Journal of Forestry Research (2008) 19(3):193−198
DOI 10.1007/s11676-008-0044-1

RESEARCH PAPER

Evaluation of land-use pattern change in West Bhanugach Reserved Forest, Bangladesh, using remote sensing and GIS techniques

Md. Abdul Halim[1], Abdus Shahid[2], Mohammad Shaheed Hossain Chowdhury[3], Mst. Nazmun Nahar[4]

Md. Shawkat Islam Sohel[1], Nuruddin, Md. Jahangir[5] and Masao Koike[3]

[1]*Department of Forestry and Environmental Science, Shahjalal University of Science and Technology, Sylhet-3114, Bangladesh*

[2]*Bangladesh Space Research and Remote Sensing Organization (SPARRSO), Agargaon, Sher-e Bangla Nagar, Dhaka 1207, Bangladesh*

[3]*Forest Policy Laboratory, Department of Forest Science, Faculty of Agriculture, Shinshu University, 399-4598 Nagano-Ken, Japan*

[4] *Department of Geology and Mining, Rajshahi University, Rajshahi-6000, Bangladesh*

[5] *Department of Civil and Environmental Engineering, Shahjalal University of Science and Technology, Sylhet-3114, Bangladesh*

Abstract: A study was conducted to investigate the land-use pattern change over a period of 18 years (1988–2006) by using remote sensing and Geographical Information System (GIS) technologies, in the West Bhanugach Reserved Forest, a hill forest, in Sylhet Forest Division of Bangladesh. The images were processed using ERDAS Imagine software. Both supervised and unsupervised approaches were applied and ground control points were collected using a GPS. Maps were prepared using GIS software. Results showed that vegetation cover drastically decreased from the year 1988 to 1996 (1 826 ha to 1 714.85 ha), but increased gradually from the year 1996 to 2006 (1 714.85 ha to 1 847.83 ha) due to the initiation of co-management practice involving local communities. Change in bare land was inversely proportionate to the amount of vegetation cover changes unless any other land-uses were converted into bare land. The area of water bodies increased from the year 1988 to 1996 (307.67 ha to 379.53 ha), but decreased from the year 1996 to 1997, then remained invariabile from the year 1997 to 2006. Some recommendations were also made for applying the RS and GIS techniques to study the land-use pattern change in the Bhanugach Reserved Forest and to create a GIS data base for the study area.

Keywords: land-use; remote sensing; Geographical Information System; West Bhanugach Reserved Forest; Bangladesh

Introduction

The landscape is dynamic in relation to spatial, structural and functional patterns. Land-use is the purpose for which human exploit the land cover (Fresco 1994). It is a product of interactions between a society's cultural background, state, and its physical needs on the one hand, and the natural potential of land on the other (Ram et al. 1993). Resources, ecosystem, biophysical environment, and land-use on the surface of the earth undergo changes over time. It is obviously constrained by environmental factors (e.g. soil characteristics, climate, topography, and vegetation) (McCracker et al. 1998) and human forces (Fernandez et al. 1992) (e.g. specific management practices, social, political and economical forces) (Medley et al. 1995).

Land-use change is the modification in the purpose of the land, which is not necessarily only the change in land cover but also changes in intensity and management (Verburg 2000). Both human-induced and natural land cover/use changes are critical issues due to their great influence on global warming, loss of biodiversity, and impact on human life (Sala et al. 2000; Geoghegan et al. 2001; Lopez et al. 2001). Change detection is a process of identifying and analyzing the differences of an object or a phenomenon through monitoring at different times (Singh 1989; Mouat et al. 1993). A wide range of applications can be benefited from the study of change process over a specified area at different times. Recent literature deals with the application of change analysis to different problem domains (e.g. land use/cover change dynamics, global change analysis, monitoring of pressure on the environment, monitoring of agricultural production, assessing damages due to forest fires and deforestation, and monitoring damages due to natural calamities like floods, earthquakes, and volcanic eruption etc.) (Anwar 2002). Information about land-use change is necessary to update land cover maps and for effective management and planning of the resources for sustainable development (Alphan 2003; Muttitanon et al. 2005). Furthermore, timely and reliable data on land-use may facilitate the formation of integrated resource management policies. Even though detailed land-use information are well

Received: 2008-01-12; Accepted: 2008-03-26

The online version is available at http://www.springerlink.com
Biography: Md. Abdul Halim (1983-), B.Sc (Hon's) in Forestry, Department of Forestry & Environmental Science, Shahjalal University of Science and Technology, Sylhet-3114, Bangladesh.
E-mail: xou03@yahoo.com
Responsible editor: Hu Yanbo

equipped and updated in most of the developed countries, lack of geospatial database for land-use persists in developing countries and may hinder proper development planning.

