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Multi-Criteria Agricultural Land Suitability Analysis for Plantation in Mula River Basin, Rahuri Region by using Remote Sensing & GIS Technology

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Abstract

The point of this study was primarily focused on the identification of the suitable land for agriculture crop in the Mula River Basin Rahuri Region which is mostly covered by vegetation cover. Analytic hierarchy process with a combination of Geographic information system (GIS) is utilized for the evaluation in which three distinct parameters were chosen. The Analytic hierarchy process with integration of GIS was established very useful for the identification of the suitable site for agriculture. At the end of the evaluation, it was computed that 136.4 km2 (27%) of the study area is highly suitable, 285.5 km^2 (64%) is moderately suitable and 47.2 km^2 (9%) of the study area is not suitable for agriculture. However, the problems of the low production caused by geomorphological characteristics, such as very high elevation, a high degree of slope, the presence of bare rocks, and low availability of the irrigation system. All these threats resulted in a very less amount of land in the study area being identified highly suitable for agricultural production.

Key words : Remote sensing, GIS, Analytic hierarchy process, Cartosat DEM, Mula River Basin.

The land has been always a basic factor for growing crops. The term land suitability can be defined in this regard as the ability of a particular type of land to support for a specific use, and the land suitability classification process involves the evaluation and grouping of a particular land area in terms of their suitability for a defined use (Prakash, 2003). Land suitability analysis can help establish strategies to increase agricultural productivity (Pramanik, 2016) by identifying inherent and potential capabilities of land for intended objectives (Bandyopadhyay et al. 2009). It can also help identify priority areas for potential management and/or policy interventions through land and/or soil restoration programs, for instance. Geographical information system (GIS) is a useful technique to investigates the multiple geospatial data with precision and higher flexibility in land suitability analysis (Mokarram and Aminzadeh, 2010; Mendas and Delali, 2012). Therefore, multi criteria decision making (MCDM) process has been integrated with geospatial techniques in various studies for the potential land use decision-making process to solve complex problems of land management with best alternatives. This techniques extensively used for land suitability analysis to identify the potential lands for watershed management (Steiner et al., 2000), plantation (Zolekar and Bhagat, 2014), agriculture (Bandyopadhyay et al., 2009; Akinci et al., 2013), etc.

Analytic hierarchy process (AHP) is extensively utilized for multi-criterion decision making of land suitability for the various field. It determines the weight of importance for different land use based on pairwise comparisons of various parameters according to their relative significance (Miller et al. 1998). Analytic hierarchy process was firstly developed by Saaty (1980), establish a hierarchical model for solving complex problems of land management with best alternatives (Roig-Tierno *et al*. 2013). As a multi-criterion decision-making method, the analytic hierarchy process has been used widely for solving an extensive variety of problems based on complex parameters across various levels where the interaction among parameters is common characteristics.

Weighted overlay method (WOM) along with the analytic hierarchy process provides a very assuring outcome for the site suitability assessment of agricultural land use. The method can be useful to the multi-level hierarchical structure of various constraints and criteria (Triantaphyllou and Mann 1995). . It has steps to analyze the relative influence of weights on each parameter, before obtaining the final score (Boroushaki and Malczewski 2008; Bunruamkaew and Murayam 2011). Analytical hierarchy process is one of the auspicious method utilized for agricultural land suitability assessment based on individual parameters through quantitative assessment (Chen et al. 2010; Akinci et al. 2013; Khahro et al. 2014). Pairwise comparison is also used to calculate the overall score of individual elements or criteria. Integration of GIS and analytical hierarchy process helps to decision support system by the generation of suitability maps (Khahro et al. 2014).

Objective

To determine the areas suitable for agriculture in Mula River Basin, Rahuri region using GIS , AHP and WOA method. The AHP and WOA method is one of the multi-criteria decision-making approaches that are commonly used in agricultural land use suitability analysis.

