

POPULATION AND LAND COVER DYNAMICS OF SUNDARBANS IMPACT ZONE IN BANGLADESH

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Abstract

Sundarbans is the largest mangrove forest of the world that lies in Bangladesh and India. This paper examined the correlation among population dynamics of Sundarbans impact zone (SIZ) from 1974 to 2011; impact of climate change on the forest; and changes in land cover of the forest from 1973 to 2010. Population size of SIZ was increased by 1.6 times between 1974 and 2011, whereas decreased by 2% during 2001 to 2011. During 1973 to 2010, water bodies, barren land and vegetated land reduced by 7.35%, 49.56% and 15.92% respectively; while grass land increased by 228.14% during the same period. But both population size and vegetated land declined during 2001 and 2011. This was due to the landfall of two severe cyclones in 2007 and 2009 through Sundarbans which resulted thousands of human casualties and out migration, and destruction of the forest. In addition, anthropogenic interventions like low flow from Ganges River and policy constraints also contributed to the demolition of Sundarbans. Thus, population growth, climate change and anthropogenic interventions are playing a decisive role to the depletion of forest resources from the Sundarbans mangrove forest.

Keywords: Sundarbans reserved forest, Sundarbans impact zone, population dynamics, climate change, land cover change

1. Introduction

The densely populated and climate fragile Bangladesh has shared the world's largest mangrove forest with India. Around 38% of the world's mangroves occur in Asia of which Indonesia alone accounts for 19% (FAO 2007). Sundarbans mangroves forest (SMF) is the largest contiguous coastal wetland system in the world. This forest is also one of the productive mangrove wetland ecosystems in the Ganges-Brahmaputra delta (Islam – Gnauck 2008). The area of the Sundarbans forest cover is about 10,000 km² in southwest Bangladesh (known as Sundarbans reserve forest, SRF) and West Bengal (known as Sundarbans National Park) of India (UNESCO WHC). Around 62% of the forest covers lies

in Bangladesh, while the remaining 38% is in India (Siddiqi 2001; Lacerda 2001). The SRF is located at the southern edge of Gangetic delta bordering Bay of Bengal and is bounded by Baleswar River on the east and Harinbanga River (international boundary with India) on the west (UNESCO WHC). The SRF covers an area of 6,017 km² which accounts for 4.07% of total area of Bangladesh and 40% of total area managed by Forest Department of Bangladesh (BBS 2014). The Sundarbans Reserved Forest is both a Ramsar site, since 1992, and a World Heritage site of the UNESCO since 1997 (FAO 2007). This forest provides natural protection to the lives and properties of coastal communities from cyclones and storm surges.

Around 2% of the total labor of Bangladesh was engaged in the forestry sector in 2013 and contributed about 2% of total Gross Domestic Product (GDP) of Bangladesh (BBS 2014). The SRF contributes about 41% of the total forest revenue (Islam 2010). The SRF is surrounded by a very densely populated area who are mostly depends on Sundarbans for their livelihoods. Approximately 2.5 million people live in the small villages surrounding the Sundarbans, while the number of people within 20 km of the Sundarbans boundary is 3.14 million (MARC 1995). Numerous people engage in commercial exploitation of Sundari (*Heritiera fomes*), Gewa (*Excoecaria agallocha*), Goran (*Ceriops decandra*), and other tree species, while local people depend on forest for firewood, timber for boats, poles for house-posts and rafters, golpata (*Nipa fruticans*) leaf for roofing, grass for matting and fodder, reeds for fencing, and fish for their own consumption. There is no permanent settlement in SRF (Chaffey et al. 1985). But the forest is under threats due anthropogenic interventions. The SMF was about 16,700 km² around 200 years ago (Banglapedia 2015) which has now dwindled down to half of its original size, the rest of the land being deforested and converted to agricultural landscape (Hussain - Archarya 1994).

Mangrove ecosystems of the world are threatened through various forms of human pressure, in particular extraction, pollution and reclamation (Akhter 2006). High population pressure in coastal areas has led to the conversion of many mangrove areas to other uses (FAO 2007). According to 2011 census, the total population of Bangladesh was 149.77 million with a density of 1015 per km² (BBS 2011). The heavy population pressure is placing growing demand on natural resources, especially forest sector. At approximately 0.0002 km² per person of forest, Bangladesh currently has one of the lowest per capita forest ratios in the world (Zaman 2011).

There is a reciprocal relationship between population factors (size, distribution and composition) and environmental factors (air, water and surface forms). This relationship (population-environment relationship) is affected by some intervening factors which include social, political, technological and cultural factors. The objective of this paper was to explore the correlation among population dynamics of Sundarbans impact zone (SIZ), impact of climate change on Sundarbans and changes of land cover in SRF. To describe the correlation, this research used population and environment framework which was proposed by MacKellar et al.