Bangladesh is a developing country experiencing high population growth where unemployment has been exacerbating the overall situation with a great pressure on natural resources. Forest is an important one among other natural resources but due to extreme poverty the forests there are under the threat of deforestation (BBS 2004). In hilly region of the country, this scenario is ruder (Rasheed 2003). Because, the hill peoples have very limited alternative sources of income but depend on forests. Due to their inconsistent use (shifting cultivation, intentional fire, over exploitation, illegal felling etc.) of the forests they are making the unsustainable use of these natural resources (Iftekhar 2006). According to Allan (1986), hilly areas are particularly sensitive to drivers of land-use changes. Land abandonment and forest expansion is common in hilly areas worldwide. But in case of Bangladesh, due to high population pressure and other socio-cultural reasons, the hill peoples will not abandon their places creating no scope for forest expansion; rather, with the hunger-stricken situation, they along with the migrated mainland people do harm to forests regularly. In this circumstance, the idea of sustainable development seems to be abstract with the availability of no or very few updated information on land-use pattern and changes in the hilly region of the country. For sustainable utilization of the forested ecosystems, it is essential to know the natural characteristics, extent and location, its quality, productivity, suitability and limitations of various land-uses. In order to improve the economic condition of the area without further deteriorating the bio-environment, every bit of the available land has to be used in the most rational way. This requires present and past landuse/land cover data of the area (Chaurasia et al. 1996).

Besides, the economic and ecological importance of forests is well understood (Franklin et al. 2000). Thus the importance of mapping, quantifying, and monitoring changes in the physical characteristics of forest cover has been widely recognized as a key element in the study of global change (Nemani et al. 1996). Alongside, the location and rates of forest structural change and the degree to which landscapes respond to these disturbances require extensive investigation (Borak et al. 2000; Rogan et al. 2002).

In recent years, a growing number of studies have combined principles from landscape ecology with spatial-econometric methods to account for how human decision-making, ecosystem function, and their interaction affect landscape changes across different spatial scales (e.g. Kline et al. 2001; Irwin et al. 2002; Anwar 2002; Hite et al. 2003; Fang et al. 2005; Srinivisan 2005; Vance et al. 2005), many of which have used data from satellite imagery to study the land-use-change pattern, and information obtained from these studies can illuminate the still poorly understood role of natural amenities as drivers of development (Alig et al. 2004).

Application of remotely sensed data made possible to study the changes in land cover in less time, at low cost and with better accuracy (Kachhwaha 1985) in association with Geographical Information System (GIS) that provide suitable platform for data analysis, update and retrieval (Star et al. 1997; McCracker et al. 1998; Chilar 2000). Hence, space-borne remotely sensed data may be particularly useful in developing countries where recent and reliable spatial information is lacking (Dong et al. 1997). In Bangladesh a few studies (Islam et al. 1988; Quadir et al. 1998; Hossain 2005; Islam et al. 2006) on land-use change have been conducted hitherto leaving a greater scope for working on this sector for ensuring sustainable development. Considering the present demand and urgency, the present study was conducted in the West Bhanugach Reserved Forest in Sylhet Forest Division of Bangladesh to investigate the land-use pattern change over a period of 18 years (February, 1988- February, 2006) using remote sensing and GIS technologies, which will be helpful in creating dynamic information system for land-use planning and also in developing national development policy.

Materials and methods

Study Site

A deliberate sampling method was applied to select the West Bhanugach Reserved Forest (Fig. 1) as the study area. The site is located in the civil administrative units of Kamalganj Thana, Maulvibazar District under the forest administration unit of Moulavibazar range under Sylhet Forest Division, Bangldesh. The GPS location of the site is between 24°18′–24°24′ N and 91°46′–91°50′ E. The reserved forest is divided into three beats; viz. Lawachara, Chautali and Kalachara with a total area of 2 610.31 ha (Anon 1970), of which Lawachara beat was declared as a national park in 1996 (Gazette Notification (PBM (S-3)7/96/367 on 07 July 1996) with an area of 1 250 ha (NACOM 2003). The other beats, Kalachara and Chautali, are of 878.2 ha and 482.11 ha, respectively.

