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Climate Change and Sea-Level Rise: A Review of Studies on Low-Lying and Island Countries

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CLIMATE CHANGE AND SEA LEVEL RISE: A REVIEW OF STUDIES ON LOW LYING AND ISLAND COUNTRIES

Nidhi Rawat[1,2] M S Umesh Babu[1] and Sunil Nautiyal[1]

Abstract

This is review paper focuses on climate change and its impact on sea level rise in the countries of low lying areas (Bangladesh) and islands (Tonga). The study makes an attempt to highlight the causes and impacts of sea level rise. The review shows that there is an increase in the seal level rise (0.2 m) in the coastline of Bangladesh that is adversely affecting nearby biodiversity spots. As a noticeable result, one of the most fragile ecosystems Sundarban mangrove is facing the threat of rising sea levels. The renowned, native plant Sundari is on the verge of extinction. Similarly, the study found numerous instances related to sea level rise in the island country of Tonga.

Key Words: Climate Change, Sea Level Rise, Low land, Island, Impacts.

1. Introduction

Climate change has a direct impact on rising sea levels. Sea level rise is happening due to a thermal expansion, melting of glaciers from Greenland and West Antarctica ice sheets *(Anemuller*, 2006). Approximately, 600 million people live in coastal areas that are less than 10 m above sea level and some two-third of world's cities, that have populations over five million, are located in these risk areas[1]. If the present state of climate change continues, some of the cities need to be relocated otherwise it will result in climate refugees, those who are forced to leave their homes and communities because of the effect of climate change and global warming. In March and April 2012, the President of Maldives, Mohamed Nasheed stated that: "If carbon emissions were to become nil today, the planet would not see a difference for 60-70 years". Nasheed added that, "if carbon emissions continue at the rate they are climbing today, my country will be under water in seven years[2]". There is enough evidence to show that Island nations are much more vulnerable to the impacts of climate change which causes sea levels to rise leading to the inundation of islands. Island communities are massively affected by the impacts of global climate change.

Climate change impacts also make other processes prominent; for example, tsunamis may be higher under the influences of sea level rise *(Lazrus*, 2012). Many islands like Maldives, Marshall Islands, Federated States of Micronesia, Kiribati, Tuvalu and Arctic islands such as Shishmaref (*Marino et al.,* 2009) and small islands in Nunavut (*Ford et al.*, 2006) may become uninhabitable due to the rise in sea levels. Coastal areas in Bangladesh is hugely affected due to sea level rise.

The factors which causes sea level are:

- Thermal expansion leading to rise in sea level.
- When continental glaciers melt, the run-off rise sea level accordingly.
- Glaciers melt at Greenland & West Antarctica
- Anthropogenic activities are influencing ice sheets melt[3] (*Van Kooten*, 2013).

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Impacts of sea level rise are:

- Loss of fragile land and population displacement
- Affects agriculture sector (e.g.- loss of yield and unemployment)
- Salinization
- Reduce freshwater availability
- Erosion of sandy beaches
- Hamper coastal tourism

(*Shukla et al.,* 2003; *Leatherman et al., 1997).*

2. Global Perspectives of Climate Change

Climate change is hugely affecting the island states and their communities, with the loss of their livelihood practices and biodiversity. The climatic conditions variability is triggering a rise in sea levels , thereby affecting the coastal areas as well as islands deeply. Sea level rise is a major impact of climate change and is the most important concern around the world at present. According to (IPCC, 2014), the emission of greenhouse gases from small islands are negligible in relation to global emissions but threat to these small island nations is very high.

The lives of people are at stake with the destruction of resources as well as biodiversity. According to (IPCC, 1998), a 30 cm rise in sea level would increase flood intensity by 36-58% all along the coastal lines.

IPCCs projections on sea level rise show scenarios from 0.3-1.1 m by the year 2100 with a best estimate of 0.66 m rise, which can inundate low-lying wetland, erode sea shores, increase salinity, rise coastal salt water tables, and exacerbate coastal flooding and also storm damage[4].

