RESEARCH ARTICLE

Integration of Remote Sensing, GIS and Participatory Approach for Coastal Island Resource Use Zoning in Bangladesh

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Abstract

Coastal natural resources in the Cox's Bazar coast of Bangladesh have been used for multiple purposes and have strongly influenced socio-economic development. Remote sensing imagery provides cost-effective support in compiling the latest information about the environment and natural resources, while GIS facilitates multidisciplinary analysis and decision support. Integrated analysis can serve as vital input for better planning, policy formulation, and decision-making in national development. Landsat TM imagery and topographic maps of some coastal islands on the Cox's Bazar coast, Bangladesh were analyzed and hills, plain land, tidal land, mangroves and waterways were identified and mapped. Participatory rapid appraisal was utilized to elucidate the major sources of livelihood for coastal communities associated with the different land uses; these included agriculture, aquaculture, fishing, fish drying, sea salt production and trading. Proper resource utilization and integration among stakeholder activities can increase environment-friendly economic options, which can have a positive role in successful poverty alleviation and socio-economic development programs for coastal rural communities.

Keywords: coastal natural resources, land use pattern, mangrove afforestation, participatory appraisal

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Introduction

The Koriardiar, Matarbari, Moheshkhali and Sonadia islands close to the Cox's Bazar coast of Bangladesh have had great importance since pre-historic times for their abundance of natural resources, which have been used for a variety of purposes and have strongly influenced socio-economic development in the local communities. Economic activities in the islands are based on the primary sector: salt production, shrimp culture, fishing and agriculture. Successful resource management requires the participation of local people, government authorities, NGOs, researchers and investors. A participatory approach resource planning for the islands can help to consider the long-term interests of the host community, on whom most of the activities depend. This bottom-up people-led approach is based on the assumption that coastal island management programs will be more successful if local communities are involved in planning and implementing policies and programs. It is recognized that sustainable resource utilization requires training and education of all levels of society, where indigenous people and their communities have a vital role in environmental management and development because of their knowledge and traditional practices (Younis, 1997). Involvement of local communities in management gives them a sense of awareness of the resources and ensures their continued livelihood and economic well-being. In this way, the development of the coastal islands links ecology with economics, sociology and politics; promotes policies and practices which discourage further degradation; establishes priorities; provides incentives for improvement; and provides sufficient resources for local people so that they manage themselves willingly.

The Cox's Bazar coast consists of fluvial and tidal geomorphological deposits created from weathered materials from the nearby uplands, ultimately carried away by major rivers, and their numerous small tributaries and coastal canals, leading to the formation of a newly accreted coastal landscape. In the tropics, mangrove typically forms on such coasts. This is important since the Cox's Bazar coast is well known as a cyclone path, and is subject to periodic cyclones that originate in the Bay of Bengal, and therefore, the creation and maintenance of such a green shelterbelt to mitigate the damaging effect of cyclonic winds, storm surges and tidal waves, is a necessity (Hossain et al., 2003a). Nearly one million people have been killed in Bangladesh by cyclones since 1820 (Talukder et al., 1992); an estimated 10% of the world's cyclones developing in the Indian Ocean (Gray, 1968). In the islands and coastal mainland of Bangladesh the major aftermaths of a cyclone are loss of human life, livestock, fisheries, agricultural properties and production, inundation of land and ponds by saline water, destruction of houses, break-down of the sanitation system, pollution of drinking water and contamination of food supplies (Hossain, 2001).

Continuous exploitation of natural resources with little or inadequate management leads to resource degradation and lower productivity levels. Sustainable development of a region requires the optimal use of natural resources. Development plans

for optimal management of coastal natural resources on a sustainable basis require reliable, up-to-date spatial information on various natural resources and physical/terrain parameters, as well as profiles of the climate and socio-economic conditions of the area (Sharma, 1997). An integrated approach using remote sensing and spatial information systems provides cost-effective support in compiling the various elements of resources inventory, which include land use mapping, a comprehensive database for resource assessment, analytical tools for decision making and an impact analysis for plan evaluation (Rao, 1996). Any development plan should be site-specific and cater directly to the management of resources at the local level. However, a sustainable development plan should also provide practical measures for development impacts and their long term monitoring.

The relationship between human activity and the earth's resource has reached a turning point and thus the question of integrated natural resource management has sparked a crisis in development thinking today. The basic concept of remote sensing depends on the fact that all objects on the earth reflect, scatter or emit the sun's light energy. Applying the knowledge of differences in the proportions of energy reflected by the earth surface, remote sensing can provide information on object properties e.g., land use, vegetation density, water temperature, etc. Thus, many earth features of interest can be identified, mapped and studied on the basis of their spectral characteristics (Lillisand and Kiefer, 2000; Jensen, 2000). The GIS technology interlinks spatial and attribute data for outputs in the form of maps, tables, and figures. Maps are very much useful for resource planners, field officers and local people in understanding the real situations of the resources. Thus, GIS is becoming one of the most useful and powerful analytical tools for resource planners and managers (FAO, 1988). The integrated use of remote sensing and GIS technology does not only improve the quality of geographic information but also enables information previously unavailable to be economically produced. Participatory tool such as group meetings have several advantages, including access to a large body of knowledge and mutual checking.

Objective of this study

The main objective of this study is to record and assess present land/resource use pattern, and to prepare a resource classification for sus-tainable utilization.