This forest falls under the bio-ecological zone: 9b-Sylhet Hills (Nishat et al. 2002). The soils are brown, sandy clay loam to clay loam of Pliocene origin (Hossain et al. 1989). The area is undulating with slopes and hillocks ranging from 10–50 m and are scattered in the forest. Numerous streams flow through the forest. Numerous trails and tracks are found within the forest, created by the local people for collecting wood from the forest (Feeroz et al. 2000).

The climate of the forest is in general warm and humid but the weather is cool and pleasant during winter. The temperature varies on an average from minimum 26.8°C in February to 36.1°C in June. The humidity is high in the forest throughout the year, with monthly average humidity varying from 74% in March to 89% in July. The area covered under the reserved forest is one of the wettest in the country, thus, the rainfall is quite high, with an annual average of 4 000 mm approximately, with maximum rainfall falling during June to September from South-West monsoon. Pre-monsoon Nor'westerly and cyclonic storms are accompanied by high-speed winds and rains, which do considerable damage to property and trees (Nishorgo 2007).

The forest can be classified as semi-evergreen and mixed deciduous forest (Champion et al. 1965; Das 1989; Feeroz et al. 2000; Ahsan 2000) where tall trees are deciduous and the under-storey evergreen (Ahsan 2000). The forest originally supported an indigenous vegetation cover of mixed tropical evergreen forest (Alam 1998). However, almost all of the original forest cover has been removed or substantially altered and thus has turned into a secondary forest. The old plantations (around 1920's) are of primarily native species (but many of them are exotic to the forest), which have developed a multistoried structure, including re-growth of creepers and naturally occurring trees and undergrowth species. In the oldest of these areas, the vegetation cover has demonstrated the structure of natural forest, and evolution towards a natural structure (FSP 2000; Chemonics 2000). The canopy height varies from 10 m to 30 m. The top canopy comprises *Tectona sp., Ariocarpus chaplasha, Tetrameles* sp*., Hopea odorata., Toona ciliata, Pygenum* sp*.,* etc. The second canopy comprises *Quercus* spp., *Syzygium* sp*., Gmelina* sp*., Dillenia* sp*., Grewia* sp*., Ficus* sp., etc. The underneath includes *Bambusa* spp., *Alsophila* sp., *Geodorum* sp., *Eupatorium odoratum* etc. and several ferns and epiphytes (Feeroz et al. 2000).

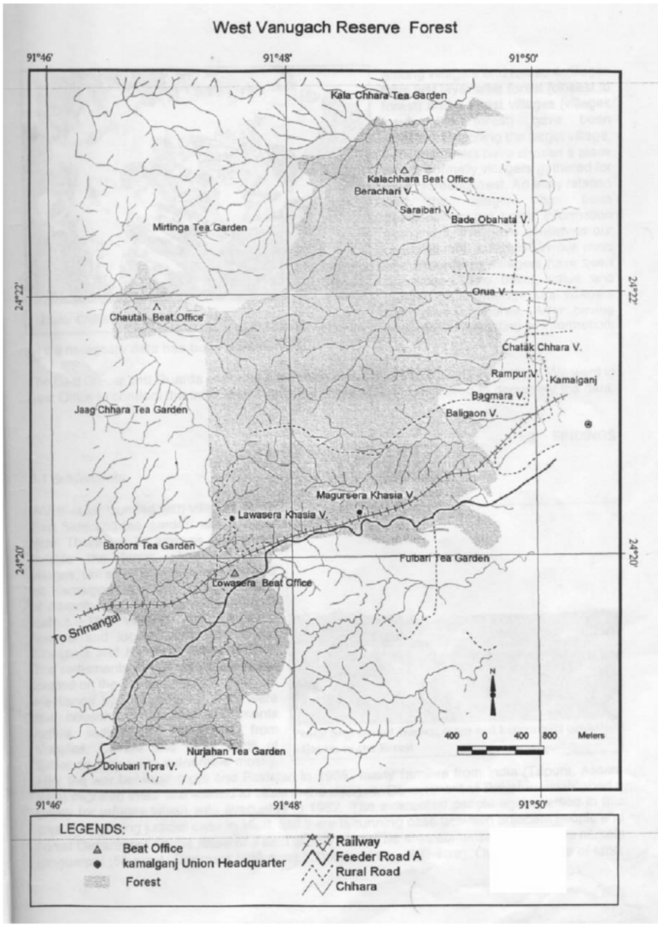

Fig. 1 Showing the study area

Methods

Materials used

Satellite imagery: a) Landsat TM FCC February, 1988 (Band 5, 3, 4); b) SPOT FCC February, 1996 (XS1, XS2, XS3); c) Landsat TM FCC January, 1997 (Band 2, 3, 4); d) Landsat TM FCC February, 2006 (Band 3, 4, 5);

