Improper land use results in land degradation as well as decline in agricultural productivity. To obtain optimum benefit from the land, proper utilization of its resources is necessary. Land suitability analysis is the evaluation and grouping of specific areas of land in terms of their suitability for a defined use, which is a precondition for sustainable land use planning. This study investigated the applicability of Geographical Information System (GIS) techniques in combination with multi-criteria land evaluation for analysing land suitability. The study used the weighted overlay technique for multi-criteria evaluation with GIS for the assessment of suitability of wheat cultivation in Beko watershed (Purulia, India). The watershed area is moderately suitable for wheat crop production, with constraints like imperfect drainage and poor soil depth.

**Keywords:** spatial analysis; GIS; remote sensing; multi-criteria decision analysis; spatial decision support system

1. Introduction

Agriculture is one of the dominant sectors supporting rural life. Globally, agriculture can potentially increase food supplies faster than the growth of population (1). Yet, the capacity for available resources and technologies to satisfy the demands of the growing population for food and other agricultural commodities remains uncertain (2). Among the rain-fed lowland rice areas of eastern India, the district of Purulia constitutes an area of particularly low agricultural productivity and a high incidence of poverty. Most rural households practise subsistence farming under adverse and risky environmental conditions. Because of several decades of non-sustainable land-use practices coupled with highly erosive monsoon rains and deforestation, soil erosion is proceeding rapidly in many parts of the eastern India, particularly in the plateau region.

However, in view of the poor performance of the agricultural sector in relation to the fast growing population, intensification of agriculture is critical. This calls for judicious planning of land resources to augment agricultural production to meet the ever increasing demand for food, while achieving environmental protection. An efficient agricultural production system requires proper planning and timely management of available land under an appropriate land allocation scheme. Thangasamy et al. (3) assessed the suitability of soils of the Shivagiri watershed for arable crops, grazing and forestry. The grouping of soils into classes and subclasses was done based on the severity of limitations viz., erosion risk (e), wetness (w), rooting zone, soils (s) and climatic limitations (c). Based on these criteria, the soils of the Shivagiri watershed were classified into three land capability sub-classes for better management. Such a scheme includes an evaluation of land capability and determination of suitability of each of these areas for different agricultural crops.

Various approaches of land evaluation have been developed, each having a specific methodological procedure. The qualitative systems are empirical assessment systems based on the knowledge and understanding of the area. A qualitative land suitability classification procedure was adopted by Verdoodt and Ranst (4) to translate the large-scale bio-physical data supplied by reconnaissance soil surveys into five suitability classes within a Geographical Information System (GIS) environment. Ghaffari et al. (5) used GIS to match the suitability for potatoes based on the biological requirement of the crop and the quality and characteristics of land. The methodology combined climate, land quality attributes that most influence crop suitability (long term), and topographical data (slope and altitude). It presented a GIS-based land suitability model based on the Simple Limitation Approach.

In order to determine an optimum land use type for an area, a systematic integration of data from various sources like soil science to meteorology is involved. The relative degree of contribution of various criteria can be addressed when they are grouped into various categories.

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and organized into various hierarchies. Agricultural land suitability involves major decisions at various levels starting from choosing a major land-use types, selection of criteria organisation of the criteria, and deciding suitability limits for each class of the criteria. The relative importance of these parameters can be evaluated to determine the suitability by multi-criteria evaluation (MCE) techniques. Diverse approaches to decision-making using relevant techniques have been adopted from time to time. In the present study, an attempt has been undertaken to use a weighted MCE and GIS in union to identify the most idealistic land evaluation for crop suitability assessment. This fusion approach of integrated MCE–GIS was adopted to overcome the shortcomings of the earlier unrealistic multi-criteria land evaluation approaches of non-spatial assessments on assumptions of spatial homogeneity. Malczewski (6) advocated using GIS to perform spatial multi-criteria decision-making (MCDM) as it easily provides a means for developing valuation criteria based on neighbourhood analysis operations. Ceballos-Silva and Lopez-Blanco (7) used matrix pairwise comparison for land suitability that overcomes the problem of determining weights. The MCE–GIS technique combines both traditional and modern approaches to analyse land evaluation. Spatial MCE, like MCE–GIS allows spatial reference information and analysis techniques to be combined and transformed into a decision based on the decision maker’s preferences. An investigation was carried out to develop a MCDM technique using matrix pairwise comparison by characterizing and mapping the soils of the area and including the climatic variable of rainfall distribution using a GIS platform, in an endeavour to evaluate land suitability for agricultural crops.