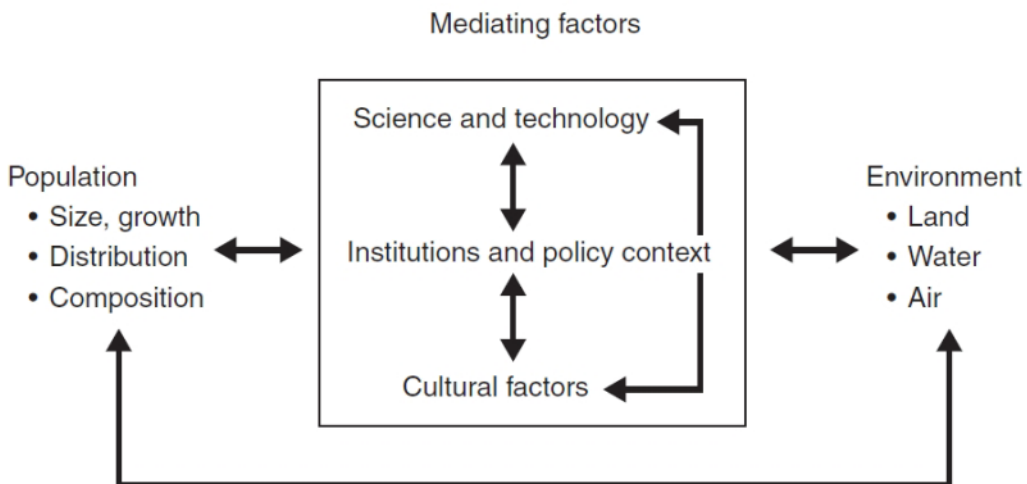


Fig. 1. Framework for population and environment linkage (Adopted from Hunter 2000)

(1998) as shown in Fig. 1. Specifically, this framework described following aspects:

- Relationship between population factors (size, distribution and composition) and environmental change
- Primary forces that mediate this relationship: science and technology, institutional and policy contexts, and cultural factors
- Environmental implications that are affected by population dynamics (climate change and land-use change).

Emch and Peterson (2006) used normalized differential vegetation index (NDVI), maximum likelihood classification, and subpixel classification methods to reveal spatial distribution of deforested areas of Sundarbans from 1989 to 2000. The study of Islam (2014) discovered that Sundarbans mangrove forest (both in Bangladesh and India) decreased by 19.3% due severe tropical cyclone in 1977 and 1988. Islam (2014) argued that the fate of Sundarbans depends to climatic issues e.g., salinity, frequency of

severe tropical cyclone and tidal effect those directly depend to global warming.

Rahman et al (2013) studied on the effectiveness of different classification methods for extraction of Mangrove forest in Sundarbans using Landsat ETM+ data and found that the band ratio/supervised classification approach produces the best accuracy in detecting the mangrove class. Giri et al. (2007) studied on Sundarbans forest dynamics (both India and Bangladesh) using multi-temporal satellite data from 1970s, 1990s, and 2000s through supervised classification approach. Their study found that areal extent of Sundarbans mangrove forest has not changed significantly (approximately 1.2%) in the last 25 years and the forest is constantly changing due to erosion, aggradation, deforestation and mangrove rehabilitation programs. The study of BIDS (2010) described the socio-demographic dynamics of SIZ.

Therefore, this present research work

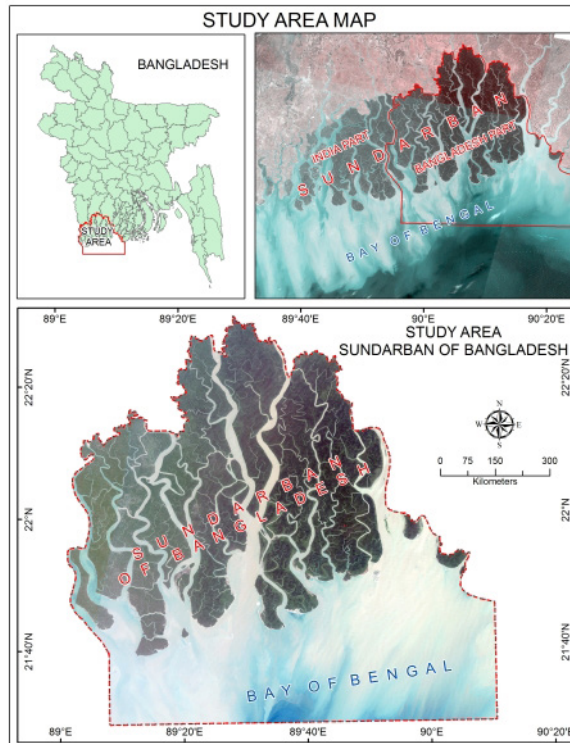


Fig. 2. Map of study area

Table 1. Land cover classification scheme of SIZ

Land cover types	Description
Barren land	Exposed soils/ sandy surfaces in SIZ
Grass land	Small woody or non-woody plants in SIZ
Vegetation	Dense vegetation (mangrove and non-mangrove) in SIZ
Water body	River channels, rivulets and canals in SIZ

examined the role of demographic variables of SIZ and impacts of climate change to change the land cover of Sundarbans over the last four decades (during 1973 to 2010). Sundarbans has a highly fragile ecosystem and its delicate balance may be adversely affected if these (demographic and climate change) pressures are not dealt with.