The imageries have moderate color contrast and are cloud-free. Use of Landsat TM and SPOT imageries for vegetation cover mapping and change detection is also supported by a number of national and international studies: Islam et al*.* (1983), Naithani (1990), Rosenholm (1993), Quadir et al*.* (1998), Islam et al*.* (2006).

Forest Cover Maps (scale 1:15 840). The Forest Cover Maps are based on the interpretation of aerial photographs from 1981 and present different forest types. The maps have been prepared under the project "Assistance to the Forestry Sector UNDP/FAO Project", BGD/78/017;

Survey of Bangladesh Topographic Maps (scale 1 : 250,000 and 1 : 50,000);

Software used: a) PC Based IMAGINE Ortho BASE software (8.3.1 & 8.4) available at SPARRSO laboratory; b) ARC/INFO 4.0; c) ARCVIEW 3.2 a.;

GPS: GARMIN GPS 12XL.

Geometric correction

To make the images workable, the data needed to be transformed to a uniform ground co-ordinate system of a chosen map projection. With the help of topo maps of 1:50 000, a good number of Destination Ground Control Points (GCPs) were selected mainly from distinctive features like rail-road crossing, road-river crossing, etc., and the corresponding points were selected in the source images. Then the topo-points were digitised and projected from geographic to BTM (Bangladesh Transverse Macerator). Because of having high resolution (20 m × 20 m) of SPOT it was used as reference image for geometric correction of the other images. At least 10 GCPs (Ground Control Point) were taken in Polynomial 1, and 8 GCPS for up to Polynomial 5.

Interpretation key

Interpretation key (Table 1) was developed by using the existing maps of the forest cover compared with the tonal characteristics of the hardcopy prints/transparencies of the false color composite (FCC) imageries.

Table 1. Interpretation key for interpretation of Landsat TM and SOPT imageries

	Feature ID	Feature	Signature in the image
TM interpretation key	1	Vegetation	Dark to light red with smooth texture
	11	Bare land	Bright white with smooth texture
	2	Water bodies	Dark to light blue with smooth texture
SPOT interpretation key	1	Vegetation	Dark red to bright red with smooth texture
	11	Bare land	Whitish
	2	Water bodies	Dark light blue with smooth texture

Interpretation of the satellite imageries
Interpretation of imageries was done using Erdas Imagine with the help of available maps and field visits. The images (both SPOT and Landsat TM) were brought into the same spatial resolution of 30 m.

Creation of the GIS data base
The boundaries were digitized from topographic map sheets (1:50 000 scale) covering the study area. The imagery interpretations were digitized, and all the coverages were transferred into the real world coordinate system (Lambert conic conformal system, Everest Projection). The polygon topologies were built for all the above coverages.

Area measurement and change detection
From the IMAGINE attribute table, areas from all the maps were calculated. The area obtained from the management plan from the year 1963–1964 to 1982–1983 of the study site was compared with the area obtained from the Landsat TM imagery of the year 1988. It was more or less (deviation not more than 5%) similar between them and it was considered as base area for change detection.

Data analysis
Data analysis was done using Microsoft Excel 2003 and SPSS 10.

Results and discussions

The maps were prepared (Fig. 2) from the geometrically corrected images and presented in the Lambert Conic Conformal (LCC) (Everest Projection) grid system. While managing the polygons in different maps obtained from images of different years we made a neighboring. We have merged any polygon less than 1 000 m^2 with the nearest one. After measuring the area, the areas obtained from the images are matched with the area available in literatures. The amount of error was 0.4% as measured. From the Landsat TM image of the 1988 of the study site, we calculated the area as 2 599.08 ha, which is a little bit deviated from the area obtained from literature (Anon 1970) as 2 610.31 ha. The areas of different maps were computed from the vector attribute table of the Imagine. The results obtained from the area measurement are given in the Table 2.