Barnett and Campbell (2010) have articulated the challenges before island communities to "adapt, to sustain their needs, rights, and values" and the challenges before international community to reduce greenhouse gas emissions and support island communities to adapt. Hands (1977) and Holzer (1985) suggests that human-induced land subsidence due to ground water withdrawal is a major problem in many coastal cities. Nicholls and Leatherman (1995) stated that highly-populated deltaic areas, China, Bangladesh, and Egypt are highly susceptible to sea-level rise. The coastal wetlands are expected to experience losses at a global scale given the accelerated sea-level rise, exacerbating accelerated existing rates of losses due to natural and human-induced factors.

It is common for the rate of subsidence to locally exceed the maximum projected rate for global sea-level rise in the coming century. In Shanghai, ground elevations have been lowered by as much as 2.8 m since the 1920s, although this human-induced subsidence appears to be under control (*Hands*, 1977; *Holzer*, 1985).

Globally, average sea level rose between 0.1 and 0.2 m during the 20th century and based on tide gauge data, the rate of global mean sea level rise was in the range of 1.0-2.0 mm/year compared to an average rate of about 0.1-0.2 mm/year over the last 3,000 years (*Nicholls* and *Leatherman*, 1996). Increasing global average temperature, sea-level rise and extremes in the hydrologic cycle can have negative impacts on human health and diseases like malaria, dengue, fever, diarrhoeal diseases,

acute respiratory infections and asthma, which were identified in the island states. Small island states are most vulnerable to climate variability and long-term climate change.

The AR4 of the IPCC projected that global sea levels will rise by up to ~ 60 cm by 2100 as a result of ocean warming and glaciers melting. Since, the early 90's, SLR has been routinely measured by high-precision altimeter satellites. From 1993 to 2009, the mean rate of SLR amounts to 3.3+/- 0.4 mm/year, suggesting that sea level rise is accelerating. Tegart *et al.,* (1990) highlighted that a 30-50 cm sea level rise projected by 2050 would threaten low islands, and a 1m rise by 2100 would make some island countries uninhabitable.

In the Third Assessment Report (TAR), 2001 quoted below, two factors are mentioned which are related to the sea-level rise: First relates to sustainability noting that "with limited resources and low adaptive capacity, the islands face the considerable challenge of meeting the social and economic needs of their populations in a manner that is sustainable" and Secondly, the report states that "for most small islands the reality of climate change is just one of many serious challenges with which they are confronted" (*Nurse et al.*, 2001).

