A Spatial Analysis of Crop-land Suitability for Sustainable Agricultural Development in Aiyar Basin, Tamil Nadu

M. Gomathi¹, V. Pavithra¹, K. Balasubramani²* and K. Kumaraswamy¹

¹Department of Geography, Bharathidasan University, Tiruchirappalli – 620 024, Tamil Nadu, India.
²Department of Geography, Central University of Tamil Nadu, Thiruvarur - 610 005, Tamil Nadu, India.

Authors’ contributions

This work was carried out in collaboration between all authors. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/JGEESI/2018/46109
Editors:
(1) Dr. Kaveh Ostad-Ali-Askari, Department of Civil Engineering, Isfahan (Khorasgan) Branch, Islamic Azad University, Iran.

Reviewers:
(1) Diony Alves Reis, Federal University of Western Bahia, Brazil.
(2) Julius R. Orimoloye, University of Ibadan, Nigeria.
Complete Peer review History: http://www.sdiarticle3.com/review-history/46109

Received 10 October 2018
Accepted 19 December 2018
Published 11 January 2019

ABSTRACT

Land suitability analysis for agriculture plays a key role in sustainable agricultural production. The aim of this study is to develop suitability maps for major agricultural crops using multi-criteria spatial analysis for Aiyar basin - a sub-basin of Cauvery basin in Central Tamil Nadu as a case study. The main criteria such as soil, topography, irrigation and socio-economic factors and 18 sub-criteria (soil depth, drainage, texture, pH, salinity, sodicity, CEC, organic carbon, base saturation, slope, erosion, geomorphology, canal, groundwater, irrigation intensity, agricultural labour availability, cultivators and agricultural credit banks) were used for the suitability analysis. All the criteria used for the suitability classification were not equally important; each criterion would contribute towards the crop growth and yield at different levels. Hence, the relative importance of these criteria was formulated on the basis of the guidelines of the National Bureau of Soil Survey and Land Use Planning (NBSS & LUP) as adapted to local conditions. The Geographic Information System (GIS) based Analytical Hierarchy Process (AHP) method was used to determine the weight and rating for each criterion. Then the criterion layers were classified into four suitability classes which were high

*Corresponding author: E-mail: geobalas@gmail.com, geobalas@cutn.ac.in;
Keywords: GIS; Crop suitability; agricultural planning; sustainable development.

1. INTRODUCTION

Due to rapid growth in population, one-way it causes increased demand for the production of agricultural crops and another side it degrades the availability of land for agriculture. The challenge of more production with available land necessitates high priority towards the selection of crops which best suits a given land area. Any selection of crops for an area can be done through systematic suitability analysis [1]. The suitability is a function of crop requirements and land characteristics and it is a measure of how well the qualities of land unit match the requirements of a particular form of land use [2]. In order to define the suitability of an area for a specific practice, several criteria need to be evaluated [3]. Multi-Criteria Evaluation (MCE) approaches coupled with Geographical Information System (GIS) are useful in evaluating various production variables according to their relative importance on the optimal growth conditions for crops [4,5]. In general, MCE has been developed to improve spatial decision making when a set of alternatives need to be evaluated on the basis of conflicting and incommensurate criteria [6]. Many GIS-based land suitability analysis approaches normally use a boolean overlay for land suitability analysis. However, this approach lacks a well-defined mechanism for incorporating the decision-maker’s preferences into the GIS procedures [7]. The Analytical Hierarchy Process (AHP) gained high popularity because of easiness in obtaining the weights and capacity to integrate heterogeneous data, and therefore AHP is applied in a wide variety of decision support systems [8]. This also applies to land suitability studies which normally require a multi-criteria approach [9]. Hence, in the present study, MCE approach using AHP incorporated with GIS was applied to assess the land suitability of the study area for selected crops such as paddy (*Oryza sativa* L.), pulses (*Vigna mungo* L., *Vigna radiata* L. and *Macrotiloma uniflorum*) maize (*Zea mays* L.) and cashew (*Anacardium occidentale*). These crops are considered for the present study, because: paddy is an important wet crop cultivated in almost all the villages of the study area; different varieties of pulses are dominant second ranking crop in plain regions of the basin; maize is an important dry crop of the basin; cashew is a preferred crop nowadays and need to be tested its suitability throughout the basin [10].

