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Multi-Criteria Decision Making and GIS Approached Land Suitability Analysis for Pearl Millet Cultivation in Banka Block of Banka District, Bihar

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ABSTRACT

Land suitability analysis, an important aspect used in land use planning, and provides an integrated information for land resources management. Hence, the main objective of the study is to analyze the land suitability for the pearl millet crop of Banka block using Geographical Information System (GIS) and Multi Criteria Decision Making (MCDM) approaches. To fulfill the objectives, there are 9 parameters, viz., land use and land cover, elevation, slope, soil texture, pH, EC, OC, temperature, and precipitation were considered. However, satellite imageries of Land sat-8 (2022) and Shuttle Radar Topography Mission (SRTM) data were employed to assess the physiography, elevation, slope, and land use/land cover pattern under RS-GIS domain. The results revealed that out of the total geographical area (114.95 km^2), only 25.01 % of the land in the northern part of the study area is highly suitable (S1), followed by 41.21% of the land found to be moderately suitable (S2) in the middle portion, and 12.32 % of the land is marginally suitable (S3) which is in the southwest part for pearl millet. The remaining land (21.5 %) was found to be not suitable (S4) due to the presence of bed rock, hilly terrain, built-up lands, and water bodies. The integration of soil, climate, and topographic parameters has aided in mapping the suitable lands for pearl millet. This information may be beneficial for farmers' advisory services and as a database for further utilization in land-use planning.

Keywords: *Geographical Information System (GIS), Land suitability, Multi-Criteria Decision Making (MCDM), Pearl Millet, Remote Sensing, Analytic Hierarchy Process (AHP)*

INTRODUCTION

Pearl millet (*Pennisetumglaucum* L.) is considered as Nutri-cereal due to its rich source of protein, fibers and micronutrients like zinc and iron [1-2]. These nutri-cereals have been reported to help to reduce the negative impacts of climate change and alleviate malnutrition. The land provides mechanical support to the plants and nutrients, making land suitability is an important aspect of assessing the capacity of the land towards supporting crop production in a sustainable manner [3]. Therefore, evaluating land resources is necessary to promote agricultural activities in a proper land-use system [4]. Land suitability analysis also helps to decision-makers, land use planners, and other stakeholders to create a system for the management of cropping patterns.

Land suitability evaluation involves examining the potential of land for a specified utilization [5-7], considering climatic condition, spatial variability of vegetation, soil type, and other physiographical characteristics for requirements for various major crops viz. rice, wheat, maize, sorghum, green gram etc. [8-10]. Geographical Information System (GIS) based multi-criteria decision making (MCDM) was highlighted as a tool to identify the site-specific locations for watershed management, agriculture, plantations, settlement and industrialization [2].

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In the context of managing soil resources, soil survey involves soil sampling, their physical-chemical analysis and mapping to provide valuable information and suitable sites for sustainable agricultural practices. Consequently, remote sensing (RS) and GIS methods were employed to create an extensive assessment of soil resources and to make a contingent plan for the productivity of the land resources for a particular location [11].

By using satellite data from IRS-P6, LISS-IV, Cartosat-1 and Cartosat-2, to create a thematic map to analyze the soil resources effectively [12]. A Global Positioning System (GPS) receiver is used to collect soil samples from various locations together with their latitudes, longitudes, and other geospatial features to create soil fertility maps under the RS-GIS domain [13]. However, Inverse Distance Methods (IDW), variogram, krigging, and nugget algorithms for grid-based soil resource mapping, their database generation, and for the management of soil nutrients of the area of interest under RS-GIS domain [14-15].

Rice, wheat, pulses, and oilseeds are grown in Banka district. However, unplanned agricultural land, forest degradation, intense weathering, rainfed condition and moisture stress in soils were observed in Banka block. In the context of land use planning, cultivation of pearl millet may be an alternative option to minimize these constraints. Hence, it was observed that remote sensing, GIS, and Analytical Hierarchy Process (AHP) techniques based identification of suitable sites for implementing an appropriate land use strategy and the enhancement of millets in Banka block may be helpful, and to keep these facts in mind, the present study was carried out.

MATERIAL AND METHODS

Study Area

To carry out the study, Banka block of Banka district of Bhagalpur division in Bihar has been chosen, which consists of 114.95 km^2 and extends from 24°30' N to 25°06' N and from 86°30' E to 87°07' E (Fig. 1). The southern part of Banka block is undulated, having uplands to medium-uplands. However, the northern part is occupied by lowlands with flat surfaces. Tributaries of the Chanan and Kadwa rivers flow from south-west toward north-east and merge with the Ganges.

