CROP-LAND SUITABILITY ANALYSIS USING A MULTICRITERIA EVALUATION & GIS APPROACH

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Abstract

Crop-land suitability analysis is a prerequisite to achieve optimum utilization of the available land resources for sustainable agricultural production. One of the most important and urgent problems in Bangladesh is to improve agricultural land management and cropping patterns to increase the agricultural production with efficient use of land resources. In Bangladesh, agriculture is the mainstay of national economy and rice is the major food but the production is very low. In particular the rice production of Bangladesh does not meet the demands due to its rapidly growing population. The aim of this study is to determine physical land suitability for rice crop using a Multi-Criteria Evaluation (MCE) & GIS approach and to compare present land use vs. potential land use. The aim in integrating Multi-Criteria Evaluation with Geographical Information Systems (GIS) is to provide more flexible and more accurate decisions to the decision makers in order to evaluate the effective factors. The study was carried out in Haripur Upazila, Thakurgaon district of north-west part in Bangladesh. Relevant biophysical variables of soil and topography were considered for suitability analysis. All data were stored in Arc GIS 9.0 environment and the factor maps were generated. For Multi-Criteria Evaluation (MCE), Pairwise Comparison Matrix known as Analytical Hierarchy Process (AHP) was applied and the suitable areas for rice crop were identified. To generate present land use/cover map, Terra/ASTER 22 March 2003 satellite image was classified using ERDAS Imagine 8.7 by means of supervised classification. According to the present land use/cover map, the rice cultivated area was 6727.88 ha. Finally, we overlaid the land use/cover map with the suitability map for rice production to identify differences and similarities between the present and potential land use. However, the crop-land evaluation results of the present study identified that in the study area, 37 percent of total rice crop currently being used was under highly suitable areas and 25 percent was under moderately suitable areas. A substantial portion (35 percent) was under marginally suitable areas. The results showed that agricultural practiced, which prevailed in the study area didn't match with the potential suitability in the marginally suitable area. Thus, the average yield of the study area was substantially affected because of a significant proportion of rice crop was under marginally suitable areas. This research provided information at local level that could be used by farmers to select cropping patterns and suitability.

Key words: Land suitability, Land use/cover, Multi-Criteria Evaluation (MCE), Terra/ASTER, GIS, Rice.

1. Introduction

Agricultural resources are considered to be one of the most important renewable and dynamic natural resources. Comprehensive, reliable and timely information on agricultural resources is very much necessary for a country like Bangladesh, where agriculture is the mainstay of our national economy. But it is being pressurized by high population growth and natural hazards like flood, drought, and cyclone and soil erosion. As a result, the productivity of the land is declining and the country can not produce as much food as needed for the increasing population. In particular the rice production of Bangladesh does not meet the food demands of rapidly growing population, where rice is the major food (World Food Programme and Ministry of Disaster Management & Relief, 2005).

In Bangladesh, as in many developing countries, current land use is not suitable, therefore, there is an urgent need to use land in the most rational and possible way. In this sense, GIS and RS technology offers a dynamic tool for multidimensional process of land use. Remote sensing (RS) provides landscape information synoptically, repetitively and objectively. It is an important source of spatial information such as land use/land cover, drainage and topography. GIS is a powerful tool for geo-environmental analysis and appraisal of natural resources. It allows the user to integrate data bases generated from various sources including RS on a single platform and analyze them efficiently in a spatio-temporal domain.

The suitable areas for agricultural use are determined by an evaluation of the climate, soil, and topographical environmental components and the understanding of local biophysical restraints. In this kind of situation, many variables are involved and each one should be weighted according to their relative importance on the optimal growth conditions for crops through Multi-Criteria Evaluation (MCE) and GIS.

One of the most useful features of GIS is the ability to overlay different layers or maps. However, the overlay procedure does not enable one to take into account that the underlying variables are not equally important (Janssen and Rietveld, 1990). One approach that can help overcome such limitations is MCE (Carver, 1991), which has received renewed attention within the context of GIS-based decision-making (Pereira and Duckstein, 1993). The objective of using MCE models is to find solutions to decision-making problems characterized by multiple alternatives, which can be evaluated by means of decision criteria (Jankowski et al., 2001). In this study, we applied Analytical Hierarchy Process (AHP) in integrating MCE with GIS. The aim of this research was to delineate the suitable areas for rice (Oryza sativa) crop using the relevant variables of soil and topographic database through the MCE technique within a GIS context to improve rice production and examined the distribution of rice crop derived from Terra/ASTER image in relation with its suitability level in Haripur Upazila, Bangladesh.