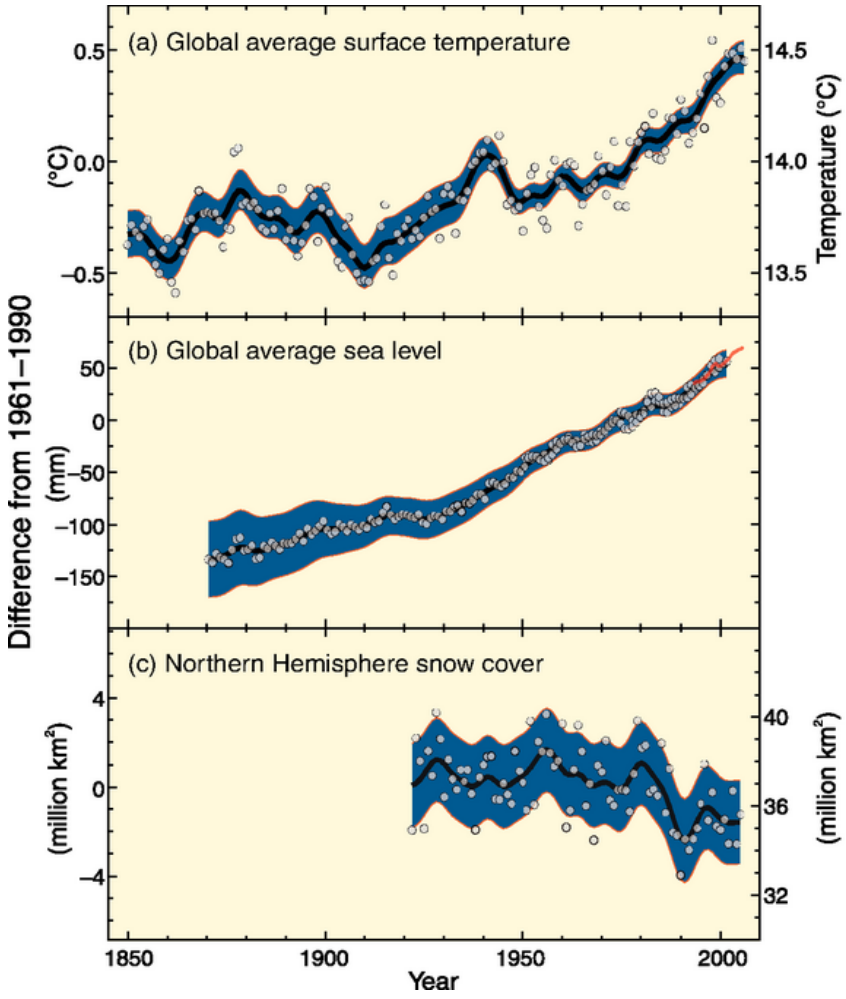
On the Torres Islands, Vanuatu communities have been displaced due to increasing inundation of low-lying settlement areas due to a combination of tectonic subsidence and sea-level rise (*Ballu et al.*, 2011).

The loss of coral reef habitat has damaging implications for coastal fisheries (*Munday et al.,* 2009) in small islands where reef-based subsistence and tourism activities are critical to the wellbeing and economics of islands (*Bell et al.*, 2011).

Nicholls *et al.,* (2011) have modelled impacts of 4-degree Celsius warming, producing a 0.5 to 2.0 m sea level rise to represent the impacts on land loss and migration.

Figure 1: Changes in Surface Temperature, Sea Level and Snow Cover in Northern Hemisphere

Figure 1: Changes in Surface Temperature, Sea Level and Snow Cover in Northern Hemisphere



Source: IPCC, 2007

In Figure 1, all differences are relative to corresponding averages for the period 1961-1990. Smoothed curves represent decadal averaged values while circles show yearly values. The shaded areas are the uncertainty intervals estimated from a comprehensive analysis of known uncertainties (a and b) and from time series (c). It can be notice that the sea level increase is consistent with global warming.

Table 1: Possible Impacts of Climate Change Due to Changes in Extreme Weather and Climate Events, Based on Projections from Mid to Late 21st Century.