2. STUDY AREA

Aiyar basin is a part of Cauvery river basin and it covers part of Tiruchirappalli, Namakkal and Salem districts of Tamil Nadu (Fig.1). It extends between 10° 53’ N to 11° 25’ N latitude and 78° 19’ to 78° 41’E longitudes. The river Aiyar rises between the Pachamalai hills and Kollimalai hills and joins the river Cauvery near Upper Anicut. The total area of the basin is about 1,360 sq.km and composed of 130 revenue villages. Besides the main river Aiyar, ponds, canals and small streams play a key role in promoting agricultural activities in the study area. The maximum elevation of 1,390 metre above MSL (mean sea level) is found in the north-western part of the basin and the minimum elevation of 80 metre above MSL is found in the south-eastern part. The contour line of 260 metre above MSL forms the boundary between the plains and the hills. The geomorphology of the study area comprises of pediplains, floodplains, structural hills, residual hills, valley fills, pediments and plateau with undulating plains. The soil in this region comprises of sandy loam, loam, clay loam, sandy clay loam, clay, sandy clay and loamy sand. The average temperature in the study area varies from 24°C to 41°C with an average annual rainfall of about 600-1,100 mm. The employment and revenue of this area depend mainly on agriculture and allied activities. Though, in general, the proportion of the net sown area to the geographical area is over 42 percent, there is appreciable variation in cropping pattern of the basin [10].

3. MATERIALS AND METHODS

Based on a literature review and discussions with domain experts, four main criteria were identified
namely soil, topography, irrigation and socio-economic conditions for this suitability analysis. Each of the main criteria was divided into several sub-criteria on the basis of crop and farmer’s requirements. The soil criterion was further divided into 9 sub-criteria i.e. texture, depth, drainage, pH, cation exchange capacity (CEC), salinity (EC), sodicity (ESP), base saturation and organic carbon (OC). The topography criterion was divided into slope, geomorphology and erosion. The irrigation criterion was classified into 3 sub-criteria i.e. canal, groundwater and irrigation intensity. The socio-economic conditions were divided into agri-labours, agri-cultivators and agri-credit banks. The soil data obtained from Tamil Nadu Agricultural University (TNAU) was used for preparing soil criteria. The Digital Elevation Model (DEM) derived from CARTOSAT Stereo Pairs was used to derive slope and soil erosion information. Geomorphology of the basin was traced from Bhuvan Geoportal. The irrigation and socio-economic data obtained from District Statistics and Census Handbook (2011) were used for remaining criteria. All the data processed in ArcGIS and thematic maps were generated (Figs. 2, 3 and 4).
Fig. 2. Thematic layers of soil texture, depth, drainage, pH, salinity and sodicity

Fig. 3. Thematic layers of cation exchange capacity, base saturation, organic carbon, slope, geomorphology and erosion
Based on the National Bureau of Soil Survey and Land Use Planning (NBSS & LUP) guidelines [11], the suitability level for each criterion was ranked as highly suitable (S1), moderately suitable (S2), marginally suitable (S3) and not suitable (N). The overall methodology followed in the study is illustrated in Fig. 5.

