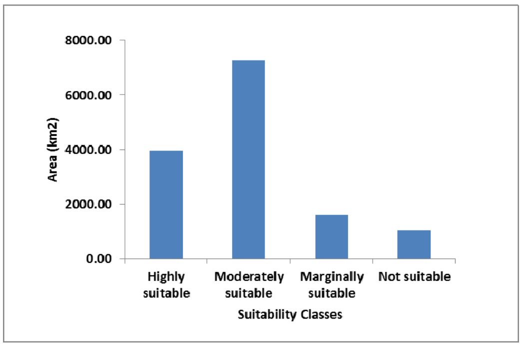

Fig 8b: Area under different land suitability category.

Table 4: Land suitability classes and corresponding area.

Suitability classes	Area (km^2)	% to total area
Highly suitable (S1)	3948.81	28.54
Moderately suitable (S2)	7259.12	52.47
Marginally suitable (S3)	1592.14	11.51
Restricted (N)	1034.93	7.48
Total	13835.00	100

Source: Computed

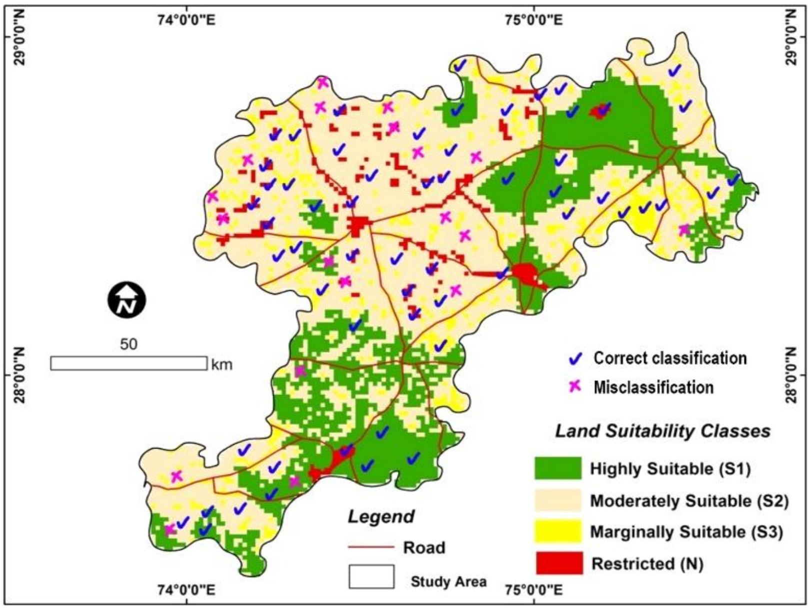

Fig 9: Spatial distribution of correct classification and misclassified locations.

CONCLUSION

In the current study, GIS assisted AHP was found useful to assess pearl millet land suitability in arid western plain of Rajasthan, India. Mean temperature in the growing season, rainfall, Landuse/landcover and slope of the land showed higher percentage of influence in the present study. Highly suitable category was found to be suitable for the pearl millet without any significant restriction, while in moderately suitable category, relatively better firm management was needed. Marginally suitable category needs attention in terms of proper inputs in agriculture like fertilizers. The proposed model exhibited higher level of accuracy and thus it can be concluded that current model will help farmers and agricultural planners to develop sustainable and cost-effective pearl millet production strategies and fill the gap between local food production and food imports.

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