Study Area

The study area is Mula River Basin in Rahuri taluka region of Ahmednagar district of Maharashtra state, India. The Mula River Basin is situated at 19°6'00" to 19°36'00" N latitude and 74°24'00" to 74°48'00" E longitude and at an altitude of 511 m above M.S.L. The area covered in this investigation is about 469.08 sq km. Climatically, the region falls under the semi-arid and sub- tropical zone with average annual rainfall of 566.5 mm. The distribution of rain is uneven, coupled with frequent droughts. The rainy days vary from 15 to 45 in different years. The annual mean maximum and minimum temperature range between 33 to 43 0C and 10.10 to 22.9 0C, respectively. The annual mean pan evaporation ranges from 3.7 to 12.4 mm day-1. The annual mean wind speed ranges from 3.2 to 13.09 km hr-1. The annual mean maximum and minimum relative humidity ranges from 59 to 90 per cent and 21 to 61 per cent, respectively. The location map of the study area is given in plate 1.

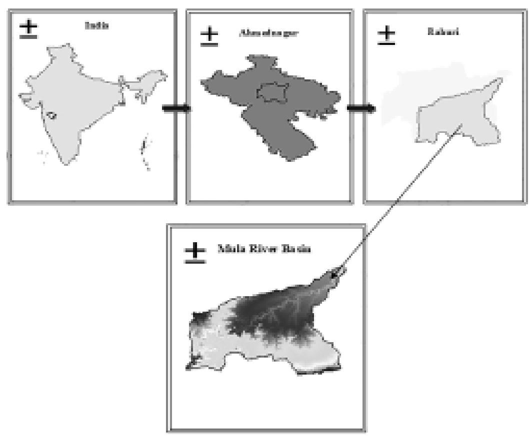

Plate 1. Location map of Study Area

Materials and Methods

In the present study multi-criterion, site suitability modeling is developed to establish appropriate and potential locations for agricultural development based on a group of constraints and criteria. Depending on their significance and importance in the agriculture six different constraints and criteria were selected that determine agricultural land suitability in the basin: Slope, DEM, Aspect, Hill shade, Stream order, and Flow direction.

The DEM image used to prepare different map with the help of spatial analyst tools in ArcGIS 10.3.1 version software. DEM data of 32 m resolution was downloaded from Bhuvan store and processed in ArcMap 10.3.1. Moreover, weights for each of the selected criterion were calculated using the AHP technique. After the weight of each raster dataset was computed, a GIS based WOA was carried out to establish a suitability map. The methodology used in the current study is summarized in Fig. 1.

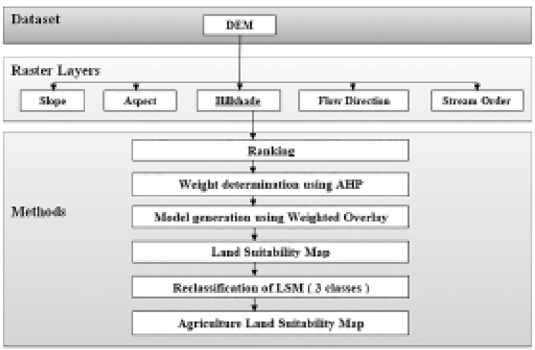

Fig. 1. Process diagram of the methods used in study

Generation of criteria maps : Slope, Aspect, Hillshade, Flow direction and Stream Order map were generated using Cartosat-1-DEM - Version-1 Digital Elevation Models (DEMs) data of 32 m resolution obtained from Bhuvan store.

Determination of Ranks : The experts' opinions and literature review were used for assigning of ranks (1 to 6) of criterion. Lower rank indicates the most important level of criterion for agriculture and higher rank indicates the least important level of parameters. Elements like slope, aspect and DEM have most influence on plantation and vegetation cover and assigned ranked 1 to 3, respectively. Hillshade, Flow direction, and Stream order have moderate influence on plantation therefore assigned ranked 4 to 6, respectively.