3.1 Analytical Hierarchy Process (AHP)

The relative importance of main and sub-criteria need to be evaluated independently to determine the suitability level [12]. The AHP approach is the easiest way to determine the weights of the criteria based on the Saaty scale of number 9 to 1/9 [5]. A rating of 9 indicates that in relation to the column factor, the row factor is extremely important; whereas the rating of 1/9 indicates that relative to column factor, row factor is extremely less important [7]. If the row factor and column factor is an equally important rating of 1 was given. Pairwise comparison matrix (PCM) was developed for main and sub-criteria using Saaty scale and eigen values were computed using a geometric mean method and normalized as percentage weights. Table 1 shows a pairwise comparison matrix for paddy crop. The same approach was followed for all other crops and weights were derived.

3.2 Standardization of Criteria

In suitability analysis, each evaluation criterion will be ordered in a range of values as S1, S2, S3, N indicating the degree of suitability with respect to a criterion, based on the crop requirements [11,13,14]. These classes have to be rated based on, how important is the class S1 with respect to a particular sub-criterion to accomplish the goal [5]. The rating of these classes can be done on 0 to 1 scale or 0 – 10 or 0 – 100. In this study, the 0-1 scale was used to obtain the rating. To avoid biased weight allocation and rating, the Consistency Ratio (CR) was used. The acceptable CR value should be less than 0.1 or 10 percent [13].

\[ CI = (\lambda_{max} - n)/(n - 1) \]  
\[ CR = CI / RI \]
Where, $\lambda_{\text{max}}$ is the maximum eigen value; CI is Consistency Index; CR is Consistency Ratio; n is the number of criteria or sub-criteria in each pairwise comparison matrix; RI is random coincidence index = $1.98 \times (n-2)/n$.

**Table 1.** Weighed criteria for paddy

<table>
<thead>
<tr>
<th>Soil</th>
<th>Topography</th>
<th>Socio-Economic</th>
<th>Irrigation</th>
<th>Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soil</td>
<td>1.000</td>
<td>2.000</td>
<td>7.000</td>
<td>2.000</td>
</tr>
<tr>
<td>Topography</td>
<td>0.500</td>
<td>1.000</td>
<td>6.000</td>
<td>2.000</td>
</tr>
<tr>
<td>Socio-Economic</td>
<td>0.143</td>
<td>0.167</td>
<td>1.000</td>
<td>0.167</td>
</tr>
<tr>
<td>Irrigation</td>
<td>0.500</td>
<td>0.500</td>
<td>1.000</td>
<td>0.212</td>
</tr>
</tbody>
</table>

**CR=0.03**

**Table 2.** Rating of suitability classes for slope class (Ideal AHP)

<table>
<thead>
<tr>
<th>Slope</th>
<th>S1</th>
<th>S2</th>
<th>S3</th>
<th>N1</th>
<th>Rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1</td>
<td>1.000</td>
<td>3.000</td>
<td>5.000</td>
<td>8.000</td>
<td>1.000</td>
</tr>
<tr>
<td>S2</td>
<td>0.333</td>
<td>1.000</td>
<td>3.000</td>
<td>6.000</td>
<td>0.469</td>
</tr>
<tr>
<td>S3</td>
<td>0.200</td>
<td>0.333</td>
<td>1.000</td>
<td>4.000</td>
<td>0.217</td>
</tr>
<tr>
<td>N1</td>
<td>0.125</td>
<td>0.167</td>
<td>0.250</td>
<td>1.000</td>
<td>0.082</td>
</tr>
</tbody>
</table>

**CR=0.05**
In this study, CR was calculated for all the selected crops and all were within the acceptable level. Once the weight and rating for all the criteria were obtained for each crop, then they were integrated to attribute table of respect criterion layer (Table 2 represents the example case of slope parameter). After that, spatial overlay operation was performed using ArcGIS to generate crop suitability map for paddy, pulses, maize and cashew crops.

4. RESULTS AND DISCUSSION

Although the study area has a wide variety of crops, the crops such as paddy, pulses and maize are found to be first or second ranking crops in many villages. Paddy is an important wet crop cultivated throughout the basin wherever the topography and irrigation facilities are conducive to it. The high-concentration of pulses over plain regions of the basin leads to an important second ranking crop in many villages. Maize is an important dry crop of the study area mainly found in the northeastern parts of the basin [10]. The concentration of cashew is comparatively less; however, climate and soil conditions of the study area are suitable for the cultivation of cashew. Hence these four crops were evaluated for the present study. The results of the suitability analysis of these four crops are represented in Table 3.