Banka block varies greatly in summer and winter temperatures. In the summer season, the average maximum temperature recorded is approximately 43°C, while in winter, the average minimum temperature recorded is nearly 08°C. The summer season began in March and lasted until June and followed by the rainy season from mid-June and to end of September while the winter season began in November and lasted until February (IMD, 2022). The majority of the rainfall is during the south-west monsoon, which begins on June 15th and continues until the end of September. However, the study area received a mean annual rainfall 1200 mm in the year of 2020 while with some low rainfall was recorded 1124 mm in the year of 2021. A rainfall range of 350-1200 mm is necessary to meet the criteria for highly suitable (S1) for pearl millet [9]. There is mixed and degraded forest vegetation found in hilly terrain and foot hills in the south-west part of Banka block. However, north part is occupied with agricultural lands.

Satellite images, hard ware and software used

The multi-spectral images of Landsat- 8 (2021-2022) and SRTM data for the Digital Elevation Model (DEM) were used for mapping of land use pattern (Fig. 3E and 3I) and topography (elevation and slope) respectively (Fig.3E and Fig.3F). However, the administrative boundaries of Banka block in Banka district were trace out using topographical sheets with scales of 1:250000 and 1:500000.

Computer systems (HP Platinum 4core processor) and QGIS software (Version 3.8.2) have been used for the mapping, digitization, and visual interpretation of satellite imagery. In order to validate the derived data, soil survey reports, topographical maps, and auxiliary data were also used as references.

Criteria for land suitability analysis

The land suitability class viz. highly suitable (S1), moderately suitable (S2), marginally suitable (S3), and not suitable (NS) was classified using standard practices established by FAO [5-6 and 8-9]. To assess the suitability class of the crop, there are nine (9) criteria were considered, viz., elevation, slope, soil pH, EC, OC, soil texture, temperature, rainfall, and LU/LC for the analysis of land suitability for pearl millet pertained in (Table 3).

An integrated GIS and Analytical Hierarchy Process (AHP) was employed to evaluate the study area's land suitability for pearl millet. Similar work for some *rabi* crops viz. wheat, barley, mustard, and sugarcane was carried out [9], and some the major *kharif* crops such as rice, maize, sorghum, pearl millet and cotton through the MCE technique by using the soil physic-chemical parameters and climatic characteristics [16-17].

Applying of MCDM using spatial AHP procedure

In the RS-GIS domain, the Analytical Hierarchy Process (AHP) procedure was utilized to assign the relative importance of criteria, sub criteria, and suitability classes and there is a hierarchy in the relationship between the objectives and their attributes [4]. The objectives can be distinguished at the highest level, while the attributes can be broken down at a lower level. However, in terms of the creation of a comparison matrix at each and every level of hierarchy, the pair-wise comparison matrix (PWCM) which rates the relative significance of the two factors was applied for the evaluation of the cropland's suitability (Table 1). Hence, a scale was introduced by [18] with values ranging from 9 to 1/9, and it was used to determine the relative importance/weight of criteria, sub-criteria, and suitability classes, where the row factor is rated at 9 which indicates more significant than the column factor. However, a rating of 1/9 means that the row factor is less significant in comparison to the column factor (Table 2).

To avoid bias in the weighting of the criteria, the Consistency Ratio was employed. A CR value of 10% (0.1) or less is regarded as appropriate [19], as a general rule of thumb.

Consistency Index (CI) = $(\lambda - n) / (n - 1)$ ... (1)

Consistency Ratio (CR)= CI / RI.... (2)

Where: λ represents the average of the consistency vector, RI represents the Random Index and n is the number of criteria or sub-criteria in each pairwise comparison matrix.

The CR is 0.10 or less, the further analysis can proceed [18]. If the consistency value is more than 0.10, the judgment needs to be revised in order to identify the sources of the inconsistency and make the necessary corrections. If the pairwise comparison exhibits perfect consistency, as indicated by a CR value of 0. The judgments matrix is deemed reasonably consistent as long as the threshold value stays below 0.1. The weighted overlay analysis method was integrated with all nine theme layers in the GIS platform to create a land suitability map for the pearl millet in the Banka block.