Study area

Koriardiar, Matarbari, Moheshkhali and Sonadia are four islands lying in cluster along the coast, to the north of Cox's Bazar town. The length of the islands is about 30 km in a north-south direction and they are about 12 km wide in an east-west direction. The geographical location of the islands is between latitude $21^{o}20'$ and $21^{o}50'$N, and longitude $91^{o}45'$ and 92^{o}E (Figure 1). They are surrounded by the Moheshkhali channel to the east, the Bay of Bengal to the south and west, and by Kutubdia Island to the north. There are numerous canals (locally called khal), creeks and micro-channels criss-crossing the islands. Most of the canals are tidal and suitable for navigation. Tidal water plays an important role in supplying water

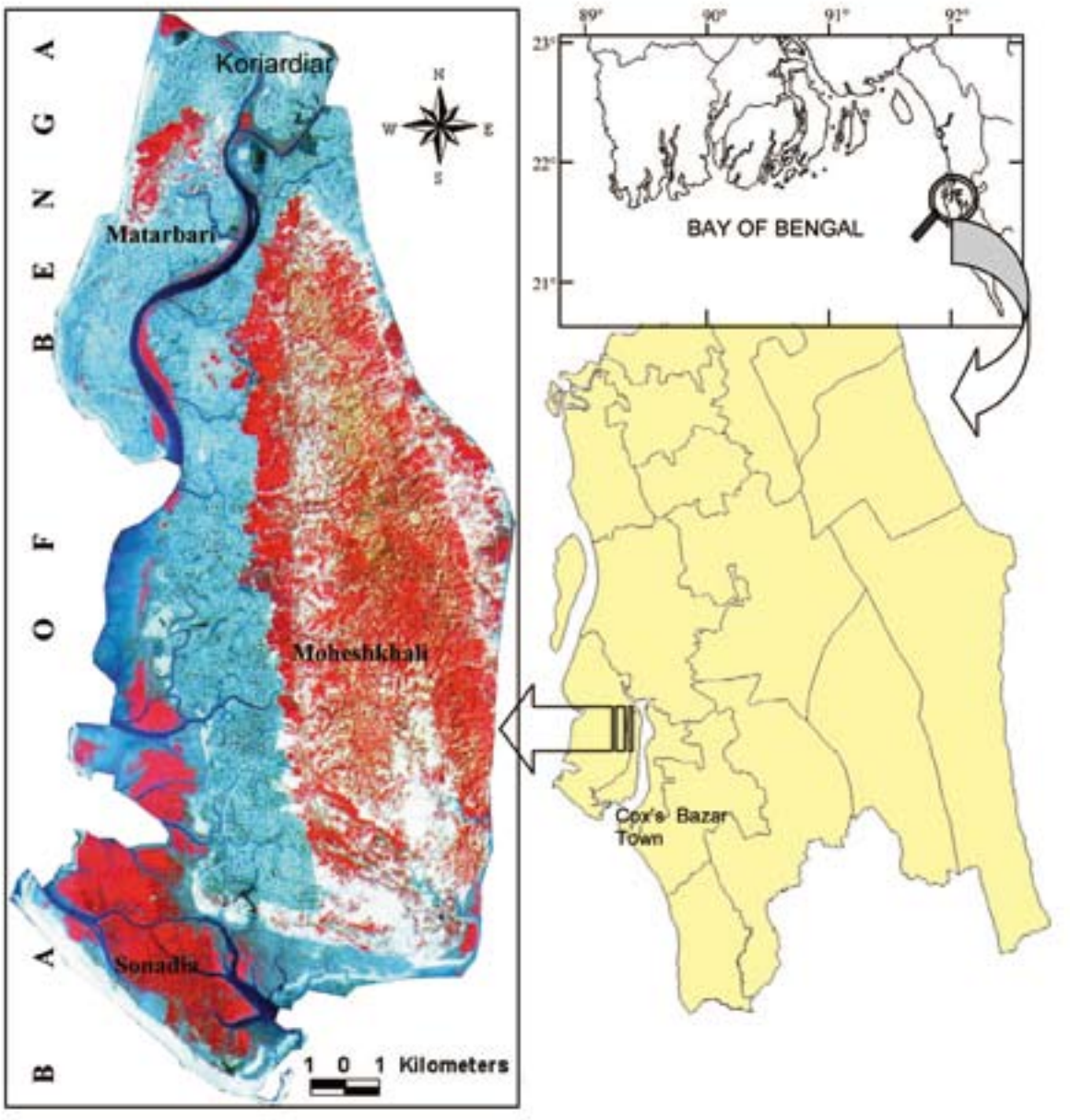


Figure 1. Geographical location of Bangladesh coast, enlarged (left) Landsat TM image showing the study area of Koriardiar, Matarbari, Moheshkhali and Sonadia islands.

for shrimp farming and sea salt production through out the islands.

Materials and methods

1. Materials

The research team was composed of a natural resource management specialist, a remote sensing and GIS expert, an environmentalist and one research associate. A sociologist and a conservation biologist were regularly consulted during the research work. A photographer joined the team to document the major activities. The thematic maps were generated using topographic maps at 1:10,000 scale, published by the Survey of Bangladesh in 1999, and land type maps at 1:50,000 scale, published by the Soil Resources Development Institute (SRDI) in 2002. These and other relevant aspatial data (tidal condition, and demography) were collected from various government departments. Landsat TM satellite images for January 14, 2001 were acquired from SPARRSO (Bangladesh Space Research and Remote Sensing Organization). The topographic maps, satellite data and land use maps were used to develop various thematic maps. The image processor ENVI (The Environment for Visualizing Images) was used for data analysis. Arc View GIS software was also used to digitize all the maps. The attribute tables were simultaneously created from the analysis (Figure 2).

2. Satellite image interpretation

The Landsat TM image of the study area was analyzed to identify the geographical features. The image was first spatially geo-rectified selecting 25 Ground Control Point (GCPs) from the UTM map projection, using a first order polynomial and then re-sampled with bilinear algorithm. All the selected GCP's were easily identifiable and per-manent in nature for measuring accurate results. A Root Mean Square (RMS) error of 0.41 (less than one pixel, 30m) was accepted for the correction process. Then, map to image registration was used to create image data covering the whole area. All the data such as satellite images, topographic maps and other ancillary data were used for digital image processing and visual interpretation. Digital image processing was applied for two purposes: firstly to enhance image quality and extract more information through image enhancement functions; and secondly, to classify images to separate different resource base, which were combined with other data sources, for example visual interpretation for creating final thematic maps.

ISODATA unsupervised classification (use of information from the image itself to identify spectral clusters, which are interpreted as classes) was performed considering minimum and maximum classes of 5-10, 10-15 and 15-20, where the 10-15 classes turned out to be useful. Subsequently, principal component analyses (PCA) were carried out on the raw data but the approach did not prove to be useful. Supervised classifications were carried out on the basis of region of interest (ROIs), where the ground truth or so-called training areas (collected during field investigation) were regions of terrain with known properties or characteristics (Research Systems Inc., 2000). Parallelepiped and maximum likelihood classification strategy were applied: Lillesand and Kiefer (2000) discuss both of these techniques extensively.