2. Methodology
Spatial MCDM is a process where geographical data are combined and transformed into a decision. Multi-criteria decision-making involves input data, the decision maker’s preferences and manipulation of both information using specified decision rules. Since the evaluation criteria were related to geographical entities and the relations between them, they were thematically represented. Using these criteria in the form of relevant rasters (layers), an attempt was made to integrate multi-criteria land evaluation and GIS for wheat suitability analysis (Figure 1). The current land use, topography, soil properties, etc. indicated wheat as a potential crop for the evaluation study for the study area. In this particular endeavour, few intrinsic land quality parameters have been selected for evaluation. Once land units within the area are identified as a basis for the diagnosis of problems, they are mapped using GIS. On identification of the problem, the set of criteria for evaluation are also designated.

![Flowchart of the methodology of mechanism of integrated GIS–MCE for suitability analysis of wheat.](image-url)

Figure 1. Flowchart of the methodology of mechanism of integrated GIS–MCE for suitability analysis of wheat.
suitability map is classified based on their land use quality priority for the specified land use requirements. According to Food & Agriculture Organisation (FAO) (8), land suitability is classified into two classes (i.e. suitable and not suitable) based on the crop specific soil, climate and topographic data guidelines. These classes are further classified based on their benefits and limitations (Table 1).

### 2.1. Area delineation

Since an extensive land use analysis was one of the desired outcomes of this study, the area chosen for the purpose has been limited to a watershed. The shuttle radar topographic mission (SRTM) digital elevation model (DEM) was used to delineate the watershed, extracting the river. This area is demarcated after a digital river network extraction based on a crucial model on a GIS platform (Figure 2).

In order to address land suitability for wheat cultivation in the study area, the evaluation criteria considered are as follows:

- Soil physical properties (texture, depth and drainage)
- Soil chemical properties (pH)
- Topographic factor (slope)
- Climate factors (rainfall)
- Land use/land cover

### 2.2. Thematic database creation

An extensive digital repository of the spatial and attribute data related to the characteristics of each of the soil mapping units’ characteristics within the study area is developed in the GIS. An elaborate digital soil database was created by using texture, depth, pH and drainage information on a GIS platform. A slope map layer is derived in ArcMap by using the SRTM DEM. The slope map is significant in defining the flow direction within a watershed. A rainfall distribution map is prepared by spatial interpolation of the four years daily rainfall data in ArcMap. The land use/land cover information of the Beko watershed is generated from the LISS-III imagery of December 2008 using the supervised classification technique (Maximum Likelihood Classifier) in ERDAS 9.0 based on the Ground Control Points collected from an extensive field survey using GARMIN GPS device.

### 2.3. Land suitability analysis

The objectives considered for the evaluation study are soil, topography, climate and land use. These parameters have been taken into account for analysis towards the identification of suitable areas for agricultural development.

#### 2.3.1. Crop requirement

The crop requirements are expressed by defining optimal, marginal and unsuitable conditions for each land

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**Table 1. Land suitability classification for rain-fed agriculture.**

| Suitability class | Suitability | Description                                                                 |
|-------------------|-------------|-------------------------------------------------------------------------------|
| S1                | Highly      | Land without any significant limitations                                      |
| S2                | Moderately  | Moderately severe limitations which reduce productivity or benefits or increase required inputs |
| S3                | Marginally  | Overall severe limitations; given land use is only marginally justifiable     |
| N1                | Not suitable| Limitations not currently overcome with existing knowledge within acceptable cost limits |
| N2                | Permanently non-suitable | Limitations so severe that they preclude all possibilities of the given use |
attributes that directly or indirectly influences plant growth, performance and biomass production. The requirement table was established through a review of experimental findings and literature on parameters like crop phenology and morphology, length of growth cycle and time of maturity, and specific climatic and soil physical and chemical requirements. The following biophysical requirements related to the following conditions for the successful growth and production of wheat is selected in the present crop environmental requirements characterization for evaluation:

- Climate: rainfall;
- Rooting condition: soil depth and texture;
- Wetness: soil drainage;
- Fertility status: soil pH and organic matter;
- Mechanization potential and risk of erosion referring to slope.