The final suitability map was produced using the weighted sum overlay technique in the open-source geospatial Q-GIS software after the standardized thematic layers and their weights for the pearl millet crop were determined.

METHODOLOGY

Hence, the methodology is summarized below for step-by-step processing of the data in GIS domain (Fig.2).

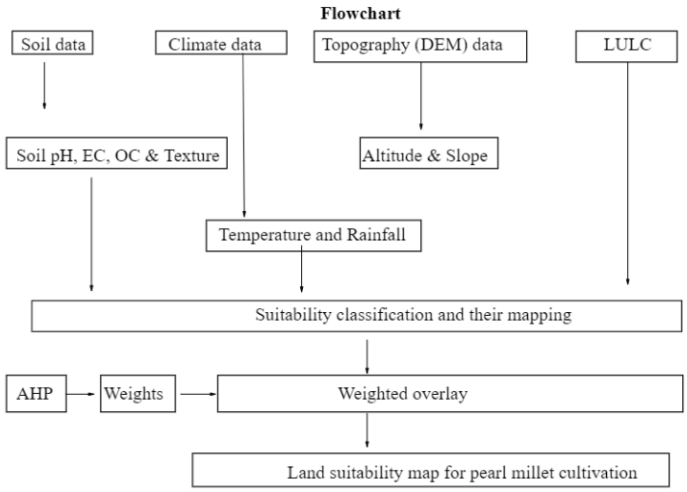

Fig. 2 Flow chart showing land suitability mapping for pearl millet

RESULTS AND DISCUSSION

Climatic suitability

The study area has been distinguished by mean temperature and rainfall pattern over a period of 30 years. Mean Temperature was found to be moderately suitable, and it varied between 23-25° C (Fig. 3H). However, mean rain-fall was found to be moderately suitable in the range of 65-110 cm (Fig.3G). The rainy season starts in July and ends in September which comes under monsoon. The findings showed that for the rain-fed pearl millet cultivation in the study area, the mean growing season temperature (S2) and rainfall (S2) are both reasonably suitable.

Topographic suitability

The study's deciding factor for identifying areas that would be good for pearl millet was slope. The Digital Elevation Model (DEM) for the suitability classes in the study area was used to classify the slope. As a result, the study area's slope has been divided into four groups: 0-1.5%, 1.5-2%, 2.-2.5 %, and >2.5 % (Fig.3F). However, elevation, varied from 10 to 185 meters (Fig.3E). The results showed that the nearby hilly terrain with a gentle slope was highly suitable, followed by moderately suitable and marginally suitable terrain.

Soil suitability

The most significant component of the soil criterion in the land suitability classification is the pH of the soil, which indicates the suitability of the soil for a given crop by providing details on the solubility and possible availability of elements for crops (Brady & Weil, 1999). The soil in the research area has a moderate acid reaction, as shown by the pH values of the soil in water, which varied from 5.13 to 6.71 (Fig. 3A). The pH analysis suggested that pearl millet could be grown in a moderately suitable environment (S2). However, the analysis indicates that the region is extremely suitable (S1) for the cultivation of pearl millet crops (Fig. 3J). Electrical conductivity (EC) is an indicator for determining saline soils (Fig. 3 B). The marginally suitable area for the production of pearl millet is demonstrated by the analysis for Organic Carbon (OC) in (Fig. 3C). The maximum area of texture variability was found to be sandy loam to loam (Fig 3D).

Overall suitability

The weighted overlay shows that northern part of the research area is highly suitable, (25 %), followed by moderately suitable in the middle portion (46.21%), followed marginally suitable in the southwest for pearl millet (15.32 %) (Fig.3J). South west region has some constraints caused by waste land found to be near hilly terrain and plateau region(Fig. 3I). This can be improved by implementing the right interventions, such as agronomic practices, integrated soil fertility management, structures for collecting moisture, and measures to conserve water and soil.

CONCLUSION

The primary factors used to determine a piece of land's suitability for pearl millet cultivation were soil, climate, and topographical features. The integration of soil, climate, and topographic parameters for the assessment of land suitability in the study was found to be greatly aided by GIS-integrated interpolation techniques with AHP analysis. The land suitability map that was generated shows that the study area's lands from the north to the southwest are highly suitable (S1), moderately suitable (S2), and marginally suitable.

FUTURE SCOPE OF THE STUDY

Research findings may be helpful to assess the suitable crops and land use planning of the area of interest. Outcomes will be also helpful to support to providing the supplementary data source for the initiation of the same type of suitability analysis of other crops.

CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

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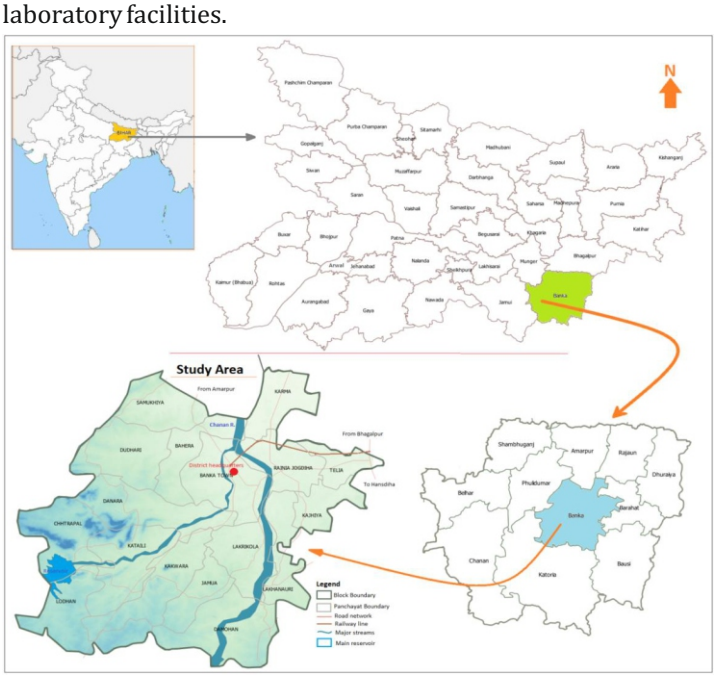


Fig. 1 Location map of the study area

Table 1: Pair wise comparison matrix for assigning weights

	OC	pH	Texture	EC	Temp.	rainfall	LULC	Elevation	Slope	Geometric Mean	Weight	Priority (%)
OC	1.00	3.00	4.00	3.00	5.00	5.00	4.00	5.00	4.00	3.47	0.36	35.84
pH	0.33	1.00	0.33	0.33	4.00	4.00	3.00	3.00	3.00	1.36	0.14	14.08
Texture	0.25	3.00	1.00	3.00	0.25	4.00	0.25	3.00	3.00	1.20	0.12	12.39
EC	0.33	3.00	0.33	1.00	4.00	0.14	4.00	3.00	3.00	1.24	0.13	12.81
Temp.	0.20	0.33	0.33	0.33	1.00	3.00	3.00	1.00	3.00	0.84	0.09	8.65
Rainfall	0.20	0.33	0.20	0.33	0.20	1.00	4.00	0.33	1.00	0.47	0.05	4.89
LULC	0.25	0.14	0.33	0.20	0.25	0.33	1.00	4.00	3.00	0.51	0.05	5.29
Elevation	0.20	0.33	0.14	0.17	0.14	0.25	0.25	1.00	3.00	0.33	0.03	3.38
Slope	0.25	0.14	0.14	0.25	0.25	0.14	0.33	0.33	1.00	0.26	0.03	2.67
Sum										**9.67**	**100**	**100**
Max=10.78			**CI= 0.051**			**RI= 1.45**			**CR= 0.035**			

Table 2: Random Consistency Index (RCI) for analytical hierarchy process (AHP)