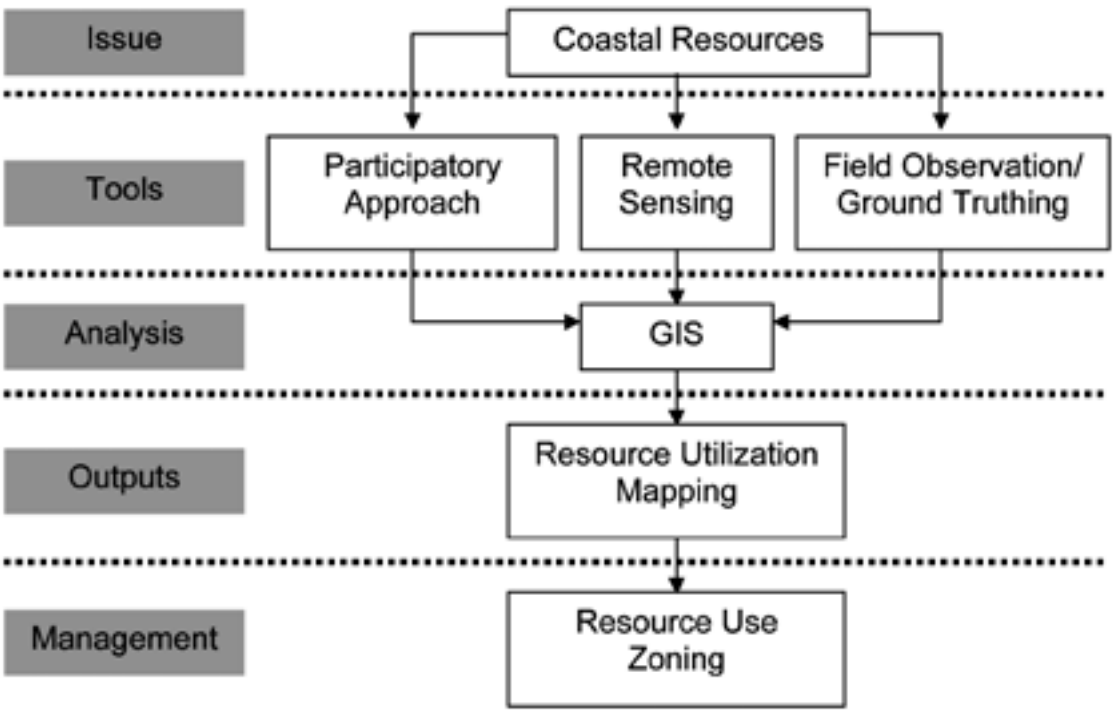


Figure 2. Integration of remote sensing, GIS and participatory approach for coastal resource use

Maxi-mum likelihood classification was found to be most useful for discriminating classes.

3. Ground truthing

The acquisition of field data is required to supplement and verify features from digital image processing and visual interpretation of Landsat TM image compared actual conditions. After finishing the image processing, the reference points in the study area were chosen for ground verification. The reference points were surveyed for collecting data and comparing the preliminary map to the real world. A preliminary map of the different natural resources of 4 islands were thus corrected and revised. The resource map was finalized by using Arc View GIS software.

4. Participatory approach

Participatory appraisal involves a series of qualitative multidisciplinary approaches to learning about local-level conditions and local peoples' perspectives. Rapid Participatory Rural Appraisal (RRA/PRA) was carried out using field observations and community level group meetings with different stakeholder groups on the coastal islands from January to April 2002 to gather primary information following the approaches of Pido (1995), Pido et al. (1996), Townsley (1996) and IIRR (1998). Direct observation prevents rapid appraisal from being misled by myth (Chambers, 1980) and it often provides more valid and less costly information than other research methods (KKU, 1987). Group meetings with local communities are an important

way of learning about local conditions and resources (Pelto and Pelto, 1978).

Two PRA tools were chiefly employed, the seasonal calendar and transects. The seasonal calendar technique is helpful for documenting regular cyclical periods (i.e., seasonal) and significant events that occur during a year and influence the life of the community (Tripp and Woolley, 1989; IIRR, 1998; Townsley, 1996 and Pido et al., 1996). Community members were asked questions in group meeting regarding the duration of the rainy and dry season, environmental conditions, land use patterns, and their activities. Group meetings had several advantages, including access to a large body of knowledge and mutual checking. There was a self-correcting mechanism within the group whereby if one person described an over-favorable picture of his/her own or group's behavior, a peer may give a more realistic observation. In cross checking among different groups, a high degree of uniformity was maintained.

Transect is simply a cross section of a territorial space wherein fields are mapped, cropping patterns and practices observed. Transects are relatively easy to do, depending on the ruggedness of terrain and visibility as affected by topography and vegetation (Rhoades, 1987). Among the advantages of transect is the simple portrayal of the resources present and the associated economic, social and environmental issues in spatial terms (Pido et al., 1996). Using the satellite imagery and topographical maps, the research team visited from the Bay of Bengal coast along an access road toward higher elevations of Moheshkhali hill. Detailed notes were periodically taken of natural vegetation and sketches made of field shapes, settlement patterns, distance between fields and, whenever possible, local communities interviewed.

Prior information was sent to the stake-holders through the community leaders to introduce and to explain the objectives of the research to them. Observations were recorded through transects across the area defined by using maps and satellite images. Photographs were taken as evidence of certain facts before interpretation. The transects were carried out in as wide as possible an area to observe land use patterns, resource conditions, problems and potential and to interview a range of people. To produce useable outputs, observations were recorded as drawings and notes. Stakeholder selection and analysis were required to find out the appropriate groups for collecting information and to reveal the relationship between their activities. A checklist of topics was used to aid the memory.

Results

After analyzing the data, coastal natural resources were identified and studied in terms of their relation with other associated features. The GIS derived figure clearly indicates the location and extent of plain land, tidal land, mangrove forest, hill land, rivers and canals (Figure 3). The area under each unit and the percentages of the total area are shown in Table1.

1. Natural resources and environment investigation

1.1 Hill land

About 13,684 ha of Moheshkhali Island are covered by hills and hillocks with an elevation of 60 to 100 m. A high ridge lines most of the

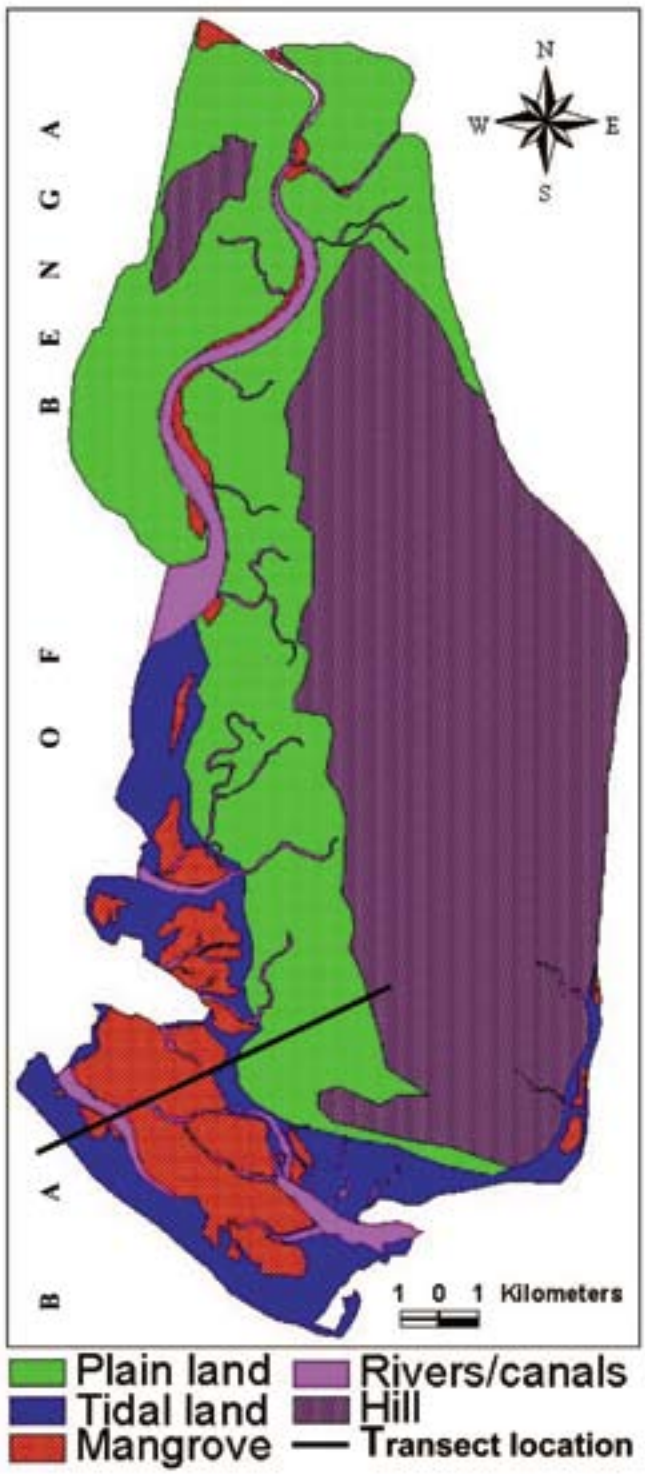


Figure 3. Coastal natural resources of the Koriardiar, Matarbari, Moheshkhali and Sonadia islands at Cox's Bazar, Bangladesh.

east coast, with an isolated hillock present on Matarbari island. The soils of the hills are reddish to dark brown in color and rich in ferrous content (Islam and Hoque, 1999). Known as the Moheshkhali Hills, this ridge protects some parts of the islands as well as nearby coastal zone from the open sea. The hills were once heavily forested but the hill forest has been cleared and the land leveled through cutting and filling for agriculture, betel orchards, settlement and other development activities. As a result, the forest coverage has been decreased at an alarming rate, resulting a series of ecological problems, particularly soil erosion and loss of biodiversity.

1.2 Plain land

The plain land covers an area of 10,803 ha. The plain land extends from the north to the southern border along the western side of Moheshkhali Island. The elevation ranges from 10 to 15 m above MSL and the soils are characterized by high clay content. The plain land is criss-crossed by tidal canals and creeks. The flat plains in the coastal areas are the most important resources that support a variety of land uses such as crop production, betel leaf cultivation, livestock rearing, salt production, shrimp/fish farming, fish drying, infrastructure development, fishing crafts and gear manufacturing, and harbor activities. Due to human interventions for development activities, the soils have been eroding at an accelerated rate. Settlements are mostly concentrated at the lower edge of the hills and upper edge of the plain land.

1.3. Tidal land

Seawater enters the waterways during high tide and submerges the low-lying areas adjacent to these waterways, forming tidal flats. About 4,013 ha of Sonadia Island and the southwestern part of the Moheshkhali Island are mostly accreted muddy land 2-3 meters above the present sea level. This area has an extremely low topography, is marshy and features barren tracts of land, regularly inundated by tidal water and therefore waterlogged. The salt beds, shrimp ponds and lowland agricultural areas on the islands mainly lie on old tidal flats formed by sediment deposition. The tidal land occurs absolutely flat monotonous geomorphic units of about 2 m elevation that can be characterized by dark gray coarse silty clay sediments (Islam and Hoque, 1999).

1.4 Mangroves

Mangrove forests are considered government property and are crucial for the coastal ecosystem. Government interventions appear to have had a positive impact on the status of mangroves. This has been brought about through implementing laws and regulations concerning mangrove forest and supporting mangrove afforestation programs. During the 1960s, the coastal areas of Bangladesh experienced severe cyclones and associated tidal bores. It was suggested that development of forests along the coast would help to protect lives and properties from future disasters. The Forest Department initiated mangrove afforestation outside of the protective coastal embankments from 1966 with the primary objective of saving life and properties of the people living in the area from cyclone and tidal bore (Das and Siddiqi, 1985). A World Bank mission in 1977 observed the affores-tation activities and an expansion of the ongoing plantation activities in the coastal areas

was identified as the most suitable component of the Bangladesh forestry program for IDA assistance. Subsequently, the objectives of coastal afforestation were expanded to production of timber for fuel wood and creation of employment opportunity in remote rural areas (Saenger, 1987).

About 2806 ha of the study area has been designated for mangrove afforestation since 1966 with the aim of developing a dense mangrove forest as well as a green belt along the coast. Most of the mangroves are situated in Sonadia Island and western part of the Moheshkhali Island. Mangrove plantations are also scattered in Koriardiar and Matarbari islands as well as on the southeastern coast of Moheshkhali island. The mangrove in the tidal floodplain comprises is located on mud flats with low ridges, inter-ridge depressions and shallow basins.

Local people derive both direct and indirect benefits from the mangroves. Many household necessities, such as firewood, housing materials, boat making materials, herbal plants for traditional medicines and other minor products are collected from the mangrove forest (Hossain et al. 2001a). In recent years, however, the mangrove forest of the islands has been encroached, mainly for shrimp farming, but with some salt beds. The clearance of mangroves is not only causing a colossal loss of coastal habitat, aquatic resources and biodiversity, but it is also increasing soil erosion, changing sedimentation patterns and shoreline configurations, increasing vulnerability to cyclonic storms, tidal bores and the denudation of feeding, breeding and nursery grounds of various marine, estuarine and fresh water fishery resources (Hossain et al., 2001b). Though the protective benefits of coastal mangrove plantation against cyclone and wave action have not been quantified, its importance is well recognized (Siddiqi et al., 1992).

1.5 Hydrology

The satellite-image revealed that most of the waterways are flowing in a westward direction from the high ridges on the east of the island to the Bay of Bengal. These include the Karia khal, Kohalia khal, Jamer khal, Um khal, Madardia khal etc. (Figure 4). Only a few small waterways flow eastward to the Moheshkhali channel; the two major canals on the east coast of Moheshkhali island are Gorakghata and Madirchara.

During the monsoon season freshwater is abundant, whereas during the winter water becomes a scarce resource. With deforestation, some canals overflow their banks during the monsoon months causing damage to crops, lives and properties. Occasionally a canal changes its course due to flash floods. Traditionally, the highly porous soils on the hills and high valleys have served as aquifers to store rainwater enabling continuous seepage supply to feed the canals during the dry season, but due to deforestation and thus reduced canal flow in winter, the surface water systems suffer from saline water intrusion, making the resource unsuitable for agricultural and domestic uses. The ground water aquifers in the coastal areas are also under growing stress of salinization resulting from over-exploitation. Sea level rise and low canal flows substantially contribute to that stress. Winter agriculture in the islands is dependent on ground water. Rural water supply almost entirely depends on surface freshwater sources.

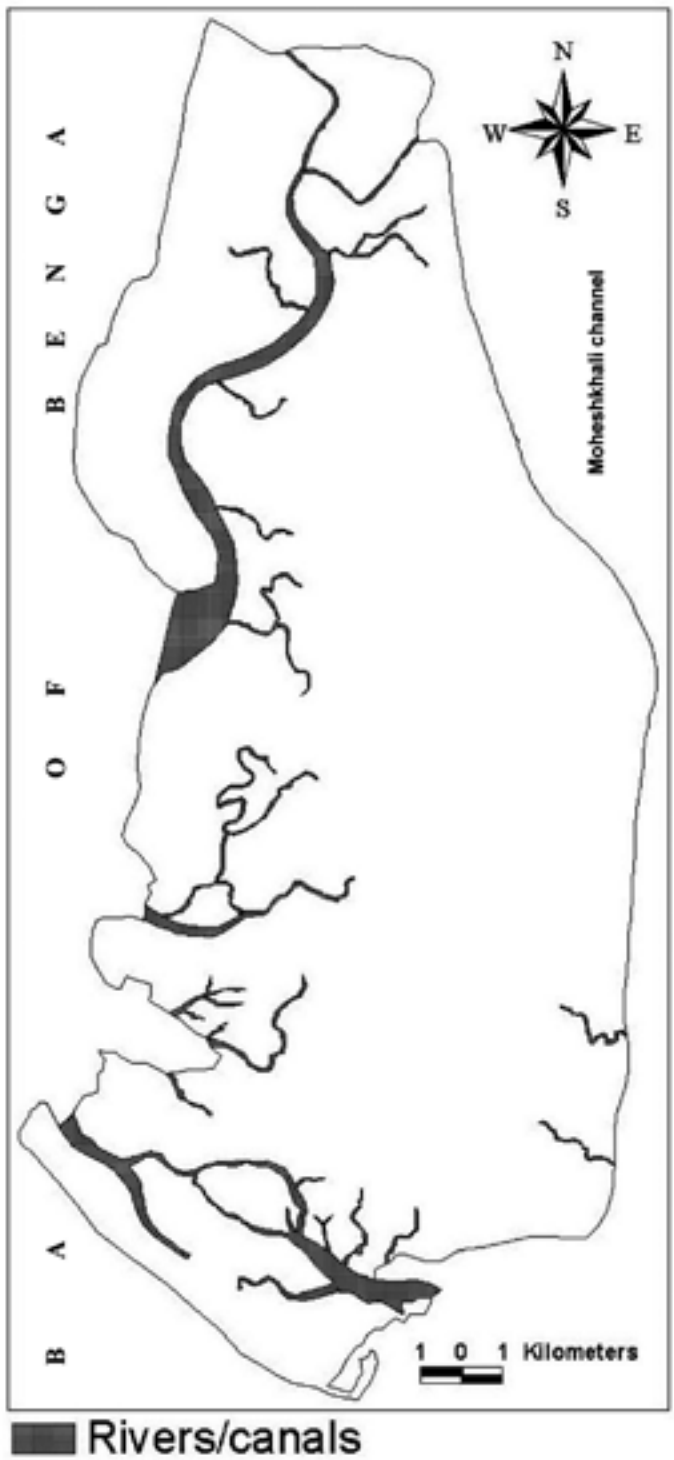


Figure 4. Waterways of the Koriardiar, Matarbari, Moheshkhali and Sonadia islands at Cox's Bazar, Bangladesh.

1.6 Physical processes

Tidal streams are important local mechanisms of water, nutrient, sediment and pollutant movement. They are also the reason why rich marine biota exist in coastal waters. Important also is tidal turbulence over the seabed, which mixes the water column vertically. Around the Moheshkhali Island tides are semi-diurnal with two periods of high and two periods of low waters during a lunar day. The tidal range is strong, ranging from 0.07 m at neap tide to 4.42 m at spring tide on the Cox's Bazar coast. The main, broad scale circulation in the marine water of Bangladesh is of clockwise and anti-clockwise rotation, which is created by the wind. The current velocity varies from 4.5 to 5.5 knots during spring tide in the summer monsoon, and 2.3 to 3.9 knots in the neap tide. Waves running up the coast often throw large numbers of organisms on to the beach, where they die. Wave height in the marine water of Bangladesh varies from 6-9 meter.

2. Socio-economic condition

According to the population census in 2001, there were 43,000 households in Moheshkhali Thana and the total population of these households was 246,000 with 52.44% male and 47.56% female (BBS, 2004). The coastal island communities of the Cox's Bazar coast are almost totally cut off from the rest of the country and the world at large. The people of the study area do not have adequate access to health, family planning, schooling, infrastructure and electricity. A large proportion of the community is illiterate; the average literacy rate is 28.8% with 32.5% male and 25.1% female. Television is expensive and in the absence of electricity often does not reach remote communities. In such a situation their only real access to information and news is radio and, of course, inter-personal communication (Hossain and Lin, 2001).

2.1 Occupations

The major occupations of the people are salt production, fishing, agriculture and shrimp farming, both as daily labor and owner-operators. One person may be engaged in two or more different occupations i.e., he may have shrimp ponds, salt beds and agricultural land. Some occupations are seasonal, so a person can take up different activities at different times of the year (Hossain and Lin, 2001). Cultivation of betel leaf in the hill valleys and foothills has recently increased rapidly, giving the island dwellers another employment opportunity. Some people are also engaged in small and cottage industries, particularly making bamboo materials and selling these in the local market (Figure 5).

Women are not involved directly in primary production sectors such as agriculture, sea salt production, aquaculture and fishing, but perform fisheries-related activities such as unloading, sorting, gutting, net mending, processing and marketing. These supplementary and supportive roles played by the womenfolk were succinctly described by Firth (1943), who noted that "when the fishermen comes in wet and tired after a days fishing he expects his wife to be down on the beach, to throw skids for the boats, help in the sale of fish, distribute the free catch allowance to crew members and carry back the husbands fishing gear to the house". Women's involvement in shorebased

Figure 5. Hand-made bamboo products in a local market of Moheshkhali island at Cox's Bazar, Bangladesh.

activities in small-scale fisheries is most evident in the seafood-processing sector, involving both home-based sun drying and industrial shrimp processing plants. Other economic activities involving extensive women's participation are fish trading and marketing. There are two categories of women fish traders, namely, those selling only the catch brought in by their husbands, and those who are engaged in the buying and selling of the fish traded in the market.

These development activities and increasing economic demands have resulted in excessive pressure on land. The adverse effects of land use changes on the physical environment and also on the socio-cultural situation are already noticeable and are alarming. Among the trading people, most are engaged in Cox's Bazar town in hotels and restaurants, selling of handicrafts and gift items for tourists, supplying of fish, shrimp and salt.

2.2 Seasonality

As noted above, many occupations are seasonal (Figure 6). Except for trading, no year round activities were found in these coastal islands. Shrimp farming is practiced in different seasons in two different zones i.e., in tidal lands during the winter season and in plain lands during rainy season. Both the plain lands and the tidal lands have been used for sea salt production during the winter season due to the high evaporation rate in November to April when the temperature is high, skies are clear and the windy season is in full progress. The coastal communities have taken full advantages of this seasonal variation to establish a salt evaporation industry. The island's communities catch fish from the nearby canals, rivers and the

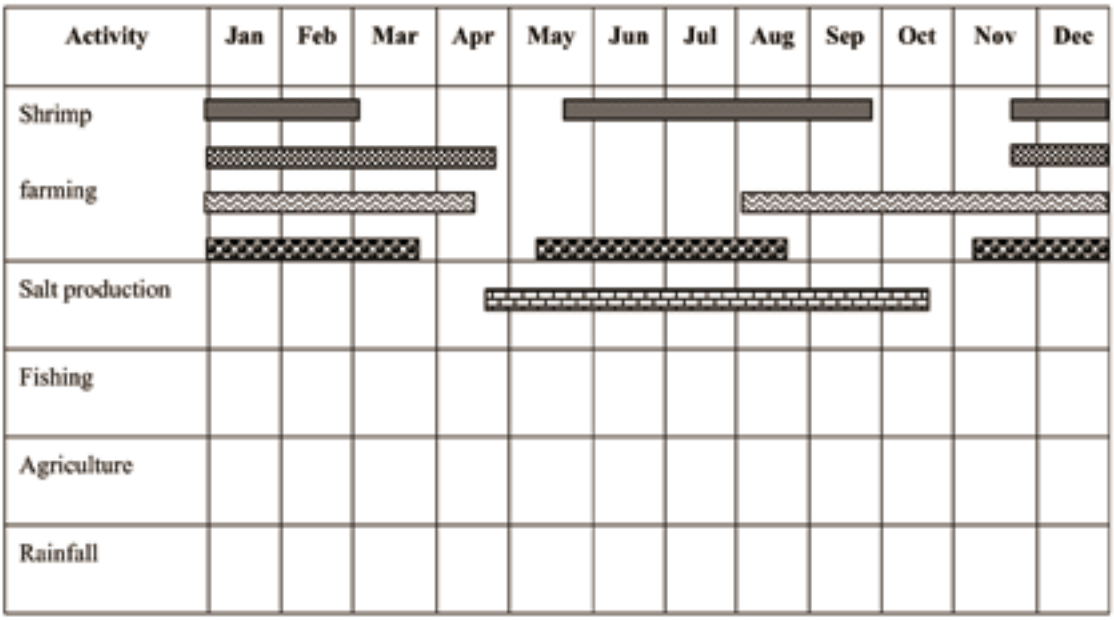
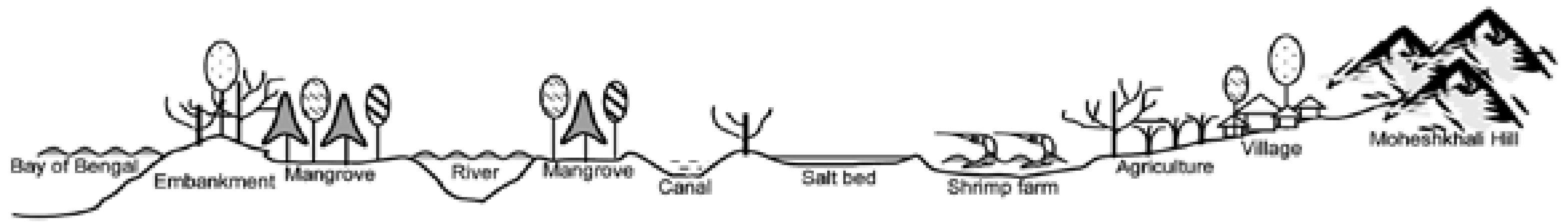


Figure 6. Seasonal calendar showing community activities in the Koriardiar, Matarbari, Moheshkhali and Sonadia islands at Cox's Bazar, Bangladesh.

Bay of Bengal for their own consumption and also for selling almost all round the year, except for the period of heavy rain (May to July) when there is rough weather and cyclonic storms associated with the southwest monsoon winds. Paddy is cultivated mainly in plain land during rainy season. Seasonal vegetable, peanuts, watermelon, and betel leaf grows in plain lands and hill slopes during the winter season.

2.3 Transect analysis

Land use pattern transects were made in several parts of the study area but the southwest to northeast direction across the Sonadia and Moheshkhali islands is presented as typical (Figures 3 and 7). Figure 7 shows the existing land use patterns and livelihood activities, problems and available opportunities for each land type. The Bay of Bengal, rivers and canals are important navigation routes and sources for fisheries resources, on which livelihoods of the coastal communities depend. Coastal erosion and storm surges emerged as a major problem, while localized water pollution occurs in some places due to agricultural runoff and upstream discharge. The mangrove forest is an attractive habitat for aquatic and terrestrial flora and fauna, and also acts as protective barrier against storm surges. Over-exploitation, cyclonic storms and clearance for saltpans and shrimp ponds are the major issues leading to mangrove destruction. Land ownership, heavy rain, salt price fluctuation are the major problems for the sea salt production, while shrimp farming is faced with disease problems, water pollution, and land use conflicts. Paddy, seasonal vegetable and betel leaf are cultivated for family consumption and sale but create a problem because farmers utilize pesticides



Land use	Bay of Bengal	Embank-ment	Mangroves	River	Mangroves	Canal	Salt bed	Shrimp Farm	Agriculture	Settlement	Mohesh-khali Hill
Resources	Fish, shrimp, oyster, mussel, coral reef, algae	Land, tree, grass	Aquatic and terrestrial flora and fauna	Fish, shrimp, oyster, mussel	Aquatic and terrestrial flora and fauna	Water, fish, shrimp, mussel	Land	Shrimp, fish	Land	Tree, livestock	Dense forest, birds, other organisms
Activities	Industrial fishing, navigation	Local transport, grazing	Feeding, breeding and spawning ground, collection of forest resources	Water supply, fishing, navigation	Feeding, breeding and spawning ground, collection of forest resources	Water supply, naviga-tion, shrimp fry collec-tion	Concentrate sea water, salt production,	Pond preparation, management, harvesting	Cultivation of rice, vegetable, betel leaf	Housing, gardening, poultry, social forestry	Community livelihood
Land type		Tidal land	Mangrove		Mangrove		Tidal land, plain land	Tidal land, plain land	Plain land, slope of the hill	Plain land, hill bottom	Hill

Problem/ issues	Erosion, accretion, water pollution, storm surges	Hamper adaptation of aquatic organisms	Overexploitation of resources, lack of proper management	Water contamination, reduce fishery resources	Over-exploitation of resources, lack of proper management	Water contamination	Land ownership, rain water, salt price fluctuation	Low production, diseases, water pollution, land use conflicts	Utilization of pesticides and chemical fertilizers	Lack of safe drinking water, toilet, electricity, transportation, education	Overexploitation of resources
Opportuni -ties	Domestic consumption and export of fishery resources, employment	Protection, shelter	Community livelihood, protection, shelter	Communi -ty livelihood	Community livelihood, protection, shelter	Community livelihood	Salt and high saline water selling	Family consumption of fish, shrimp export, employment	Family consumption, selling of products	Family consump- tion and selling of chicken, duck, goat, cow and different fruits	Protection, shelter

Figure 7. Transect analysis showing present land use pattern of Moheshkhali island at Cox's Bazar, Bangladesh

and chemical fertilizers.

3. Poverty alleviation and coastal development

The analysis of the socio-economic situation of the coastal islands of Cox's Bazar has demonstrated a complex livelihood system, which offers limited and highly seasonal opportunities for many local households, for whom securing a sustainable livelihood is made more difficult by isolation and deteriorating environmental conditions. The task of overcoming poverty in the islands is enormous and will require commitment and hard work. Funds for poverty alleviation initiatives from the government and NGO allocated every year are mainly composed of relief payments and special micro-credit schemes. Such funds are not sufficient to root out poverty. It is important to offer farmers and fishers improved income generating opportunities enabling them to take advantage of the major resources available in the islands. These possible opportunities are reviewed below.