Pair-wise Comparison Matrix is created with the help of scale of relative importance.

Table 1. Ranks assigned to criterion

Rank	**1**	**2**	**3**	**4**	**5**	**6**
Criterion	Slope	Aspect	Digital Elevation Model	Hill-shade	Flow Direction	Stream Order

Saaty Scale

Table 2. Saaty scale

1	Equal Importance
3	Moderate Importance
5	Strong Importance
7	Very strong Importance
9	Extreme Importance
2, 4, 6, 8	Intermediate Values
1/3, 1/5, 1/7, 1/9	Values for inverse comparison

Calculation of weight for criteria maps: The analytic hierarchy process (AHP) is used to calculate weights for the criteria maps. It is a structured method for analyzing complex decisions by breaking them into pairwise alternatives of two at a time (Saaty 1988, 2008). Using the pair-wise comparison matrix, the analytic hierarchy process calculates comparative weights for individual criterion layers. The judgments in the Pair- wise comparison matrix (relative levels of importance of the parameters) were formed basis on experts' opinion and literature. Consistency Ratio (CR) calculates logical inconsistency of the judgments and facilitates detection of possible error. Saaty (1997) reported that a CR value up to 0.1 is acceptable for pair-wise comparison matrix judgment.

Table 3. Pairwise comparison matrix

Criteria	Slope	Aspect	DEM	Hillshade	Flow Direction	Stream Order	Weights
Slope	1/1	2/1	3/1	4/1	5/1	6/1	0.4081
Aspect	1/2	2/2	3/2	4/2	5/2	6/2	0.2041
DEM	1/3	2/3	3/3	4/3	5/3	6/3	0.1360
Hillshade	1/4	2/4	3/4	4/4	5/4	6/4	0.1020
Flow Direction	1/5	2/5	3/5	4/5	5/5	6/5	0.0816
Stream Order	1/6	2/6	3/6	4/6	5/6	6/6	0.0680

Site suitability model for agriculture using weighted overlay analysis : After computation of weights for each raster layer using AHP, weighted overlay analysis (WOA) is performed on an ArcGIS 10.3 software. Weighted overlay is an intersection of standardized and differently weighted layers during suitability analysis (Zolekar and Bhagat, 2015). The weights quantify the relative importance of the suitability criteria considered. The suitability scores assigned for the sub-criteria within each criteria layer were multiplied with the weights assigned for each criterion to calculate the final suitability map using the WOA technique.

$$S = \sum_{(i=1)}^{n} WiXi$$

Where, S is the total suitability score, Wi is the weight of the selected suitability criteria layer, Xi is the assigned sub-criteria score of suitability criteria layer, i and n is the total number of suitability criteria layer (Pramanik, 2016).

Result and Discussion

Using literatures and guidelines on land evaluation for agriculture (Bandyopadhyay et al. 2009) we identified six important criteria that determine agricultural land suitability in the basin: Slope, Aspect, DEM, Hillshade, Stream Order, and Flow direction. The weight values of selected criterions calculated in Analytical Hierarchy Process analyses and assigned scores of sub-criterion were used in Weighted Overlay Analysis to map the Land Suitability for agriculture in Mula River Basin, Rahuri Region. Land Suitability for agriculture classified into three classes i.e. highly suitable, moderately suitable, and not suitable. Weightages were given according to Table 4 shown below.

