Application of Remote Sensing and Geographic Information System (GIS) Techniques for Monitoring of Boro Rice Area Expansion in Bangladesh

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Abstract

Information on existing food growing area and crop yield and how they are changed over the period of time are prerequisite for proper food security planning and management. In Bangladesh, Boro rice (winter rice) plays a vital role in maintaining the food security of the country. In the present study, multitemporal NOAA-AVHRR 1.1 km resolution digital satellite data have been used to study the extension of Boro rice area in Bangladesh during 1989 to 1999. Study on the amplitude and pattern of the NOAA-AVHRR derived Normalized Difference Vegetation Index (NDVI) in relation to phenology and growth of the crop shows that both amplitude and the pattern of the NDVI are sensitive to the crop condition and type. Pixel based analysis has been performed using a digital linear area transformation technique. Arc/Info GIS has been used to obtain crop area statistics. The study has been supplemented by data on historical crop yield, rainfall, ground water level and irrigation. Spatio-temporal analysis of time series NOAA-AVHRR data shows significant increase in Boro rice areas over the country during the study period. Due to more profit and less hazard in winter season, farmers are cultivating more of this rice by replacing the traditional crop varieties. Such an extension of Boro rice area eventually associates a significant increase of utilization of ground water in addition to other sources for irrigation. It has been found in literature that such an exhaustive use of ground water has resulted in a gradual decline of ground water level in some places over the study area.

Key words: Boro rice, Crop acreage, Irrigation, Ground water, Satellite, NOAA-AVHRR, NDVI.

1. Introduction

Bangladesh is an agriculture-based country. About 80 percent of the total population are directly related to agricultural activities and mostly depend on earning from agriculture. This sector directly contributes around 35 percent of the gross domestic product (GDP). Rice, wheat, sugarcane, jute, oilseeds, pulses and potatoes are the principal crops. Bangladesh is a disaster-prone country, affected almost every year by some natural hazards like cyclone, flood, drought etc. which hampers the agricultural productivity of the country. Therefore it is essential to develop an effective food security system, which requires the development of an efficient crop information system (CIS) over the country. For this purpose it needs to monitor crop condition, crop growth, crop acreage estimation as well as crop yield for short and long term basis.

Satellite remote sensing along with its repetitive and synoptic viewing facilities offers an effective means for monitoring crop condition at large scale on a repetitive basis. The high spatial resolution satellite sensors like the thematic mapper (TM) on board the satellite Landsat or the high resolution visible (HRV) on board the satellite SPOT provides data at an interval of 16 and 26 days. The relatively coarse spatial...
resolution sensors as that of AVHRR on board the satellite NOAA offers data on daily basis over large area. All these data offer valuable information on the condition of the Earth's surface-atmosphere system particularly regarding vegetation. Now a days, the use of remote sensing technology have been largely multiplied over the world (Tucker et al., 1986; Goel and Norman, 1990; Ruimy et al., 1994) and particularly the agriculture is one of the major sectors where such a technology has acquired considerable momentum. Various studies have been conducted for monitoring of the condition of vegetation and agricultural crops using remote sensing (Gallo et al., 1985; Rahman, 2001; Rahman et al., 1999; Sellers, 1985). The Advanced Very High Resolution Radiometer (AVHRR) on board NOAA satellite is perhaps one of the best existing facilities for environmental monitoring at the regional or global scale (Rahman, 1996).

In this paper, the author has used the remote sensing data and GIS techniques for identification and estimation of the extension of Boro rice area for the period of 1989 and 1999 in Bangladesh.

2. Study Area

The study area covers the whole Bangladesh and aerial extent is about 1,47,570 sq. km, and it is lying between latitudes 20.70° and 26.80° N and longitudes 88.01° and 92.75° E. The area is shown in Figure 1, and it is mostly flat except in the Chittagong hilly areas in the southeastern part. There is a greater extent in the Madhupur in the central part and Barind tract areas in the northwestern part of Bangladesh.

The annual rainfall varies from about 152 cm in the western part of the country and to about 508 cm in the northeastern part, which is generally very high in the world and most of the rainfall occurs during the rainy season (July to September). The climate of the country is tropical monsoon. Average temperature continues to rise uniformly from the month of February and reaches around 42.2°C at the absolute maximum in April. The minimum temperature is usually recorded in the month of December and January. The absolute minimum temperature is 4.4°C, where the average annual temperature is 25.7°C. The average annual humidity is 75 %, while the total annual rainfall is 2,098 mm.

3. Data and Software Used

NOAA- AVHRR digital satellite data acquired on April 5, 1989 and February 16, March 25, April, 5 & 8, 1999 were used. The used ancillary data were as follows- Survey of Bangladesh (SOB) Topographic maps (1:50,000 scale), historical crop acreage, rainfall, and irrigation data supplied by Bangladesh Bureau of Statistics (BBS).

Digital image processing (DIP) of the satellite data were carried out in ERDAS IMAGINE software. Vector layers have been prepared in Arc/Info software.