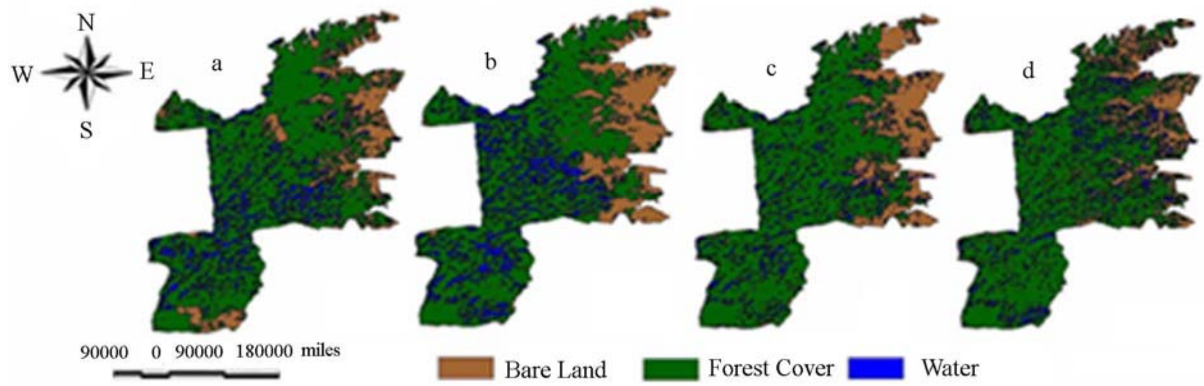

Fig. 2 The land-use patterns of Bhanugach Reserved Forest in the year 1988 (a), 1996(b), 1997(c) and 2006 (d), Bangladesh

Table 2. Showing the areas measured from the maps of different land-uses in West Bhanugach Reserved Forest, Bangladesh.

Year	Vegetation cover (ha) Grid code (1)	Bare land (ha) Grid code (11)	Water bodies (ha) Grid code (2)	Un-classed (ha) Grid code (0)	Total (ha)
1988	1826.14	465.27	307.67	NC*	2599.08
1996	1714.85	504.37	379.53	0.33	2599.08
1997	1799.37	527.78	271.55	0.38	2599.08
2006	1847.83	458.57	292.37	0.31	2599.08

*NC: Not Calculated.

As shown in Fig. 3, it was observed that vegetation cover was drastically reduced from the year 1988 to 1996. Conversely, it had been increased gradually from 1996 to 2006. This is the most interesting and hope-inducing finding of the study in that in Lawachara National Park, since 1996 co-management practice initiated by Nishorgo Support Project of BFD has been practiced (Nishorgo 2007). A number of initiatives have been taken to motivate local people and encourage them in AIG (Alternative Income Generation) activities. As a result, the extent of vegetation cover has been increased although in a slow rate.

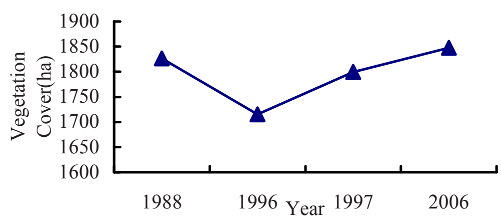

Fig. 3 The trends in vegetation cover change of West Bhanugach Reserved Forest of Bangladesh from the year 1988 to 2006

Regarding the trends of change in bare land, it was observed that the change is inversely proportionate to the amount of vegetation cover changes unless any other land-uses (e.g. water bodies) are converted into bare land. As the extent of vegetation cover increases, the extent of bare land decreases (comparing between Fig. 3 and Fig. 4). In the year 1988, the extent of bare land was 465.27 ha and it became 504.37 ha in 1996 (Fig. 4). Further the extent increased up to 527.78 ha in 1997 due to the decrease in water bodies. But, from the year 1997, the extent of bare land has drastically been decreased though the extent of water bodies remained more or less similar.

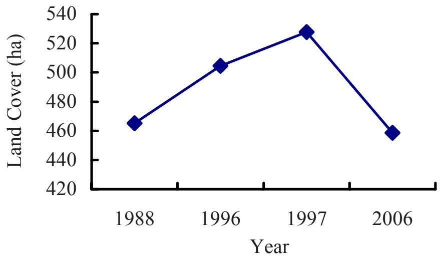

Fig. 4 The trends of change in bare land of West Bhanugach Reserved Forest of Bangladesh from the year 1988 to 2006

The area of water bodies increased from the year 1988 (307.67 ha) to 1996 (379.53 ha) but decreased from 1996 to 1997. From the year 1997 to 2006, the extent of water bodies remained more or less the same (Fig. 5). Therefore, it can be inferred that vegetation cover of the study site has been increasing with time, which reflects the efficiency of co-management approach in reserved forest and protected area management in Bangladesh.