Phenomenon and direction of trend	Likelihoods of future trends based on projections for 21st century using SRES scenarios	Examples of major projected impacts by sector			
		Agriculture, forestry and ecosystems (WG|-4.4, 5.4)	Water resources (WG-|3.4)	Human Health (WG-|8.2,8.4)	Industry , settlement and society (WG-|7.4)
Over most of the land areas warmer and fewer colder days and nights; warmer and more frequent hotter days and nights	Virtually certain	Increased yields in colder environments; decreased yields in warmer environments;increased insect outbreaks	Effects on water resources relying on snowmelt; effect on some water supplies	Reduced human mortality from decreased cold exposure	Reduced energy demand for heating; increased demand for cooling ; declining air qualities for cities; reduced disruption for transport due to snow ice; effects on winter tourism
Warm spells / heat waves; Frequency increases over most land areas	Very likely	Reduced yields in warmer regions due to heat stress ; increased danger to wildlife	Increased water demand ; water quality problems, e.g. algal booms	Increased risk of heat-related mortality, especially for the elderly , chronically sick, very young and socially isolated	Reduction in quality of life for people in warm area without appropriate housing; Impacts on elderly, very young and poor
Heavy precipitation events. Frequency increases over most areas	Very likely	Damage to crops; soil erosion; inability to cultivate land due to water logging of soil	Adverse effects on quality of surface and groundwater; contamination of water supply; water scarcity	Increased risk of death, injuries and infectious, respiratory and skin diseases.	Disruption of settlements, commerce, transport and societies due to flooding; pressures on urban and rural infrastructures
Areas affected by drought increases	Likely	Land degradation; lower yields/ crop damage and failure; increased livestock deaths; increased risk to wildlife	More widespread water stress	Increased risk of flood and water shortage; increased risk of malnutrition; Increased risk of water-and food –borne diseases	Water shortage for settlements, industry and societies; reduced hydropower generation potentials; potential for population migration
Intense tropical cyclone activity	Likely	Damage to crops; wind throw (uprooting of trees); damage to coral reefs	Power outages causing disruption of public water supply	Increased risks of death, injuries, water and flood borne diseases; post-traumatic stress disorders	Disruption by flood and high winds; withdrawal of risk coverage in vulnerable areas by private insurers; potential for population migrations; loss of property
Increased incidence of extreme high sea level (Exclude tsunamis)	Likely	Salinization of irrigation water, estuaries and fresh water systems	Decreased fresh water availability due to salt water intrusion	Increased risk of deaths and injuries by drowning in floods; migration related health effects	Cost of coastal protection versus cost of land use relocation; potential for movement of populations and infrastructure; also see tropical cyclones above

Source: IPCC, 2007

3. National Perspectives of Climate Change

As per IPCC (2007) global warming is expected to continue, with an increase in global mean sea level. According to the findings of Natesan and Parthasarathy (2010), approximately 13 km^2 of the land area of Kanyakumari would be permanently inundated due to SLR, resulting in loss of land, alteration of the coastal zone and destruction of coastal ecosystem.

Bangladesh is hugely affected by the rise in sea level, while also facing many other problems. It is in a low-lying area, being on the delta of three major rivers — the Ganges, Brahmaputra, and Meghana — making the area more vulnerable to the effects of SLR (*Huq*, 1995). All the coastal islands (covering 3,500 km^2) including Bhola, Hatia, Swandip and ecologically important of coral island of St. Martins will be totally lost under a one-meter rise in sea level (*Huq*, 1995). The Table 2 presents the major key features and figure 2 represent the map of study area Bangladesh.

Figure 2: Map of Bangladesh

Source: World Atlas

Table 2: Key Features of the Study Area, Bangladesh

Sl.No.	Parameters	Bangladesh
1.	Latitude	$23^0 42' N\ 90^0 21' E$
2.	Area	147,570 km^2
3.	Population	15.66 Crore
4.	Climate	Tropical monsoon with a hot and rainy summer and a dry winter.
5.	Level of sea rise	Projection: 1-2 global warming will lead to about 14, 32 and 88 cm sea-level rise in 2030, 2050 and 2100 respectively
6.	Reason of submergence	Rising of sea level due to natural and anthropogenic factors
7.	Area submerged	1 m sea level rise will submerge about one-third of the total area of Bangladesh thereby uprooting 25 to 30 million of people
8.	Number of people displaced	25 to 30 million of people will be displaced if sea level rises by 1m

4. Climate Change and Sea Level Rise: Bangladesh Perspectives

It is estimated that sea level will definitely rise by 0.18 to 0.59 m by the end of century (*IPCC*, 2007) whereas some research suggests that the magnitude may be far greater than the previous prediction due to recent rapid ice loss from Greenland and Antarctica (*Overpeck*, *et al.,* 2006; *Rignot et al.,* 2006). Accounting for this accelerated melting, sea level could rise in between 0.5 m and 1.4 m by 2100 (*Rahmstorf,.* 2007).