4. Methodology

The following methodology has been adopted for the present study. NOAA-AVHRR data have been collected by SPARRSO ground receiving station and the data were used for this study. Geometric correction and georeference have been performed before starting the further analysis.

Normalized Difference Vegetation Index (NDVI) was calculated using the calibrated data in channels 1 and 2. Field data collection with Global Positioning System (GPS) was performed. Collected field data have been incorporated in the derived NDVI image of the study area. An already ‘developed algorithm’ has been applied for correcting the pixel size effect on the rice cultivated NDVI image of the study area obtained in the earlier step of this methodology. Forest mask layer was generated from high resolution data of Landsat TM and the mask layer has been applied to the rice cultivated NDVI image for subtracting/excluding the forest area. Then the statistics has been generated for obtaining the Boro rice area of the country. The whole methodology has been given as a flow diagram in Figure 2.

4.1 Data Calibration and Formatting

NOAA data received here as generic binary format. Then it has been converted into ERDAS Imagine format (‘img’). Five channels data have been brought in a single scene.
through ‘layer stacking’.

4.2 Geometric Correction

NOAA-AVHRR scene has been geometrically corrected using georeferenced Landsat TM imagery and topographic maps of 1:50,000 scale. Image to image rectification approach has been adapted in ERDAS Imagine. The reference imagery used here for geometric correction has been corrected earlier by using ground control points (GCP) collected by Global Positioning System (GPS) and existing maps.

4.3 Vegetation Index Calculation

The NDVI is a spectral combination of responses in the visible and near-infrared region. The NDVI is calculated by the following equation:

\[ NDVI = \frac{\rho_2 - \rho_1}{\rho_2 + \rho_1} \]  

(1)

Here, \( \rho_2 \) and \( \rho_1 \) are the responses in the near infrared and visible bands respectively corresponding to channel 2 and channel 1 of NOAA-AVHRR.

4.4 Interpretation Key Based Classification of NDVI

After computing NDVI, the NDVI image has been classified into different classes based on the interpretation key developed by Choudhury, et al., 1999. Some extensively grown crops other than rice are excluded from the analysis to get the actual figure for rice area. The temporal characteristics of these crops such as maize, wheat, potato, sugarcane and soybean are analyzed through temporal signature analysis.

4.5 Ground Truth

The hardcopy classified NDVI image has been taken along with GPS and other necessary field equipments, and field survey has been conducted for field verification of the classified NDVI image. Homogenous class area and as well as heterogeneous area has been checked and noted down, and those have been brought into account at the time of improving the classification accuracy after coming back to the laboratory.

4.6 Pixel Size Correction

Area of one NOAA pixel is 121 hectares and within this area there may have several classes of image features. Therefore it is necessary to identify the area, which is actually under vegetation within a pixel. Chaudhary et. al., 1999 developed an equation to describe the functional relation between the ‘fractional area of the pixel’ and the ‘observed NDVI’, the equation has been given below:

\[ n = 2.7V - 0.27 \]  

(2)
Here, $n$ is the fractional area of the pixel covered by green vegetation, and $V$ is the resultant vegetation index is obtained by proportional mixing of the vegetation index of the green vegetated areas and bare soil.

### 4.7 Forest Mask Application

The forest area could not be identified properly from NOAA-AVHRR data, only the mangrove forest area has been identified slightly due to its lower canopy temperature with respect to its adjoining areas. Therefore, it was essential to supplement the forest area from other source. Accordingly, the forest area has been digitized from high resolution Landsat TM data of 1997, and a forest layer has been prepared. This layer has been applied on the classified NDVI image to mask out the forest areas. The combined image has been used to estimate the Boro rice area in Bangladesh.

### 4.8 Statistics Generation

Then the area of rice within the pixel has been calculated by using the following formula (Choudhury et al. 1999):

$$A_i = n_i \times P_a \quad \text{..........................(3)}$$

Here, ‘$A$’ is the area of rice within the pixel in hectare

‘$i$’ represent the individual pixel

‘$n$’ is the fractional area of the pixel covered by green vegetation derived from equation no. (2).

‘$P_a$’ is the area of the NOAA-AVHRR pixel in hectare i.e 121 hectares.

### 4.9 Boro Rice Area Estimation

Finally the total rice area has been calculated by using the following formula:

$$A_T = \sum A_i \quad \text{..........................(4)}$$

Here ‘$A_T$’ is the total rice area in Bangladesh

‘$A$’ is the area of rice within the pixel in hectare

‘$i$’ represent the individual pixel

The spatial distribution of Boro rice in 1989 and 1999 has been shown in Figure 3(a) and 3(b) respectively.

### 4.10 Overlay Operation for Extended Boro Rice Area Estimation

Overlay analysis has been done for identifying the extended Boro rice area and statistics has been calculated for area estimation. Thus the additional Boro rice area in 1999 and the common Boro rice area for the year 1989 and 1999 have been shown in Figure 3(c).