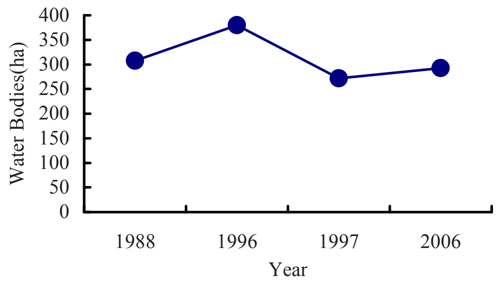

Fig. 5 The trends of change in water bodies of West Bhanugach Reserved Forest of Bangladesh from the year 1988 to 2006

Conclusions

It is greatly feasible to use RS and GIS techniques to study the changes in land-use in a developing country like Bangladesh. The application of the techniques has been started since the last few decades, but due to some limitations, it is still backward and needs the immediate attention of the experts and government. In this paper we applied the RS and GIS techniques to study the land-use pattern change in the Bhanugach Reserved Forest and create a GIS data base for the study area. While working for the supervised classification, we faced problems with poor records in the respective beat office about their resources, which made our task troublesome. Considering this, the following recommendations are made for the study area to which appropriate authority should pay necessary attention: 1) beat maps should be upgraded with proper features; 2) the maps have to be well organized so that those represent accurate features' location and extent; 3) the database should be made up-to-date vegetation class-wise and their area context-wise as SPOT's pixel size have a certain limitation of 20 m x 20 m; 4) plantations either pure or mixed should be defined with their age and density; 5) more keen monitoring of the whole area should be conducted. The most important matter is to obtain further observations immediately, keeping in mind to get the field closer to the image scene.

References

Ahsan MF. 2000. Socio-ecology of the Hoolock Gibbon (*Hylobates hoolock*) in two forests of Bangladesh. *Field Research.* pp. 284–299.

Alam MK. 1998. Annotated checklist of woody flora of Sylhet forests. Bulletin 5, *Plant Taxonomy Series*, Bangladesh Forest Research Institute, Bangladesh.

Alig R, Kline J, Lichtenstein M. 2004. Urbanization on the US landscape: looking ahead in the 21st century. *Landscape and Urban Planning*, vol. **69**: 219–234.

Allan NJR. 1986. Accessibility and altitudinal zonation models of mountains. *Mountain Research and Development*, **6**: 185–194.

Alphan H. 2003. Land use change and urbanization in Adana, Turkey. *Land Degradation and Development*, vol. 1**4**: 575–586.

Anon. 1970. Working plan for the forest of the Sylhet Division for the period 1963-64 to 1982-83. Volume-I, Compiled by Working plan division-II, Chittagong, East Pakistan, Government of the East Pakistan, Directorate of Forests.

Anwar SM. 2002. Land use change dynamics: A dynamic spatial simulation. A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science. Asian Institute of Technology, School of Advanced Technologies, Thailand, December 2002. 67p.

BBS (Bangladesh Bureau of Statistics). 2004. *Bangladesh Statistical Year Book 2002.* Bangladesh Bureau of Statistics, Ministry of Statistics, Ministry of Planning, Government of the People's Republic of Bangladesh. pp12–35.

Borak JS, Lambin EF, Strahler AH. 2000. The use of temporal metrics for landcover change detection at coarse spatial scales. *International Journal of Remote Sensing*, **21**(6–7): 1415–1432.

Champion HG, Seth SK, Khattak GM. 1965. *Forest types of Pakistan.* Peshawar, Akistan: Forest Institute.

Chaurasia R, Closhali DC, Dhaliwal SS, Sharma PKM, Kudrat M, Tiwari AK. 1996. Landuse change analysis for agricultural management: a case study of Tehsil Talwandi Sabo, Punjab. *Journal of Indian Society of Remote Sensing*, **24**(2): 115–123.

Chemonics. 2000. *Biodiversity Sustainable Forestry IQC (BIOFOR) Strengthening The Arannyk Foundation.* Site Selection Inventory and Monitoring Report. Dhaka, Bangladesh:USAID-Bangladesh.

Chilar J. 2000. Land cover mapping of large areas from satellites: status and research priorities. *International Journal of Remote Sensing*, **21**(6-7): 1093–1114.

Das DK. 1989. *Forest Types of Bangladesh.* Paper presented at the sixth National Botanical Conference held at the University of Chittagong, Chittagong on January 18-19.