The Ref. (10) indicates the environmental requirements for wheat at various suitability classes.

2.3.2. Factor/criteria rating

Factor ratings are sets of values that indicate how well each factor is satisfied by particular conditions of the corresponding land quality. The stratification is made in terms of five classes: (i) highly suitable, (ii) moderately suitable, (iii) marginally suitable, (iv) currently not suitable and (v) permanently not suitable. In this study, the major criteria undertaken are related to soil, topography (slope), climate and land use/land cover. The soil data are assessed in terms of their texture, depth, pH and drainage, etc. whereas the climatic factor involved rainfall. A compilation of all the crops requirements considered in the evaluation are made and factor rating for the crops are determined.

2.3.3. Criteria standardization

Data are measured on different units as well as on different scales of measurements. Thus, it is necessary to standardize the factors before combination and assure they are transformed, if necessary so that all factor maps are positively correlated with suitability (11). There are a number of procedures for standardization that can be used to standardize criteria maps. Linear scale transformation is the most frequently used GIS-based approach for criteria standardization (12). Thus, criteria have been standardized for this study making sure that each criterion had an equivalent measurement basis.

2.3.4. Assigning criterion weights

The purpose of weighting in land suitability analysis for agricultural crops is to determine the importance of each factor relative to other factors that affect crop yield and growth rates. The pairwise comparison technique developed by Saaty (13) in the context of a decision-making process is a ratio (reciprocal matrix) where each factor is compared with the other criteria, relative to its importance on a scale from 1 to 9. Weights are calculated by normalizing the eigen-vector associated with the maximum eigen value of the matrix. Then, the consistency ratio (CR) is computed to check the consistency of comparisons.

Figure 3. False colour composite imagery of the study area (IRS- LISS-III data of December 2008). The Beko watershed’s extent has been highlighted.
2.3.5. Aggregating criterion weights and standardized criterion maps

Finally an aggregation stage is undertaken to combine the information from the various factors and constrains (14). In this study, weights and the standardized criterion maps are aggregated by means of a weighted linear combination, an empirical contribution of Malczewski (15),

\[ S = \sum w_i \times x_i \times \prod c_j \]  

where \( S \) = Composite suitability score, \( x \) = Factors score, \( w \) = Weight assigned to \( c \) = Constrains, \( \Sigma \) = Sum of the weight, \( \Pi \) = Products of constrains

3. Study area and data

A brief description of the study area along with its areal extents will be detailed. The source of data and their
contribution to the investigation is detailed in this section.

3.1. Study area

The study is conducted in a watershed named Beko situated on the eastern plateau of India. It is geographically situated between 23°17′ to 23°31′ N latitudes and 86°30′ to 86°50′ E longitudes covering an area of 50,000 ha approximately (Figure 3).

Physiographically, the area is located at the eastern fringe of the Chhota Nagpur Plateau. Topographically, it is an undulating and highly dissected landscape, with elevation ranging from 115 to 379 m from the mean sea level. Climatically, the study area is subtropical and subhumid, with hot summers and cool dry winters. Rainfall and water availability are more serious climatic factors constraining agriculture in the study area. The dominant rivers feeding the watershed are the Rupnarayan (Kangsabati/Kansai), Dwarakeswar, Dudhbhariya and Beko. The area principally constitutes the residual soils formed by weathering of bedrocks. The soil is slightly acidic in some areas. Cultivation is predominantly mono-cropped and grown mostly under rain-fed conditions.

3.2. Data used

A multitude of sources provided the various data needed to accomplish the study. Overall, the following sources of data were used:

(a) Attribute information of soils of the area were obtained from National Bureau of Soil Survey and Land Use Planning (NBSS & LUP), Soil of Purulia district for optimizing land use, regional centre in West Bengal, India. The entire vector data layers are prepared on a GIS platform using the base maps.

(b) An essential parameter used in the study – slope is derived from the SRTM DEM that is obtained from USGS Earth Explorer.

(c) Daily precipitation data from 2001 to 2004 over five meteorological stations (West Bengal, India) is obtained from the India Meteorological Department, Govt. of India.