2. Methods and materials:

The coastal zone of Bangladesh consists of 19 districts comprising 147 sub-districts and exclusive economic zone (Islam 2004). The periphery of the SRF includes the legally declared 'ecologically critical area' assumed to be within a 20 km band surrounding the SRF (BIDS 2010). This area is called Sundarbans impact zone (SIZ) which is shown in Fig. 2. The SIZ comprises 5 districts (Bagerhat, Khulna, Satkhira, Pirojpur and Barguna), 10 sub-districts (Bagerhat Sadar, Mongla, Morrelganj, Sarankhola, Dacope, Koyra, Paikgacha, Shymnagar, Mathbaria and Patharghata) (BIDS 2010).

Population data of SIZ were collected from census reports for 1974, 1981, 1991, 2001 and 2011 of Bangladesh Bureau of Statistics (BBS). Policies and research works related to climate change impact on Sundarbans mangrove forest were systematically reviewed to understand the impact of climate change on Sundarbans. To detect changes in vegetation cover of SIZ between 1973 and 2010, this study used Landsat images of January-1973, January -1978, January -1989, January -2001 and January -2010 obtained from United States Geological Survey (USGS), Global Visualization Viewer (Glovis). Multi

Spectral Scanner (MSS), Thematic Mapper (TM) and Enhanced Thematic Plus (ETM+) sensor used to generate land cover maps in satellite image. For digital image processing, ERDAS Imagine 2013 was used. Layers stacking method was applied because of using different bands (or layers) of information. In order to make clear visualization of the objects, histogram equalization method applied and haze reduction tool used for improving the quality of the images. Then radiance was calculated from the digital number. After visual interpretation, a land cover class scheme was developed (Tab. 1). Normalized Difference Vegetation Index (NDVI) was calculated from the visible and near-infrared light reflected by vegetation using the following formula (NASA-EO, 2015):

$$NDVI = (RNIR - RRED) / (RNIR + RRED)$$

where,

RNIR: near-infrared reflectance

RRED: visible reflectance

RNIR: near-infrared reflectance

RRED: visible reflectance

NDVI of Landsat images were generated using the conditional logic. Then the area covered by each category was derived. NDVI value of raster layer was classified using the supervised classification scheme as barren land (0-0.2 μm), grass land (0.2-0.3 μm) and vegetated land (0.3-1.0 μm). NDVI value of less than and equal to 0 (zero) was kept out as water body. A detail classification scheme was shown in Tab. 1. Finally, vector maps of 1973, 1978, 1989, 2001 and 2010 were prepared using ArcGIS 10.1 software.

3. Results of the study

Population factors

Sundarbans impact zone covers an area of around 6% land of Bangladesh. More than half of total impact zone is shared by Shyamnagar, Koyra and Dacope sub-district. According to 2011 census, SIZ districts had a population of 7.8 million which constituted about 5.4% of total population of Bangladesh and around 2.2 million people inhabited in SIZ sub-district (Fig. 3) which was almost 1.5% of country's total population (BBS 2011b; BBS 2011c; BBS 2012; BBS 2013).

Population size of Bangladesh was nearly doubled between 1974 (76.4 million) and 2011 (144.04 million) (BBS 1976; BBS 2011b). At national level, population size

increased by 60% during 1981 (90 million) to 2011 (144.04 million), while at the same period, population size for Morrelganj, Bagerhat, Sarankhola, Dacope, Shyamnagar, Mongla, Paikgachha and Koyra sub-district increased by 8%, 28%, 28%, 31%, 36%, 40%, 41% and 55% respectively (BBS 1991a; BBS 1991b; BBS 1992a; BBS 1991b; BBS 1993; BBS 2011b; BBS 2012; BBS 2013). This indicated that growth of population in SIZ sub-districts in 2011 did not surpass national growth. In sober fact, absolute size of population in SIZ locality decreased in 2011 compared to 2001 census (Fig. 3).

At national level, a steady decline in population growth rate was observed since 1974, whereas, during 2001 to 2011, population growth rate was found negative for Bagerhat and Khulna district (Table 2).

Table 2. Population growth rate of SIZ districts and Bangladesh (compiled from censuses of 1974, 1981, 1991, 2001 and 2011)

Area	Census year				
	1974	1981	1991	2001	2011
Bagerhat	2.62	1.6	1.75	0.79	-0.47
Satkhira	3.45	1.7	1.66	1.56	0.62
Khulna	5.12	2.48	1.28	1.7	-0.25
Pirojpur	2.35	1.41	1.16	0.44	0.02
Barguna	2.53	1.89	1.36	0.9	0.5
Bangladesh	2.48	2.35	2.01	1.58	1.47