GIS based Criterion maps

a. Digital elevation model-

The Cartosat-1-version-1 DEM data have wide applicability in various fields (Szabo et al. 2015; Rawat et al. 2019). The digital elevation model was developed from Cartosat-1-version-1 with 32 m resolution (Plate 5.3). The DEM model is important for terrain analysis. From DEM data, it is observed that 410 - 688 m elevation was identified in the area. The highest elevation area shows land suitability is very poor due to hilly and rocky area and the lower elevation shows land was good due to clay loam, clay type of soil texture suitable for growing crop expect water spread area (Plate- 1).

b. Slope-

The slope analysis is useful to detect the potential sites for agriculture (Bandyopadhyay *et al.*, 2009), watershed management etc. The distribution of soil qualities i.e. soil depth, soil moisture, soil texture and availability of nutrients are varied with slopes (Datye and Gupte, 1984). The thickness of the soil layer decreases with increasing slope and increases with decreasing slope. Slope degree is the main factor determining erosion control. Accordingly, with an increase in slope degree, the development of soils occurs slowly (Atalay, 2006), and soil depth and fertility decrease. So that, slope indirectly limits agricultural production by affecting soil properties (Plate- 2).

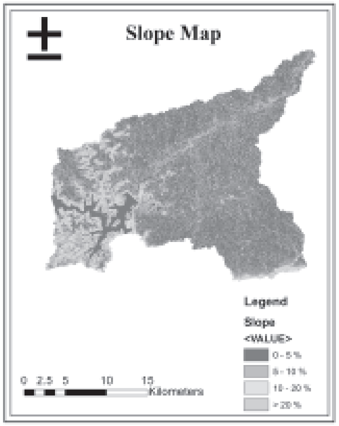

Plate 2. Slope map of the study area

c. Aspect-

To maintain their physiological activities, plants need sun exposure at certain intervals. The duration of this need varies according to the species of plant. However, in general, most plants exhibit optimum growth in the southern and western aspects that receive sunlight for a substantial portion of the day. For this reason, aspect is taken into consideration as an assessment criterion for selecting the land to be used for agriculture (Plate-3).

a. Hillshade-

Hillshade is a raster dataset visualising the elevation of the terrain. Study area having low Hillshade area so that we could go for more Agricultural crop whatever the area available we go for recreation purpose or pauster (Plate-4).

d. Flow direction-

The flow direction from every grid cell to downhill neighbour is evaluated from DEM of 32 m resolution data. It is then marked as a value in a new “flow direction” grid based on DEM

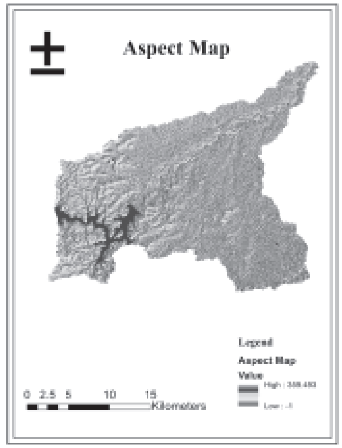

Plate 3. Aspect map of the Study Area

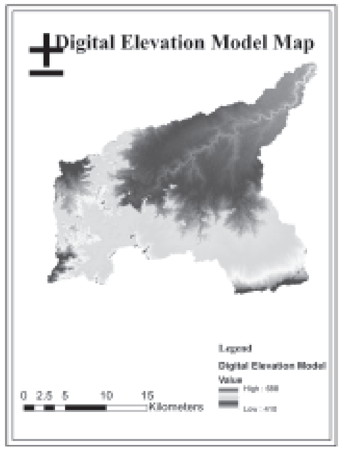

Plate 4. Digital Elevation Model

data with the help of Arc Hydro tools (Plate-5).

e. Stream Order-

Stream order designation is the morphometric analysis of drainage basin depending on hierarchy (Strachler, 1952). It is a measure of the relative size of streams (Plate-6). It is found that the Mula river basin is a 5th order trunk stream. It is found that the maximum stream order frequency of the Mula river is observed in case of first-order streams and then for second order and then decreases upto last highest order stream.