Dong Y, Forster B, Ticehurst C. 1997. Radar backscatter analysis for urban environments. *International Journal of Remote Sensing,* **18**(6): 1351–1364.

Fang S, Gertner G, Sun Z, Anderson A. 2005. The impact of interactions in spatial simulation of the dynamics of urban sprawl. *Landscape and Urban Planning*, **73**: 294–306.

Feeroz MM, Islam MA. 2000. Primates of the West Bhanugach Forest Reserve: major threats and management plan. In: M. Feroze Ahmed (ed.), Bangladesh Environment 2000. BAPA Bangladesh Poribesh Andolon. pp. 239–253.

Fernandez R, Martin A, Ortega F, Ales E. 1992. Recent changes in landscape structure and function in Mediterranean region of SW Spain (1950-1984). *Landscape Ecology,* **7**(1): 3–18.

Franklin J, Woodcock CE, Warbington R. 2000. Multi-attribute vegetation maps of Forest Service lands in California supporting resource management decisions. *Photogrammetric Engineering and Remote Sensing*, **6**: 1209–1217.

Fresco LO. 1994. Imaginable futures, a contribution to thinking about land use planning. In: Fresco LO, Stroosnijder L, Bouma J, van Keulen H (eds), The future of the land: Mobilising and Integrating Knowledge for Land Use Options. Chichester: John Wiley and Sons, pp. 1–8.

FSP (Forestry Sector Project). 2000. *First Five Year Management Plan for Lawachara National Park.* Vol. 2: Background and support material. Dhaka, Bangladesh: Forest Department, Ministry of Environment and Forests.

Geoghegan J, Villar SC, Klepeis P, Mendoza PM, Yelena O, Chowdhury RR, Turner II BL, Vance C. 2001. Modeling tropical deforestation in the southern Yucatan peninsular region: comparing survey and satellite data. *Agriculture, Ecosystems and Environment,* **85**: 25–46.

Hite D, Sohngen B, Templeton J. 2003. Zoning, development timing, and agricultural land use at the suburban fringe: a competing risks approach. *Agricultural and Resource Economics Review*, **31**(2): 145–157.

Hossain A. 2005. *Remote Sensing in Bangladesh*, In: Bangladesh Review, January-March, 2005. Published by the Department of Films and Publications, Ministry of Information, Government of the People's Republic of Bangladesh, pp 56–62.

Hossain MK, Islam QN, Islam SA, Tarafdar MA, Zashimuddin M, Ahmed A. 1989. *Assistance to the Second Agricultural Project- Bangladesh*. Status report on the activities of the Silviculture Research Division, BFRI (Bangladesh Forest Research Institute), Chittagong, Bangladesh. FO: DP/BGD/83/010, Working Paper No.6.

Iftekhar MS. 2006. Forestry in Bangladesh: An Overview. *Journal of Forestry,* **104**: 148–153.

Irwin EG, Bockstael NE. 2002. Interacting agents, spatial externalities, and the endogenous evolution of residential land use pattern. *Journal of Economic Geography*, **2**: 31–54.

Islam J, Quadir DA. 1988. *Modhupur forest map based on digital classification of Landsat TM data.* SPARRSO (Space Research and Remote Sensing Organization), Dhaka, Bangladesh.

Islam J, Ahmed AN, Hossain MA, Rashid MM, Atauzzaman M. 2006. Deforestation study of Dinajpur Sal Forest using GIS and remote sensing techniques. *J Subtrop Agric Res Dev,* **4**(1): 47–54.

Islam MJ, Khan FA. 1983. Exploration of Nijhumdwip through remote sensing technique. *A Journal of forest science,* **12**(1-2): 42–46.

Kachhwala TS. 1985. Temporal monitoring of forest land for change detection and forest cover mapping through satellite remote sensing. In: Proceedings of the 6th Asian Conf. On Remote Sensing. Hyderabad, pp 77–83.

Kline JD, Moses A, Alig RJ. 2001. Integrating urbanization into landscape-level ecological assessments. *Ecosystems*, **4**: 3–18.

Lopez E, Bocco G, Mendoza M, Duhau E. 2001. Predicting land cover and land use change in the urban fringe a case in Morelia City, Mexico. *Landscape and Urban Planning*, **55**: 271–285.