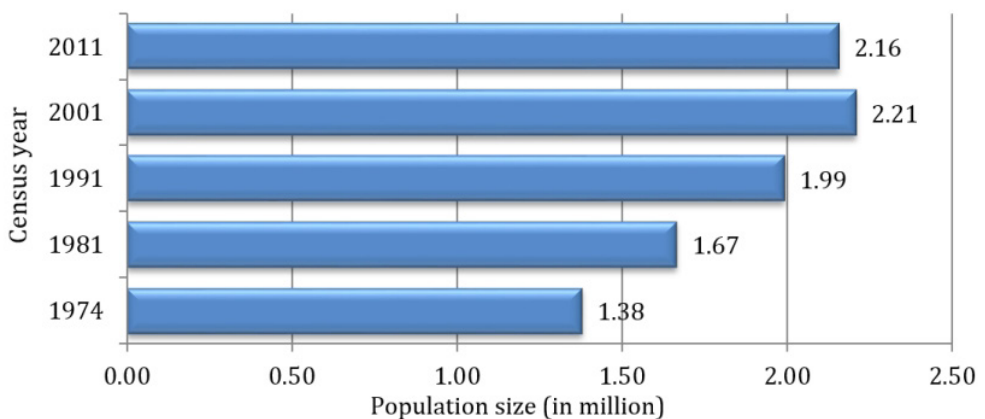


Fig. 3. Year wise population SIZ sub-districts

Moreover, population growth rate was recorded as negative for Mongla, Dacope, Morrelganj, Paikgachha and Mathbaria sub-district in 2011 (Fig. 4.). This means absolute decrease in population size in those sub-districts (Fig. 3.). Although population growth rate for Bagerhat Sadar, Sarankhola, Koyra, Shymnagar, and Patharghata sub-districts were positive, the rate was drastically dropped for every sub-districts in 2011 in contrast to 2001 (Fig. 4.) (BBS 1976; BBS 1991a; BBS 1991b; BBS 1992a; BBS 1991b; BBS 1993; BBS 2001a; BBS 2001b; BBS 2011b; BBS 2012; BBS 2013).

In 2011, population density in SIZ districts (556 per km²) and SIZ sub-districts (426 per km²) were below the national average (976 per km²). In fact, in all SIZ localities population density increased since 1981. The highest absolute change in population density observed for Bagerhat Sadar (from 763 per km² in 1981 to 977 per km² in 2011). On the other hand, during 2001 to 2011, the density of population decreased remarkably in some SIZ sub-districts like Mongla (8.8%), Morrelganj (15.7%) and Dacope (3.1%). This tendency was also recorded at some SIZ districts like Bagerhat (4.6%) and Khulna (2.4%).



Fig. 4. Comparison of population growth rate of 2001 and 2011 in SIZ sub-district