2. Materials and Methods

2.1 Study area

The study was carried out in the Haripur Upazila (sub district) of Thakurgaon district, north-west part in Bangladesh (Figure 1). It is geographically located between $25^0 45'$ to $26^0 01'$ N latitude and $88^0 04'$ to $88^0 14'$ E longitude. It is bordered to the north and east by Ranishankail Upazila and to the south and

west by India. The surface area covers approximately 20,175 hectares. The entire study area belongs to the Himalayan Piedmont alluvial plain physiographic unit, which is part of an extensive plain formed earlier by the river Teesta below the point where it breaks out of the Himalayas. The topography is almost flat with 1-5% slope. The study area has a tropical monsoon climate. The mean annual rainfall ranges between 1200 to 1800 mm which is concentrated in the months of June–September. The mean annual temperature is about 24.8^0C.

In Haripur Ipazila 14 soil groups and 10 soil mapping units have been recognized by the Soil Resources Development Institute (SRDI), Bangladesh. A soil group includes a number of similar soil series, usually 1-4, and the soil group is named after the dominant soil series. The soil properties are mostly strongly to slightly acidic with P^H ranging from 4.5 to 6.5 with poor to imperfect drainage. The hydrology conditions are quite suitable for agricultural practice. The supplementary surface water sources for agricultural use in Haripur Upazila are rivers, canals, beels (temporary water logging area) and ponds. However, there is a significant potential for increased irrigation from surface and ground water resources. The inundation depth affects the type of crops and cropping system. Maximum depth of inundation ranges from 30 to 180 cm. Rainfed and irrigated agricultural activities are practiced in the study area. Most of the study area is used as irrigated rice and wheat crops. Rice is the major crop, the other crops are potato, sugarcane, vegetables and pulses. The population of Haripur upazila is about 110,658 (Statistical year book, 1984) and mostly subsists on locally grown crops.

Figure 1

2.2 Soil and topography database

Soil information was obtained from SRDI, and Bangladesh Agricultural Research Council (BARC), Ministry of Agriculture, Bangladesh. The soil base map on 1:50,000 scale provided by the SRDI was scanned and digitized using ERDAS Imagine version 8.7 software to generate a raster layer and was corrected digitization error. Then the digitized raster layer was converted to a vector layer. The digitized polygons of soil mapping units consisted of 10 soil mapping units linked to an attribute table of quantitative soil properties. We also used qualitative soil data in absence of quantitative data. Six soil parameters, i.e., soil texture, soil moisture, soil consistency, soil pH, soil drainage and soil organic matter were added to the polygon attribute table using Arc GIS 9 software and thematic maps were developed for each of the parameters. Figure 2 shows the soil mapping units. The UTM coordinate system was used to locate geographic elements on the maps. Slope and land type information were obtained from Digital Elevation Model (DEM) using GIS software package Arc GIS 9. The source of DEM was SRTM (Shuttle Radar Topographic Mission) which was 90m spatial resolution.

Figure 2

The overall flow chart of the methodology that we followed in this research is illustrated in Figure 3.

Figure 3

2.3 Image processing

For this research, in order to generate the present land use/land cover information, the visible/near infrared

(VNIR) data of Terra/ASTER level 1B (Path-Row 139:119) acquired on 22 March 2003 which has a spatial resolution of 15 m pixel size, was processed using ERDAS Imagine version 8.7 software. Survey of Bangladesh topographical sheets on 1:50,000 scale were used for rectification of satellite data, selection of ground control points, locating training samples as well as to identify and authenticate the various features on the satellite image. The image was georeferenced to UTM, zone no. 45 N of WGS 1984. First unsupervised classification was done using spatial statistics (e.g. the ISODATA algorithm) to classify the image into a predetermined number of classes. Later, a supervised classification was done using the maximum likelihood algorithm for 3 spectral bands corresponding to green, red and near infrared (G, R, NIR). Next, necessary editing was done by ground truth data. The accuracy of the land use/cover classification was evaluated by obtaining a classification error matrix. In order to asses the accuracy of the classified images, a random reference samples of 250 points of verification were selected. The land use/cover classes of the surrounding area of these points were checked by visual interpretation using field verification data. The land use /cover classes were considered according to the dominant crops in winter (Rabi) season because the satellite image used in this study for land use/cover mapping was acquired on Rabi season. The land use/cover classes were i) rice, ii) wheat, iii) mixed crop, iv) fallow land, v) grass land, vi) water bodies and vii) settlement. Figure 4 shows the typical landscapes.

Figure 4

2.4 Assigning weight of factors and Multi Criteria Evaluation (MCE)

The purpose of weighting is to express the importance or preference of each factor relative to other factor effects on crop yield and growth rate. Factors established in this phase are not unique, but they are the most relevant. Expert opinion of crop specialization was very important in this phase. Local agronomists and researchers of BARC have identified the following variables as relevant to suitable rice growing areas: soil texture, soil moisture, soil consistency, soil pH, soil drainage, soil organic matter, slope and inundation land type as well as a relevant set of criterion.

Suitability levels for each of the factors were defined; these levels were used as a base to construct the criteria maps (one for each factor). The suitability levels were: Highly suitable-S1, Moderately suitable-S2, Marginally suitable-S3, Not suitable-N based on the structure of FAO land suitability classification. According to the FAO guide line for irrigated rice and local expert's opinion, a specific suitability level per factor for rice crop (irrigated) was defined (Table 1).

Table 1

The general procedure of MCE included several phases. First, the relevant criteria (factors and constraints; Eastman et al., 1995) were established. Using the above mentioned factors/variables as criteria, a pairwise comparison matrix was constructed. Although a variety of techniques exist for the development of weight, one of the most promising technique is the Pairwise Comparison Matrix (PWCM) developed by Saaty T. (1980) in the context of a decision making process known as the Analytical Hierarchy Process (AHP) (Eastman et al., 1995). The comparison concerns the relative importance of the two criteria involved in determining the suitability of the stated objective (Eastman et al., 1995). Ratings were provided on a nine-point continuous scale, which ranges from 1 to 9. This method has been tested theoretically and empirically for a variety of decision making situations, including spatial decision making and has been incorporated into a GIS based decision making procedure (Malczewski, 1999). In the procedure for MCE using weighted linear combination, it is necessary that the weights sum to 1. The MCE method used (weighted linear combination) requires that all factors must be standardized (Eastman, 1999) or transformed into units that can subsequently be compared (Malczewski, 1999).

In this study, the factor maps were ranked according to Saaty's underlying scale with values 1 to 9 by discussion with local crop specialist. Table 2 shows the ranking of the different classes to the different factors/parameters. Classes with higher scores are most suitable or preferred.

Table 2

Using Pairwise Comparison Matrix, factor weights were calculated and 4 composite layers were constructed (Table 3). The resolution of all the factor maps were not same, therefore, we converted all the layers with the same output raster cell size as 10 m in order to make an effective weighted overlay.

Table 3

Once the composite layers and their weights were obtained, the MCE procedure within Arc GIS 9 was applied to produce the map of suitable areas. Finally, the suitability map for rice crop (Figure 6) was identified by weighted overlay using spatial analyst tools in ArcGIS 9.

2.5 Overlay present land use/cover and the suitability map

The present land use/land cover map and the suitability map for rice crop were overlaid to identify differences as well as similarities between the present land use and the potential land use. For rice crop, a cross table between the map of suitable areas and the land use/land cover map was obtained. In this way, we obtained useful information concerning the spatial distribution of different suitability levels, according to Terra/ASTER information. This phase allowed us to fine-tune our results, because the resultant layer provided the information about how the rice crop was distributed across the various land suitability zones.

3. Results and Discussions

3.1 Image processing result

The land use/cover map derived from the Terra/ASTER satellite image that was obtained from the supervised classification is shown in Figure 5. This map shows 7 land use/cover types, which were produced from the combination of the multi spectral bands corresponding to green, red and near infrared (G, R, NIR) which were found to be appropriate to identify the land use/cover types in the study area. Image processing, by means of the supervised classification approach and the maximum likelihood algorithm, ensured that an acceptable percentage of the classified pixels were correctly classified. The overall accuracy was 86%. According to the current land use/cover map, the rice cultivated area was 6727.88 ha.

Figure 5

3.2 MCE process and overlaying land use/cover and suitability map for rice crop

The land suitability analysis was carried out in two steps. The first step comprised of delineating the total arable land into different suitability classes using AHP through MCE, explained as above. In the second step, the land use/cover map derived from the satellite data was overlaid and the extent of each suitability level per land use/cover class was calculated.

The PWCM was constructed with the 8 important factors mentioned previously and the relative importance of each one was measured through the calculation of weights. The computed weight of different parameters/factors with composite layers is shown in Table 3. Once the factor maps and the weight of composite layers were obtained, then the physical suitability map at four suitability classes (S1, S2, S3, N) was evaluated for the rice crop by weighted overlay (Figure 6). According to Figure 6 the number of hectares available to each suitability class is as follows: highly suitable (S1) 8544.42 ha, moderately suitable (S2) 4731.41, marginally suitable (S3) 5098.01 ha and not suitable (N) 847.31 ha which represent 43%, 24%, 25% and 4% of land area respectively.