### 5. Results and Discussion

#### 5.1 Boro rice Area Expansion and Comparison

Here, it has been studied the two years data at 10 years interval for estimate the aerial extension of Boro rice area in Bangladesh. The results are given below in Table 1(a) and 1(b). Here the results indicate that the cultivation of Boro rice area has been increased in Bangladesh during the study period. Although the estimation of Boro rice area by RS & GIS method is little bit higher than the estimation of BBS method but their estimated increased area in percentage is close to each other (49.55 and 44.62 % respectively).

#### 5.2 Possible Reasons for Boro rice Area Expansion in Bangladesh
which also hampered the cultivation of the next crop. On the other hand, Boro rice is cultivated under irrigated condition and there is none of the above interference, therefore farmers are choosing Boro rice cultivation instead of Aus rice.

5.2.2 Decreasing of Deep water Aman rice Area

Similarly, farmers are replacing their Deep water Aman rice (autumn rice) cultivation by Boro rice cultivation and it is also evident by decreasing trend of Deep water Aman rice cultivation in Bangladesh (Figure 5). Deep water Aman rice is cultivated in low-lying area, it is seeded in the month of April or May and harvested in December or January and the yield is very low which is considered by farmers as non-economic / non-profitable crop cultivation. Therefore the farmers have changed their cropping pattern and adopt the new one, instead of cultivating the Deep water Aman rice they are cultivating the Boro rice in those low-lying areas by using the existing surface water for irrigation from the month...
5.2.3 Development of irrigation facilities in Bangladesh

Except some low-lying areas, Boro rice is cultivated in the areas where the irrigation facilities have been developed nicely. The extensive development of irrigation facilities over the country has played a significant role for the extension of Boro rice area in Bangladesh. Data showed in Figure 6(a) indicates the increasing trend of irrigated area in Bangladesh. Along with Figure 6(b) indicates a positive correlation between irrigated area and Boro rice area. Boro rice is cultivated under irrigated condition either from surface source or ground water source of irrigation in Bangladesh.

5.3 Over exploitation of ground water and its impact on environment

In Bangladesh the increasing trend of irrigated area and Boro rice area are positively correlated apparently, which seems good. But at the same time it has to be brought under consideration that the source of irrigation water either from ground water or surface water. Figure 7 shows the variation of irrigated areas in Bangladesh: irrigated areas by Power pumps, Tube-wells (these two considered as sub-surface source of irrigation) and Sowing basket, Doons & Canals (last three considered as surface source of irrigation). In Figure 7 indicates that the area irrigated by surface water is almost saturated and the main source of irrigation water is from ground water. Due to overexploitation of ground water the groundwater table goes down and in dry season topsoil moisture also decreased. Later on when there is heavy rainfall the topsoil becomes eroded and washed away in to the river. Secondly, Arsenic contaminated ground water is being used for Boro rice irrigation and in this way grain and straw may be contaminated by arsenic and which might enter in to the human food chain. Therefore overexploitation of ground water is not friendly to ecology and environment.

Table 1(a). Table showing the aerial extent of Boro rice area in Bangladesh measured from remote sensing and Geographic Information System (GIS) method.

<table>
<thead>
<tr>
<th>Sl. No</th>
<th>Year</th>
<th>Boro rice area (in ha)</th>
<th>Extension of area than previous year (in ha)</th>
<th>Extension of area than previous year (in %)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1989</td>
<td>3008900</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>2</td>
<td>1999</td>
<td>4500000</td>
<td>1491100</td>
<td>49.55</td>
</tr>
</tbody>
</table>

Table 1(b). Table showing the aerial extent of Boro rice area in Bangladesh measured from Bangladesh Bureau of Statistics (BBS) method.

<table>
<thead>
<tr>
<th>Sl. No</th>
<th>Year</th>
<th>Boro rice area (in ha)</th>
<th>Extension of area than previous year (in ha)</th>
<th>Extension of area than previous year (in %)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1989</td>
<td>2439676</td>
<td>-</td>
<td>-</td>
</tr>
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<td>1999</td>
<td>3528340</td>
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<td>44.62</td>
</tr>
</tbody>
</table>

Figure 7. Variation of irrigated areas (mill ha) by Power pumps, Tube wells and Sowing basket, Doons & Canals in Bangladesh over the period of 1969-70 to 1998-99.

7. Conclusion

The NOAA-AVHRR data has been used to monitor the extension of Boro rice area in Bangladesh. A method based on density slicing of the NOAA-AVHRR derived NDVI image has been employed to obtain estimation of Boro rice acreage. The NOAA-AVHRR data showed good performance for Boro rice acreage estimation at country level and regional level. The Boro rice area in Bangladesh has increased significantly during the above-mentioned time. Development of irrigation facilities over the period has been played a vital role for expansion of Boro rice acreage in the country. At the time of developing the irrigation facilities for Boro rice cultivation, it should be given the more emphasis on surface water irrigation rather than the ground water source for sustainable irrigation system.
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References