McCracker SD, Brondizio E, Moran EF, Nelson D, Siqueira A, Pedrazar CR. 1998. The use of remote sensing and GIS in the collection of survey data on households and land-use: Example from the agricultural frontier of the Brazillian Amazon. In: Anais IX Simposio de sensoriamento Remoto, Santos, Brasil, 11-18 setemboro 1998, INPE, p45–52.

Medley K, Okey B, Barrett G, Lucas M, Renwick W, 1995. Landscape change with agricultural intensification in a rural watershed, southwestern Ohio, USA. *Landscape Ecology*, **10**(3): 161–176.

Ministry of Environment and Forests. 2001. *National Report on Implementation of United Nations Convention to Combat Desertification*. Government of the People's Republic of Bangladesh, Ministry of Environment and Forests, Bangladesh Secretariat, Dhaka-1000, Bangladesh. 43p.

Mouat DA, Glenda GM, Lancaster J. 1993. Remote sensing techniques in the analysis of change deletion. *Geocarto International*, **8**(2): 39–50.

Muttitanon W, Tripathi NK. 2005. Land use/cover changes in the coastal zone of Bay Don Bay, Thailand using Landsat 5 TM data. *International Journal of Remote Sensing*, **26**(11): 2311–2323.

Nature Conservation Management. 2003. *Secondary data collection for pilot protected areas: Lawachara National Park*. Prepared by: NACOM and Submitted to: International Research Group (IRG), with the financial assistance of USAID-Bangladesh and Ministry of Environment and Forest, GOB.

Naithani KK. 1990. Can satellite images replace aerial photographs? A photogrammetrist's view. *ITC Journal,* **1**: 29–31.

Nemani R, Running SW. 1996. Global vegetation cover changes from coarse resolution satellite data. *Journal of Geophysical Research*, **101**: 7157–7162.

Nisahat A, Huq SMI, Barua SP, Reza AHMA, Khan ASM. (eds.). 2002. *Bio-ecological Zones of Bangladesh*, IUCN-Bangladesh, Dhaka. 141pp.

Nishorgo. 2007. Nishorgo Support Project. available online at http://www.nishorgo.org, last accessed on 7 May, 2007.

Quadir DA, Rahman A, Haque F, Ahmed IU, Runkel M. 1998. Monitoring of forest cover in Chittagong forest division of Bangladesh using remote sensing and GIS techniques. *Journal of remote sensing and environment,* **2**: 1–18.

Ram B, Kolarkar AS. 1993. Remote Sensing application in monitoring land use changes in arid Rajasthan. *Int J Remote Sensing*, **14**(17): 3191–3200.

Rasheed KBS. 2003. Vulnerability of the forest fringe population in a degraded forest area of central Bangladesh. Paper presented in the World Forestry Congress XII, July 11–14, 2003, Canada. Available online at http://www.fao.org; last accessed on May 15, 2007.

Rogana J, Franklina J, Roberts DA. 2002. A comparison of methods for monitoring multitemporal vegetation change using Thematic Mapper imagery. *Remote Sensing of Environment,* **80**: 143–156.

Rosenholm D. 1993. Land use and vegetation cover mapping be satellite: SSC Satellite experiences 1987-1993. *ITC Journal,* **3**: 251–260.

Sala OE, Chapin FS, Armesto JJ, Berlow E, Bloomfield J, Dirzo R. 2000. Biodiversity: Global biodiversity scenarios for the year 2100. *Science,* **287**: 1770–1774.

Singh A. 1989. Digital Change Detection technique using remotely sensed data. *International Journal of Remote Sensing,* **10**: 989–1003.

Srinivasan S. 2005. Linking land use and transportation in a rapidly urbanizing context: a study in Delhi, India. *Transportation*, **32**: 87–104.

Star JL, Estes JE, McGwire KC. 1997. *Integration of geographic information systems and remote sensing*. New York, NY: Cambridge University Press.

Vance C, Iovanna R. 2005. Analyzing spatial hierarchies in remotely sensed data: insights from a multilevel model of tropical deforestation. *Land Use Policy*, **23**: 226–236.

Verburg PH, Chen Y, Soepboer W, Veldkamp A. 2000. GIS-based modeling of human-environment interactions for natural resource management. Applications in Asia. In: Proceedings of the 4th International Conference on Integrating GIS and Environmental Modeling (GIS/EM4): Problems, Prospects and Research Needs, Canada 2000, 1-13. Available at http://gissrv.iend.wau.nl/~clue/banf/banf71/banf71.html (Downloaded in August 2006).