Agricultural Land Suitability Map: The determination of weights had been completed

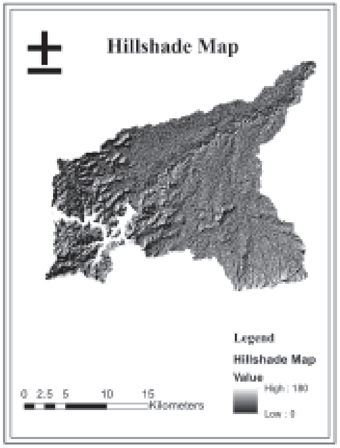

Plate 5. Hillshade map of the Study Area

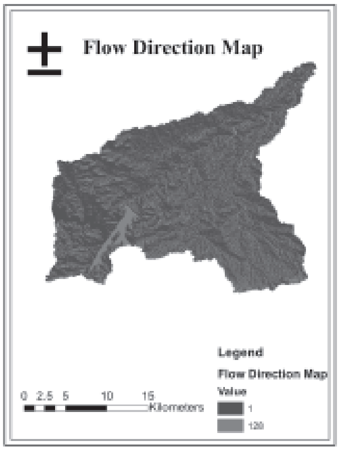

Plate 6. Flow direction map of the Study Area

by the use of pair-wise comparison matrix in the AHP technique and later these weights were utilized in the WOA method in ArcGIS to form the final suitability zones. The study area was divided into; 'Highly suitable', 'Moderately suitable', and 'not suitable for agriculture'. It was determined with the help of suitability map (Plate 9) that 27% (136.42 km^2) of the study area would be highly suitable for agricultural production, 64% (285.5 km^2) moderately suitable, 9% (47.16 km^2) not suitable land for agricultural production. The statistical distribution of Land Suitability classes of Mula River Basin Rahuri region area is shown in Table

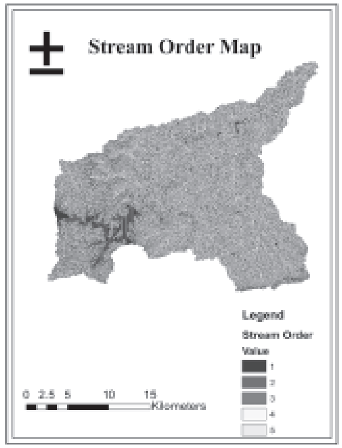

Plate 7. Stream order map of the Study Area

5 and the Agricultural land suitability map of Mula River Basin Rahuri taluka region area is shown in Plate 8.

Highly suitable: Only 27% land of reviewed area is classified into the class, 'highly suitable' for agriculture (Plate 10; Table 5). These lands have gentle to moderate slopes, deep loam soils, more water retention capacities, SM and normal pH range. This

Table 4. Assigned weights of the criterions and their classes for suitability

Criterions	Feature class	Intensity	Wt. (%)	Land suitability
Slope	0-5%	Very low	41	Very Good
	5-10%	Low		Good
	10-20%	Moderate		Moderately Good
	>20%	High		Poor
Aspect	359.493	High	20	Poor
	-1	Low		Good
Digital Elevation Model	688 m	High	14	Poor
	410 m	Low		Good
Hillshade	180	High	10	Poor
	0	Low		Good
	128	High		Poor
Flow Direction	1	Low	8	Good
	1	Very High		Very Poor
Stream order	2	High	7	Poor
	3	Moderate		Moderately good
	4	Low		Good
	5	Very low		Very good

conditions ideal for growing crops like wheat, sugarcane, cotton, jute, pulses and oilseeds. Vegetables also grown.