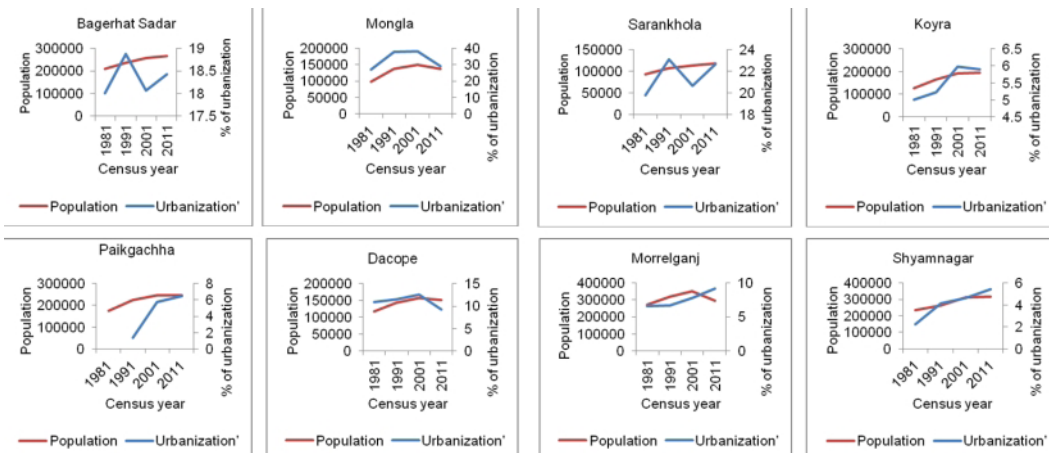


Fig. 5. Population size and urbanization rate of SIZ sub-districts

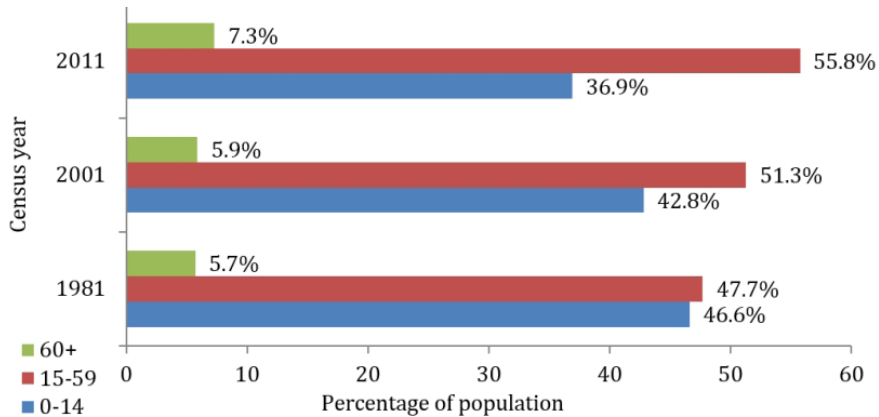


Fig. 6. Age group wise population composition of SIZ districts

Bangladesh has been experiencing a rapid urban growth since 1974. The percentage of urban population increased gradually from 8.78% in 1974 to 28% in 2011 (BBS 2011c). Compare to national level, urban growth for SIZ sub-districts were slowed. Most of the SIZ sub-districts hardly crossed double digits of urbanization rate in 2011. Urbanization rate for cyclone Sidr and Ayla affected SIZ sub-districts were declined in 2011 compared to 2001 (Fig. 5) like Mongla (29.17% in 2011 from 38.08% in 2001), Koyra (5.89% in 2011 from 5.98% in 2001) and Dacope (9.31% in 2011 from 12.57% in 2001) (BBS 2011c).

Population composition in SIZ locality changed significantly during 1981 to 2011 (Fig. 6). A smooth increase was observed for 15-59 years age group during 1981-2011 (2011a). Most of the people of this age group directly or indirectly engage in Sundarbans resources extraction. Hence, changes in age structure are closely associated with resource extractions.

Environmental factors

The coast of Bangladesh is a global hotspot for tropical cyclones. Coastal zone represents around 32% of Bangladesh's total land area and about 10% of the country's total land lies within one meter above mean sea level. Over the last few decades, the numbers of cyclone formations and landfalls has been increasing in Bay of Bengal. In the last

decade (2001s), several cyclones landfall through Sundarbans, the most devastating were cyclone Sidr (landfall on 15 November 2007) and cyclone Ayla (landfall on 25 May 2009). These two cyclones endangered lives and livelihoods of coastal communities and impact of climate change in southern coastal zone has become more pronounced after the cyclones.

The Sundarbans is already affected by increasing salinity and extreme weather events. The freshwater flow in Sundarbans depends on upstream river flow (Transboundary Rivers). Gorai River (a tributary of Ganges) carries freshwater for Sundarbans. But the natural flow of Gorai River has been disrupted after the construction of Farakka barrage on Ganges River by India in 1975 about 190 km upstream of the Gorai River mouth to divert Ganges River water through Hoogly River to Kolkata port. Since then dry season flow of Ganges River or Padma River dropped dramatically. Since 1988, Gorai River has completely disconnected from Ganges flow during dry season (November to April). Freshwater flow through creeks and rivulets of Sundarbans helps to flush salinity off from the forest floor of Sundarbans. This chronic disturbance of freshwater flow altered salinity regime of Sundarbans.

Salinity of Sundarbans increases from east to west and, hence, density of vegetation growth and canopy closure decreases from