(d) The spatial data pertaining to the location of different land uses are obtained directly from the field using Global Positioning System (GPS) device. This information is used to identify the land use pattern.
4. Results

4.1. Soil database

The soil map (Figure 4) of the area has been digitally generated from the NBSS and LUP. The attribute information associated with each spatial soil unit, namely soil depth, textural classes, drainage

Table 2. Land use/land cover distribution in the study area.

| Sl. No. | Land use          | Area (ha) | Area (%) |
|---------|-------------------|-----------|----------|
| 1       | Upper terrace     | 3283.60   | 6.56     |
| 2       | First crop        | 16,804.39 | 33.59    |
| 3       | Second crop       | 19,006.96 | 37.99    |
| 4       | Forest            | 2305.73   | 4.61     |
| 5       | Degraded forest   | 795.74    | 1.59     |
| 6       | Water body        | 5512.61   | 11.02    |
| 7       | Sandy area        | 1815.26   | 3.63     |
| 8       | Settlement        | 510.91    | 1.02     |
| Total   |                   | 50035.2   |          |

Figure 7. Standardized suitability criteria maps: (a) depth, (b) drainage, (c) texture, (d) slope, (e) pH and (f) land use/land cover.
classes and pH with their area coverage of the study area are indicated in Ref. (16). These are the basic characteristics that were used for the further multi-criteria analysis.

### 4.2. Land suitability analysis

#### 4.2.1. Factors of suitability for agricultural crops

The soil depth of this region was classified into six classes. About 11% of the area has very deep soils and mostly concentrated along the western and north-western parts, while nearly 41% is predominantly deep soils. The soil texture map of the watershed area is classified into clay loam, sandy loam, sandy clay loam and loamy sand. Nearly, 65% of the area has sandy loam soil and 33% is sandy clay loam soil. The soil drainage of the watershed area is classified into well, moderately well, somewhat excessive, excessive, imperfect and poorly drained. About 41% of the area is well drained. Approximately, 24% of the area is imperfectly drained.

#### Table 3. Normalized matrix with results.

| Factors     | Depth | Drainage | Texture | Slope | Rainfall | pH | LULC | Priority vector or weight | % of weight |
|-------------|-------|----------|---------|-------|----------|----|------|---------------------------|-------------|
| Depth       | 0.3477| 0.4570   | 0.3238  | 0.2941| 0.2970   | 0.2459| 0.2121| 0.3111                    | 31          |
| Drainage    | 0.1738| 0.2285   | 0.3238  | 0.2941| 0.2970   | 0.2459| 0.2121| 0.2536                    | 25          |
| Texture     | 0.1738| 0.1143   | 0.1619  | 0.1961| 0.1782   | 0.2459| 0.2121| 0.1832                    | 18          |
| Slope       | 0.1159| 0.0762   | 0.0810  | 0.0980| 0.1188   | 0.0984| 0.1315| 0.1057                    | 11          |
| Rainfall    | 0.0695| 0.0457   | 0.0540  | 0.0490| 0.0594   | 0.0984| 0.0909| 0.0667                    | 7           |
| pH          | 0.0695| 0.0457   | 0.0324  | 0.0490| 0.0297   | 0.0492| 0.0909| 0.0523                    | 5           |
| LULC        | 0.0497| 0.0326   | 0.0231  | 0.0196| 0.0198   | 0.0164| 0.0303| 0.0274                    | 3           |

#### Table 4. Area distribution of suitability class.

| Suitability class | Area (ha) | Area(%) |
|-------------------|-----------|---------|
| S1                | 5926.41   | 11.92   |
| S2                | 37,785.50 | 75.97   |
| S3                | 5261.47   | 10.58   |
| N1                | 54.72     | 0.11    |
| N2                | 709.23    | 1.43    |
The soil pH of the region is classified into strongly acid, moderately acid, slightly acid and neutral categories. Nearly, 19% area is found to be strongly acidic and more than 41% of the area ubiquitously distributed is moderately acidic. About 35% of the area contributes to slight acidity of soils, whereas 6% is ideally the best in terms of pH.