4.1 Paddy

Suitability analysis of paddy indicates that about 19 percent of the study area is highly suitable (S1) and 44 percent is moderately suitable (S2) for its cultivation. The parameters such as pH, ESP, slope and organic carbon were the major limiting factors for the cultivation of paddy, which brings about 25 percent of study area into not suitable (N) category (Fig. 6). By adopting appropriate management techniques about 56 percent of the study area (S2 and S3) could be utilised for paddy cultivation.

4.2 Pulses

The result of suitability analysis of pulses revealed that almost entire lowland region of the study area is suitable for pulses cultivation (Fig. 7). About 62 percent of the study area is highly (S1) to moderately suitable (S2) for pulses. The major constraints which may be precluded pulses suitability are high pH, low organic carbon content and high ESP. These constraints can be ameliorated by adopting specific management practices.

4.3 Maize

Suitability analysis for maize shows that about 20 percent of the basin is highly suitable (S1) and about 41 percent of the basin is moderately suitable (S2) for maize cultivation (Fig. 8). The central western part of the study area is not suitable for paddy cultivation but moderately to marginally suitable for maize cultivation. The higher degree of slope (> 8) is the major limiting factor for maize cultivation in upland regions of the basin. Hence, about 18 percent of the study area falls under not suitable (N) class for maize cultivation.

4.4 Cashew

About 2/3 of the study area is high (S1) to moderately suitable (S2) for cashew cultivation. It has a well-developed root system and can tolerate drought conditions, but very sensitive to waterlogging. So, soil with well drainage conditions is suitable for its cultivation. About 18 percent of the study area is found under a not suitable (N) category. Most of the northern upland regions are moderately suitable for cashew cultivation. However, compared to the suitability of other crops, cashew would thrive well in the southwestern part of the basin.

Table 3. Suitability classes and areal distribution of selected crops

<table>
<thead>
<tr>
<th></th>
<th>Paddy</th>
<th>Pulses</th>
<th>Maize</th>
<th>Cashew</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>ha</td>
<td>%</td>
<td>ha</td>
<td>%</td>
</tr>
<tr>
<td>S1</td>
<td>25750.9</td>
<td>18.93</td>
<td>30398.9</td>
<td>22.34</td>
</tr>
<tr>
<td>S2</td>
<td>59270.8</td>
<td>43.58</td>
<td>54745.3</td>
<td>40.24</td>
</tr>
<tr>
<td>S3</td>
<td>17286.4</td>
<td>12.70</td>
<td>25801.4</td>
<td>18.86</td>
</tr>
<tr>
<td>N</td>
<td>33714.1</td>
<td>24.79</td>
<td>25278.3</td>
<td>18.58</td>
</tr>
</tbody>
</table>
Fig. 6. Land suitability for paddy
Fig. 7. Land suitability for pulses
Fig. 8. Land suitability for maize
5. CONCLUSION

The AHP based method provides a reliable foundation for determining the weights and ratings of various parameters that influence the suitability of land for different crops. The comparison between present land use pattern [10] and suitability analysis indicate that about...
one-third of the study area needs a change in the present cropping pattern. The results of this study could provide an assistance and awareness to the local farmers and decision makers for selecting the crops that best suit the land characteristics. By choosing the most suitable crops, farmers can increase their productivity to a considerable extent which will promote the sustainable agricultural development of the basin. This study can be enhanced by incorporating more variables and analyzing other crops that are cultivated in the study area.

ACKNOWLEDGEMENTS

The first and last author acknowledges UGC-BSR, New Delhi for providing financial assistance to carry out this research.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES