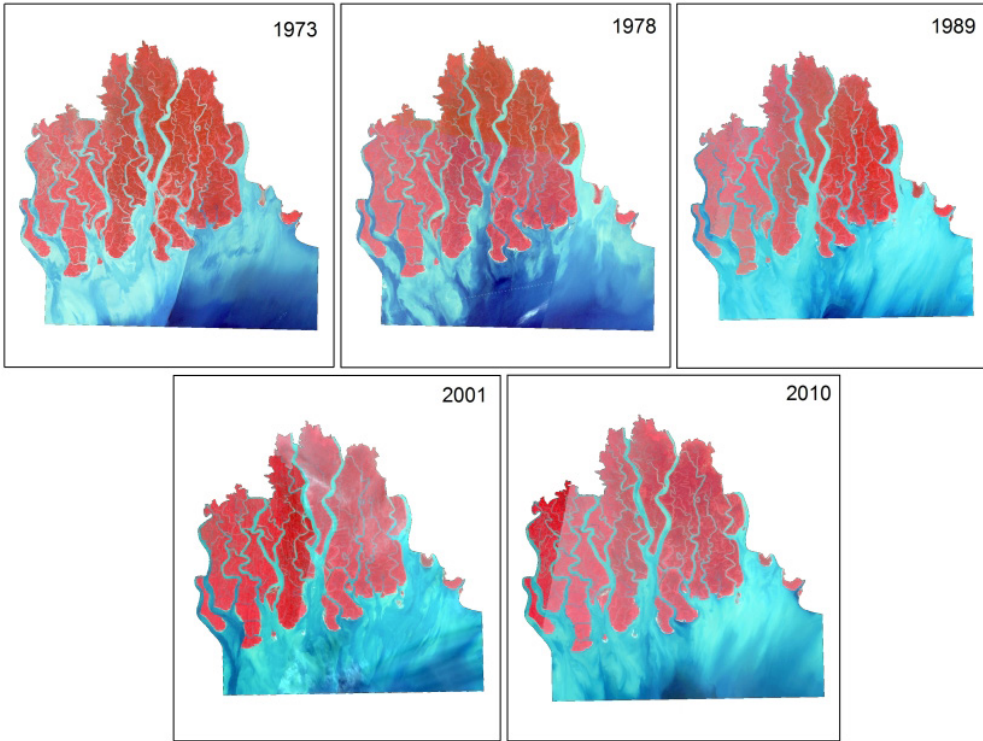


Fig. 7. Landsat images of Sundarbans from 1973 to 2010

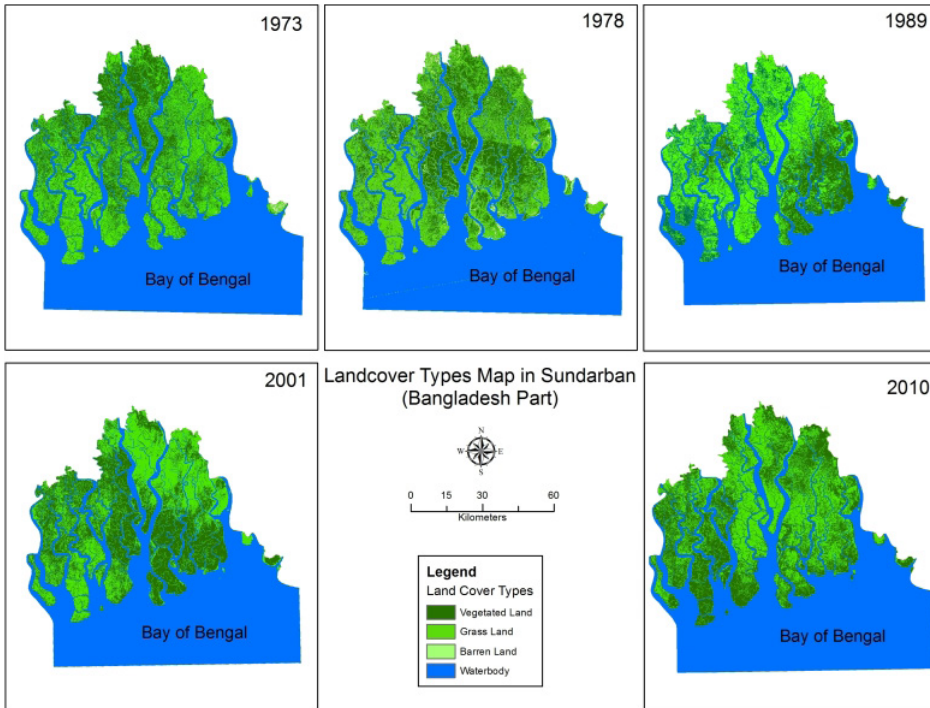


Fig. 8. Land cover map of Sundarbans from 1973 to 2010

Table 3. Areas of different land cover classes of Sundarbans (areas in km²)

Land cover	1973		1978		1989		2001		2010	
	Area	%	Area	%	Area	%	Area	%	Area	%
Water body	5488.04	58.79	5456.85	58.49	5341.20	57.32	5218.19	56.01	5084.92	54.52
Barren land	820.12	8.78	308.71	3.31	154.88	1.66	733.28	7.87	413.69	4.43
Grass land	526.17	5.64	1132.98	12.15	1513.15	16.24	1126.40	12.09	1726.57	18.51
Vegetated land	2501.05	26.79	2429.86	26.05	2308.36	24.78	2238.13	24.03	2102.94	22.54
Total area	9335.38	100	9328.40	100	9317.59	100	9316.00	100	9328.12	100

east to west. Height and growth of different mangrove species in Sundarbans are correlated with salinity level. For example, Sundari trees grows in low saline zone (5~10 ppt), Gewa in moderate saline zone (10~25 ppt) and Goran in high saline zone (over 25 ppt). The degree of salinity has strong influenced on regional distribution of species and stand-height of trees in Sundarbans. Sundari trees are being destroyed by outbreak of top-dying disease. Sea level rise also poses another threat to Sundarbans.

Land cover change of Sundarbans reserve forest

The Landsat images of SIZ were shown as Landsat images of Sundarbans (Fig. 7.). NDVI of different land cover classes (Fig. 8.) were calculated from the subsets of Landsat images of 1973, 1978, 1989, 2001 and 2010.

These values were converted into areas and presented in Table 3.

Areas occupied by water bodies in 1973, 1978, 1989, 2001 and 2010 were 5488.04 km², 5456.85 km², 5341.20 km², 5218.19 km² and 5084.92 km², respectively. Percentage occupied by water bodies to total area decreased from 58.79% in 1973 to 54.52% in 2010. Water bodies decreased about 7.35% over the last 37 years. On the other hand, area covered by barren land in 1973 was 8.78%, which was decreased in 2010 and made up 4.43% to total study area.