3.1 Agricultural development

Since the main source of livelihood for rural residents is agriculture, there is a need to push for rural development through increased support for agriculture-related activities. The elevated plain lands and the foothill slopes of the islands are suitable for agriculture. Homestead lands are slightly shady due to use of fruit and timber trees but nevertheless suitable for field crop and vegetable cultivation. Fresh water from household ponds and hill streams are already pumped for boro paddy and winter vegetable cultivation. Agri-cultural zonation is a key function of agricultural planning and design (Jianbo, 1997). Satellite images and air photos are widely applied in many countries to agricultural zonation, for creating a variety of agricultural maps and collecting resource information. Because of their high quality and expedient availability, satellite images play an important role in various aspects of agricultural zonation. The information on topographic features, meteorology, hydrology, and soil suitability for certain crops are important to local farmers that contribute to agricultural productivity and profitability. Evaluation of the available resources of the coastal islands, derived from space technology applications (such as remote sensing and GIS) can go a long way towards improving the economic conditions of coastal rural people through sustainable resource utilization.

3.2 Aquaculture development

One strategy which may be followed is the key production area (KPA) approach, which identifies and focuses the support of government and the private sector on certain priority areas whose climatic features and market conditions are favorable for producing, processing, and marketing specific products. Strong international demand, combined with static supplies of shrimp from capture fisheries and the promotion of shrimp culture by national leaders, development agencies, and private sectors has created the opportunity for shrimp culture in the coastal zone, including the islands of Cox's Bazar. During the late 1980s and early 1990s shrimp farming areas rapidly increased on leased lands of the intertidal zone, flood plain and mangrove forests, employing extensive or traditional methods, and achieving an average yield of 230 kg/ha (Hossain et al., 2001b). Following

an attempt to stock at high density to drastically increase the production of Penaeus monodon, farms along the Cox's Bazar coast went bankrupt in mid-1990s as a result of sudden outbreak of diseases caused by pollution from pond discharge. The major pollutant was organic wastes and the breakdown of nitrogen and phosphorous products; it is unlikely that toxic substances were introduced into culture facilities. An empowered farming and fisheries sector will, in turn, make higher farm-productivity and better cost-efficiency possible. Ultimately, such improvements will pave the way towards global competitiveness in aquaculture. Another element of the KPA approach is the optimization of land use, which can be achieved through the judicious management of natural resources, while simultaneously using appropriate, cost-efficient, and environment-friendly strategies and technologies. As shrimp have been cultured along the coast for quite a long period, the local people can utilize their experience of the local environment and the knowledge gathered from researchers in selecting suitable shrimp farming areas. The art and science of pond culture has largely evolved to its present form through the individual efforts of farmers, researchers and commercial companies. The government scientific community has played a minor role in this evolution (Hossain, 2001).

3.3 Sea salt production

As salt has been produced traditionally along the coast for quite a long period, the local people can again utilize their experience of the local environment (BSCIC 2001) and knowledge gathered from researchers in selecting suitable salt production areas. The methods used to recover salt from seawater in coastal islands are labor intensive. The salt beds are leveled and compacted using rollers at the onset of the dry season in November-December so that the brine solution will not seep into the soil. Each area is divided into many saltpans which function variously as reservoirs, condensers and crystalizers. The production cycle is completed within 7-10 days, depending on the environmental condition, area of salt beds and amount of water introduced. This is a cyclical system that starts in November and ends in April or sometimes the first half of May along the Cox's Bazar coast. The salt may be washed and stacked to improve its color and remove some soluble and insoluble impurities. About 19,670 ha area is currently used for salt production in different thanas along the Cox's Bazar coast, including the coastal islands, and annual average salt yields are around 21.5 m ton/ha (Hossain et al., 2003b).

3.4 Coastal fisheries

Coastal fishing is another important occupation for the islanders. Fishing is undertaken the whole year round using different types of fishing gear. However, there are about 3 months in a year, from May to July that fishing is not so active because of its low productivity and storm surges in the Bay of Bengal coast. Fishers employ more than one type of gear to meet the variability of fish species available in different seasons. For example, set bag nets, seine nets, hooks and lines are effective in the period of September to May, and gill nets and fish trap are used mainly in the period of May to August. The present mode of fishing is more market-oriented than subsistence-

oriented, as the daily living of community members depends heavily on cash, as a result of the intrusion of the market economy into the islands.

Conclusion

Application of advanced technologies and people-centered participatory methods are the best approach for the provision of timely and reliable information of better decision making. The integration of a simultaneous top-down (RS and GIS) and bottom-up (RRA/PRA, ground truthing, field observation) approach can ensure cross-validation of sensitive information on natural resource base and sectoral harmonization with local needs. It ensures maximum use of indigenous knowledge and expertise to provide information on the resource base and to complement the scientific knowledge for management.

The tidal and plain lands of the coastal islands of Koriardiar, Matarbari, Moheshkhali and Sonadia have been used mainly for the production of sea salt and shrimp but the suitability depends on the seasons. A rotational system i.e., shrimp farming during the monsoon months (May to October), and salt production during the summer months (November to April) may offer the key to sustainable management. This will maximize productivity from smaller area through vertical integration and improve the socio-economic condition of the people as well as maintain the ecological balance in the coastal region. The islands communities have been shared the marine fisheries resources of the Bay of Bengal and adjacent water areas, which helps in their livelihood practices. The hills are an important resource for environmental protection. Hill forestland has been converted for human settlement, seasonal vegetable, betel leaf grounds and many other development measures. Settlement pattern of the coastal islands has been controlled by its physiography and mostly located along the hillsides. Local communities have come to depend upon the mangrove forest for many household necessities, such as firewood, housing materials, boat making materials, herbal plants for traditional medicines, honey and other minor products. Combination of hills and coast provide the region an extraordinary scenic beauty, which is suitable for coastal eco-tourism development.

The present study suggests that the land should be divided into different zones on the basis of suitability. Establishment of zones in the coastal islands can ensure, most importantly, optimal allocation of resources for particular activities and, secondly, minimization of conflicts between different users. Coastal island development can be defined as island "people development", thus it is essential to "go to the people, learn from the people, and plan with the people". The results of the present study is a good example of integrated approach that combined information from remote sensing imagery, topographic and land type maps and Rapid Rural Appraisal, including field observation by multi-disciplinary researchers. As this study is first time of its kind in the coastal islands of Bangladesh, the results may help to identify and to determine the trends of coastal resource of Bangladesh and guide the utilization pattern in

sustainable way for socio-economic development of other coastal communities in the world.

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