Figure 6

The results showed that highly suitable areas (S1) were found mostly in the soil mapping unit 3, 5 and 9 (Figure 1 & Figure 6). These S1 areas were characterized by: inundation land type high land which is above normal flood level, soil P^H level between 5.5 to 6.5, soil drainage poorly to imperfectly drained, soil moisture high, slope level (<1%) and texture class clay; these values are in agreement with those considered in the literature. Generally not suitable areas (N) were located along the river bank. Furthermore, levels of relevant factors in not suitable areas were: sandy soil, medium low land which is flooded up to about 90-180 cm depth for a few months during the rainy season with slope 5%. Part of this land is cultivated with mustard and wheat in Rabi season but most of the land is under fallow or grass land during the year.

To improve the results, the land use/cover map (Figure 5) and the suitability map for rice (Figure 6) were overlaid to identify differences and similarities between the present land use and the potential land use for the rice crop. This was done because of the identification and accurate description of current and potential production areas are essential for research and agricultural development (Corbett, 1996). The land suitability map, spatial distribution of rice crop and their overlay are presented in Figure 6, 7 and 8 respectively.

Figure 7 and 8

According to the present land use/cover map (Figure 5), the area cultivated with rice was 6727.88 ha. The extent of each suitability level per land use/cover class is shown in Table 4. The analysis revealed that in the study area, 37% (2478.80 ha) of total rice crop was in highly suitable areas, 25% (1699.75 ha) was in moderately suitable areas. A substantial portion 35% (2380.80 ha) was under marginally suitable areas and 3% (181.68 ha) was under not suitable areas. Thus, the average yield of the study area was substantially affected because a significant proportion of rice crop was in marginally suitable areas. Therefore, economic levels of agricultural production can be achieved by (a) cultivating rice crop in highly (S1) and moderately (S2) suitable areas, (b) diversification of marginally (S3) suitable areas to crops other than rice that are more suitable in the pedo-climatic requirements.

The results of this investigation were adequate in terms of the evaluation criteria set used here because, in a particular project, only a limited number of land qualities need be selected for use in evaluation (FAO, 1993). In this investigation, the evaluation criteria were selected taking into considering the crop requirements regarding local conditions. In this MCE, the factors were selected based on agronomic knowledge of local experts and reviews of existing literature. Such an approach produced valuable information on the relative importance of the factors under evaluation and could be a useful precedent for future studies of rice and other crops. Furthermore, one of the main premises of the RS and GIS-based land suitability analysis is that the method can help minimize and even solve conflicts among competing interests regarding land use by providing better data and information to resolve the problems. This investigation also provides general alternatives for local farmers in the area of agricultural land management of a particular crop.

Table 4

4. Conclusions and recommendations

In this study, we applied remote sensing (RS) and GIS techniques to identify suitable areas for rice crop .The results obtained from this study indicate that the integration of RS-GIS and application of Multi-Criteria Evaluation using AHP could provide a superior database and guide map for decision makers considering crop substitution in order to achieve better agricultural production. This approach has been used in some studies in other countries. However, in Bangladesh this approach is a new and original application in agriculture, because it has not been used to identify suitable areas for rice crop. The study clearly brought out the spatial distribution of rice crop derived from Remote Sensing data in conjunction with evaluation of biophysical variables of soil and topographic information in GIS context is helpful in crop management options for intensification or diversification.

This investigation is a biophysical evaluation that provides information at a local level that could be used by farmers to select their cropping pattern. Additionally, the results of this study could be useful for other investigators who could use these results for diverse studies. This study has been done considering current land use/cover, topography and soil properties that affected the suitability classification of land use types. Therefore, it gives primary results. For further study, we propose to select more number of factors like soil, climate, irrigation facilities and socio-economic factors which influence the sustainable use of the land.

Acknowledgements

The authors wish to thank Md. Kamrul Habib, Principal Scientific Officer and Dilara Hassan, Scientific Officer, Soil Resources Development Institute (SRDI), Ministry of Agriculture, Bangladesh for providing soil data and adequate information about the study area as well as their comments during the research. We also thank Dr. Nur Ahmed Khondaker, Consultant, FAO (former principal scientific officer, Bangladesh Agricultural Research Council) for offering valuable suggestions and advice.

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