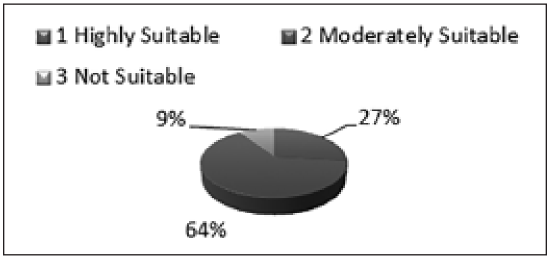

Plate 8. Pie-diagram of land suitability classification

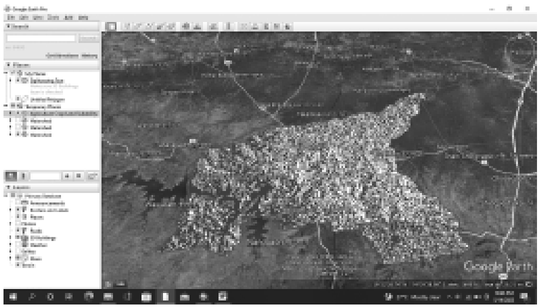

Plate 9. Mula River Basin superimposed on Google Earth

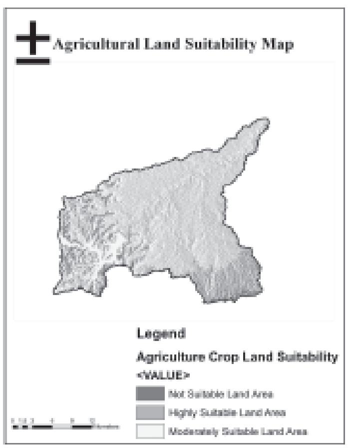

Plate 10. Land Suitability map of Mula River Basin Rahuri Region

Moderately suitable: About 64% of reviewed lands are classified into the class, 'moderately suitable' (Plate 10; Table 5). The characteristics of these lands are stiff slopes, loam soil with moderate depth, less water retention capacities, SM and erosion. It requires additional efforts for terracing, soil and water conservation, irrigation, etc. Maize, millets, sorghum, safflower, Bengal gram, barley can be grown under this conditions.

Not suitable: Not suitable lands for agriculture were estimated about 9% of reviewed area. These lands have precipitous slopes with rocky lands, barren lands, thin and dry soils, etc. (Plate 10; Table 5). Citrus fruit trees are grown under this conditions.

Conclusion

The point of this study was primarily focused on the identification of the suitable land for agriculture crop in the Mula River Basin Rahuri Region which is mostly covered by vegetation cover. Analytic hierarchy process with a combination of Geographic information system (GIS) is utilized for the evaluation in which three distinct parameters were chosen. The Analytic hierarchy process with integration of GIS was established very useful for the identification of the suitable site for agriculture. At the end of the evaluation, it was computed that 136.42 km^2 (27%) of the study area is highly suitable, 285.50 km^2 (64%) is moderately suitable and 47.15 km^2 (9%) of the study area is not suitable for agriculture. However, the problems of the low production caused by geomorphological characteristics, such as very high elevation, a high degree of slope, the presence of bare rocks, and low availability of the irrigation system. All these threats resulted in a very less amount of land in the study area being identified highly suitable for agricultural production.

What is generally noticeable is that the Northern, Western and North – Western lands of the basin seem to have larger percentage area for 'highly suitable' and 'Moderately suitable' land for agriculture. Wheat, sugarcane, cotton, jute, pulses and oilseeds grown under highly suitable land conditions. Vegetables also grown. Maize, millets, sorghum, safflower, Bengal gram, barley can be grown under moderately suitable land conditions. Due to irrigation facility, farmers are growing vegetables like tomato, gourds and fruits crops like pomegranate, mango and sugarcane.

On the other hand, the Eastern, South-Eastern and Central highlands of the basin seem to have higher coverage of 'moderately suitable and 'unsuitable' lands for agriculture. Looking at some of the main factors weighing into the AHP analysis such as slope, aspect and hillshade etc., it is easy to see that the Eastern, North-Eastern and central highlands are dominated by steep slope ranges (Plate 2). This part of the basin is also located on a relatively higher elevation range. The combinations of steep slopes and higher elevation may imply a high susceptibility for land degradation and soil erosion, in the catchments in this part of the basin resulting in higher percentage of stony upper soil. It is advised that land and water managers and policy makers in the basin prioritize such areas during land and/or soil restoration efforts.

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