n	1	2	3	4	5	6	7	8	9
RI	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45

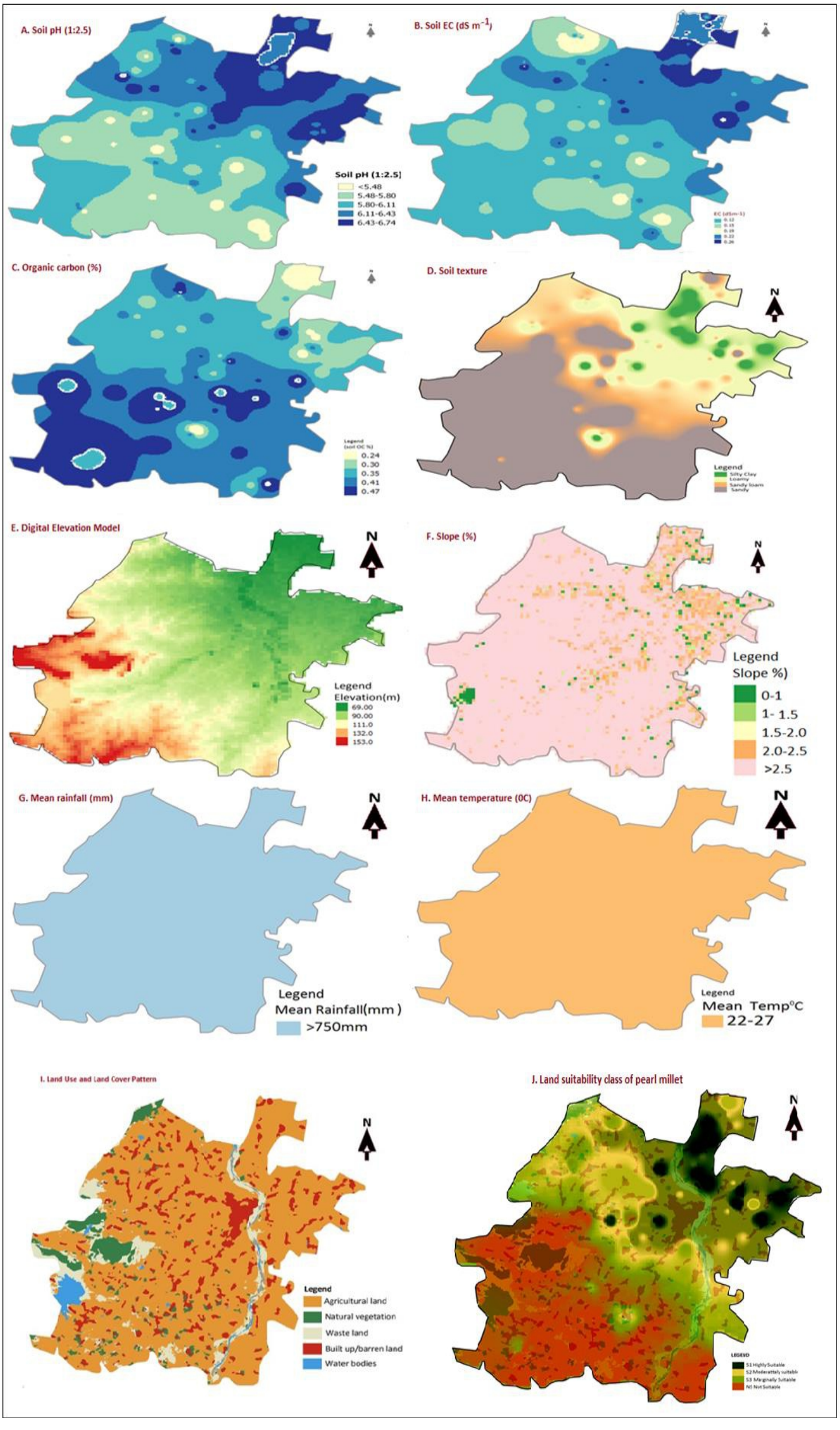
Table 3: Land suitability criteria for pearl millet

	S1	S2	S3	S4
Temp. ^{0}C	15-25	10-15, 25-30	8-10, 30-40	<8, >40
Rainfall (mm)	350-1250	250-300, 1250-1500	200-250, 1500-1750	<200, >1750
Elevation (m)	<100	100-200	200-300	>300
Slope (%)	0-1	1-3	3-5	5-10
Soil pH (1:2.5)	6.5-7.5	5.6-6.5, 7.5-8.2	5.2-5.6,8.2-8.5	4.5-5.2, >8.5
EC (Dsm^{-1})	<0.8	0.8-1.6	1.6-3.2	>3.2
OC (%)	>0.75	0.75-0.5	<0.5	
Texture	Si, SiL, CL, SiCL, L	SC, SCl, C, SiC	SL, LS	S, CS
LULC	Agricultural land	Fallow land	Pasture/plantation/orchards	Bed rock, barren land, water bodies

S1-Highly suitable; S2-Moderately suitable; S3-Marginally suitable; S4-Not suitable

Reference: [5, 6, 8, 9, 21, 16, 19 and 22]

Figure 3: *Spatial variability of A. Soil pH; B. Soil EC; C. Organic carbon; D. Soil texture; E. Digital elevation model; F. Slope; G. Mean rainfall; H. Mean temperature; I. Land use and land cover pattern and J. Overall land suitability class of pearl millet of Banka block in the Banka district, Bhagalpur.*



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