The most significant changed of land cover found for grass land (Fig. 9.). Grass land made up around 5.54% of total area in 1973 and increased to reach 18.51% by 2010. Dense vegetated land (both mangrove and non-mangrove) decreased notably during 1973 to 2010 (Fig. 9.). Vegetated area occupied

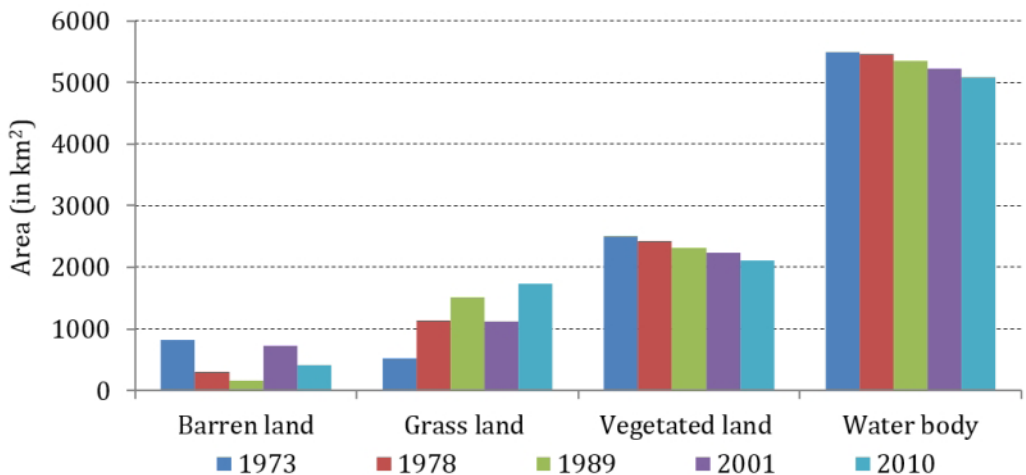


Fig. 9. Areas occupies by water bodies, barren land, grass land and vegetated land

2501.05 km² in 1973 which further dropped to 2102.94 km² in 2010.

The highest rate of decline of vegetated land observed during 2001 to 2010 period which was 6.04%, followed by 5.00% between 1978 and 1989. Regional variations of vegetation coverage were also prominent. Dense vegetation coverage was apparently distributed uniformly in forest except 2010. During this period vegetated land was more agglomerated in western part than eastern part (Fig. 8.).

Intervening factors

National and international policies and legislations play a significant role to conserve as well as depletion of forest resources. The legal forest cover of Sundarbans has not changed in the last four decades and theoretically, it is now well conserved. But it is difficult to conserve Sundarbans from the least flow of Gorai River that adversely affected SMF. India constructed a barrage (Farakka barrage) to divert Ganges River water, and as a result, southern part of Sundarbans is facing serious salinity problems. Reduction in freshwater flow through Sundarbans is one of the reasons of decreasing the abundance of Sundari tree form Sundarbans.

Institutional response represents a significant mechanism through which humans react to environmental change. In particular, policy plays a key role in determining ultimate effect of humans on environment. Hypothetically, if government of Bangladesh takes effective and efficient legal measures to conserve Sundarbans from illegal harvesting and if there is no climate change impact, even Sundarbans will further be degraded because of lack of policy integrations. The oil spills (9 December, 2014) at Shela River threatened trees, plankton, and vast populations of small fish and dolphins of Sundarbans. Even after such a disaster government did not show any attempt to restrict vessels movement through Shela River and other linked channels of Sundarbans. In addition,

government has also planned to install 1320 megawatt coal-fired power station at Rampal sub-district of Bagerhat district which is situated 14 kilometers north of Sundarbans. This project will not only worsen ecosystems of Sundarbans, but may also degrade ecologically sensitive SIZ locality through changing micro-climatic variability.

Population and poverty processes are intimately linked to forest cover change. The percentage of extreme poor (lower poverty line) people in 2010 in SIZ sub-districts (for example, Sarankhola, 28.2%; Shyamnagar, 33.8%; Koyra, 29.1%; Dacope, 24.9%) were higher than the national average (17.6%). These extreme poor people generally engaged themselves in extracting natural resources either from Sundarbans or from common property. The impact of climate change in south-western coast of Bangladesh is now visible. Population growth and climate change may speed up poverty trap in SIZ locality. Demand for timber from Sundarbans is also another cause for forest degradation. Unfortunately, this demand leads to illegal logging and cutting down of major species from Sundarbans (e.g. Sundari, Gewa, Goran trees).

4. Discussions

The linkage between environment and population trends is a less documented phenomenon for SIZ. The high rates of population growth in SIZ locality during 1980s and 1990s had significant environmental implications on Sundarbans. Increase in population in SIZ localities also caused increased demand for food and arable land. Moreover, agricultural expansion in the form of shrimp farming encouraged deforestation and encroachment of coastal land, which in turn contributes to micro-climatic change. Population growth also associates with increased demand for energy, especially fuel wood from forest, which provides energy to virtually all rural frontier population of SIZ.