The slope map (Figure 5) generated for the evaluation study has an immense influence on work efficiency, erosion control practices and crop adaptability. Rainfall being the only source of water for rain-fed agriculture, its distribution and dependability plays a significant role in optimizing crop production.

The land use map has been one of the major criteria for this MCE for wheat suitability analysis in the Beko watershed area. Figure 6 gives an overview of the existing land use/land cover of the area.

The areal extents of the land use/land cover prevalent in the study area are given in Table 2. The majority of the area of the land utilization second crop type, with nearly 37% of the total area being occupied by this type of land use. First crop is grown over nearly 33% of the area. Nearly 11% of the total area is covered with water bodies, 5% of the area is under the forest and 7% is under upper terrace. In the present study, an overall accuracy of 89.47% is derived from the classification.

4.2.2. Criteria standardization
All criteria maps have been standardized (reclassified) into five classes (S1, S2, S3, N1 and N2) values ranging from 1 to 5, where 1 represents S1 and 5 represents N2. Figure 7 shows the standardized criteria maps for wheat suitability. Each of the criteria is separately analysed for their suitability for supporting wheat crops based on the FAO crop requirements specified for wheat.

4.2.3. Assigning criterion weights
All the seven criteria, which are selected for the evaluation of wheat suitability in the study area, are weighted using pairwise comparison from which a normalized matrix (Table 3) is derived to finally calculate the CR of 0.0384 (Consistency is acceptable, as CR < 0.10).

4.2.4. Aggregating criterion weights and standardized criterion maps
By aggregating the criterion weights along with the standardized criterion maps the final wheat suitability map is obtained by using the weighted overlay technique, the result is shown in Figure 8.

Table 4 distinctly shows the areal distribution of the suitability classes observed over the studied watershed area. Of the total area, 5926.41 ha (11.92%) is found to be highly suitable (S1), whereas 37,785.50 hectares (75.97%) is moderately suitable (S2), 5261.47 ha (10.58%) was identified as marginally suitable (S3), 54.72 ha (0.11%) not suitable and 709.23 ha (1.43%) is permanently not suitable for wheat production. A meagre area is found to be highly suitable for the wheat crop. In spite of the ruggedness and resource crunch, which is quite common in the eastern plateau of India, the area under study shows distinct inclination towards moderate favourability for wheat crop production. The main constraint in the areas of moderate suitability is the most pressing problem of imperfect drainage. The areas that have been identified as marginally suitable for wheat growth are facing the problems of soil depth as well as excessive drainage. The unsuitable areas for wheat are disturbed by the soil depth factor.

5. Conclusion
Crop suitability analysis involves major decisions at various levels. It is an integral part to build up an efficient crop production system. Land evaluation as a significant element towards analysing crop suitability has great physical and chemical land qualities. Hence it is needed to contribute to the world’s food production to improve food security. In order to determine an optimum land use type for an area, a systematic integration of data from various sources like soil science to meteorology is involved. However, every criterion will contribute towards the suitability at variable degrees. The relative degree of contribution of various criteria can be addressed well when they are grouped into various categories and organized at various hierarchies. Relative importance of these parameters can be well evaluated to determine the suitability by MCE techniques.

In this study, a MCE – GIS-integrated method was undertaken to study the suitability of wheat. From the results, it is found that the total land under the study area, highly suitable for wheat is 11.92% of the study area. About 75.97% is moderately suitable (S2), 10.58% was identified as marginally suitable (S3), 0.11% not suitable and 1.43% is permanently not suitable for wheat production.

MCE of climate, soil and relief environmental components is significant in delineating suitable areas for wheat production. This study confirmed that the technique used is adequate to integrate a climate, soil and relief database in a GIS context. Besides the weighting factor process generated important information, which could be useful for future studies on wheat. The research findings are significant to ensure that the adopted methodology can be further generalized and applied to the other natural resources of the particular area or any other area of interest. The spatial decision support system developed here could be useful for the specialists to cultivate alternatives and facilitate support to decision-mak-
ing in urgent times towards suitability studies related to agricultural requirements.

In this study, a limited number of factors pertaining to the requirements of wheat only have been considered. Keeping in mind the future developments, this method can be further enriched by incorporating other socio-economic and environmental variables to obtain the optimum results. Although the technique has only been applied for a single crop, it has the potential to be applicable for a multitude of crops.

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