According to FAO (2007), Sundarbans

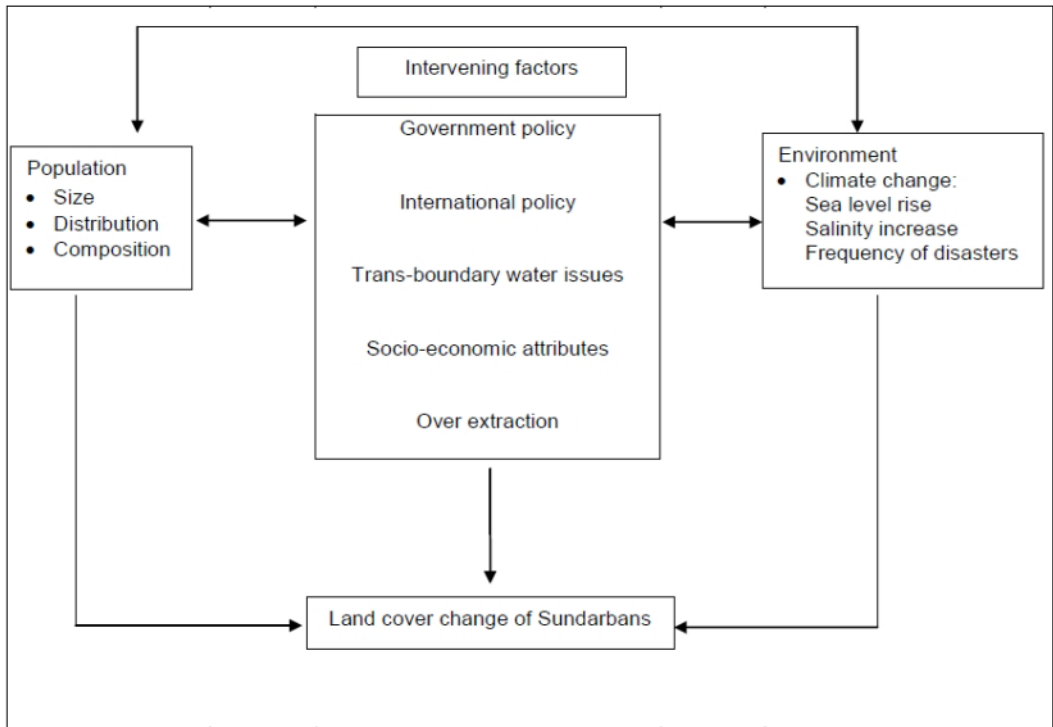


Fig. 10. Population and environment relation of Sundarbans (as proposed by the author)

Reserved Forest is well protected, and no major changes have been found during 1980 to 2005. This study was also found similar results. However, this study found significant changes within the land cover classes of Sundarbans throughout the study period.

In general, population size and composition, and urbanization are interrelated with consumption and depletion of resources. During 1981 to 1991, population size of SIZ increased by 20% whereas number of trees per square kilometer in SRF decreased by 25% (Forest Inventory of 1983 and 1996) (Chaffey et al. 1985; Choudhury - Hossain, 2011). Population size is associated with harvesting of wood for fuel. Around 57% (BBS 2011) population of SIZ districts used wood for cooking. This figure was higher for rural settings of SIZ. Level of urbanization in SIZ sub-districts were very slow and below national level. Therefore, most of the frontier people basically depend on primary level economic activities especially collecting and gathering of natural resources from

Sundarbans. At the same time, commercial shrimp cultivation increased in many folds that played a significant role to alter climatic variability of SIZ localities.

During 1973 to 2010, water bodies, barren land and vegetated land decreased by 7.35%, 49.56% and 15.92% respectively; whereas grass land increased by 228.14% during same period. This implied density of evergreen vegetation and its canopy closure decreased. This study found significant relationship between changes in population size and vegetated land. During 2001 to 2011, population growth rate of SIZ sub-district was negative, yet vegetated land decreased. This finding could be explained by climate change only. Coastal zone was affected by two major consecutive cyclones (Sidr and Ayla) in 2007 and 2009. As a result, thousands of people were displaced on embankments, roads or other collective centers. Many people migrated from SIZ for searching livelihoods. Therefore, it can be summarized that population growth, climate change

and some intervening factors contributed to change land cover of Sundarbans over the last four decades. This research thus proposed a modified version of population and environment interaction in the context of Sundarbans reserved forest.

Sundarbans mangrove ecosystems hold remarkable value for south-west coastal communities and for country as a whole. But forest resources are being destroyed at alarming rates, although total forest cover has not changed significantly. To stop and reverse current trend of resource depletion from SRF, effective, time fitting and efficient measure need to take by forest department of Bangladesh. It is also urgent to improve institutional and management capacity of forest department. Geographical information system (GIS) and remote sensing base regular monitoring system could be a sophisticated tool to identify temporal and spatial change of forest cover. To stop illicit resource extraction by influential people and frontier communities, patrolling systems need to be increased and modernized. Thousands of people of SIZ actively involves in SRF resource collection. Thus, creation of alternative livelihoods for Sundarbans dependent communities can reduce overload from Sundarbans. Outcome oriented planning for alternative livelihood generation is also indispensable. In addition, temporal ban of Sundarbans resource extraction (such as leaves collection, timber collection, fish collection and honey collection) may foster conservation efforts. Political commitment and willingness on trans-boundary river management also crucial for conserving Sundarbans from human induced climate change impacts. The role of frontier communities to conserve forest is necessarily important and their representation and active involvement could functionalize forest management committees more energetically. And, finally, it is required to ensure transparency, accountability and awareness of communities and forest managers to conserve Sundarbans from human interventions.

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