The main economic activities in the coastal area of Bangladesh are fishing, agriculture, shrimp farming, salt farming and tourism. A major source of livelihood for almost 10 million people is the Sundarbans (*Islam* and *Haque*, 2004). Main activities in the Sundarbans area are fisheries, wood collection and honey collection. More than a million households in the area have homesteads, but no cultivable land (*Islam*, 2004). In the following section, the study discusses the impact of SLR on Bangladesh, using secondary data from different sources.

Table 3: Sea Level Rise in Bangladesh and Its Possible Impact

Year	2020	2050	2100
Sea level rise	0.1m	0.25m	1 m (high end estimate)
Storm surge	-	1991 cyclone happens again with a 10 % increase in intensity; wind speed increases from 225 to 248 km/h; storm surge goes from 7.1 to 8.6 m with 0.3 m SLR.	Storm surge goes from 7.4 to 9.1 m with 1 m SLR.
Flooding	20% increase in inundation.	Increased flooding in Meghna and Ganges floodplain. Increase in monsoonal flood.	Inundated area and flood intensity will increase tremendously.
Agriculture	Inundates 0.2 Mmt. of production area; < 1 % of Current total.	0.3 m SLR will inundate 0.5 Mmt. of production area; 2% of current total.	Devastating floods may cause crop failure for any year.
Ecosystem	Inundates 15% of the Sundarbans	Inundates 40% of the Sundarbans.	The Sundarbans would be lost and other coastal wetlands would stop being a breeding ground for many estuarine fish, which would reduce their population.
Salinity	Increase	Increase	Increase

Source: World Bank, 2000

UNEP (1989) projected 1.5 m sea level rise in Bangladesh coast by 2030, affecting 22,000 km^2 (16% of total landmass) area with a population of 17 million (15% of total population). This scenario was calculated in 1989 and the expected rate of sea level rise has been modified because of uncertainty. At present expected rates, this situation will occur in about 150 years. However, number of

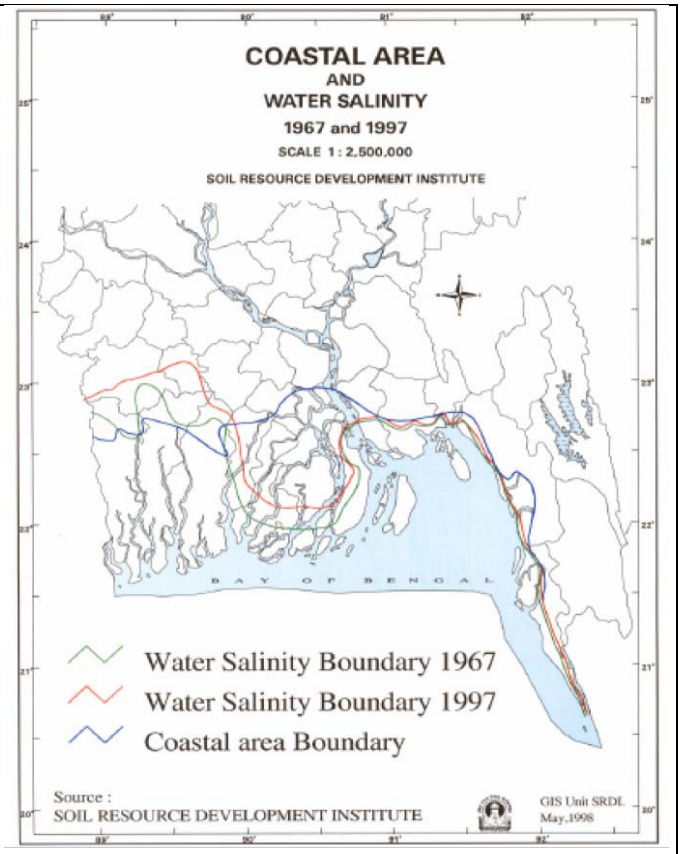
potential population affected by the projection of World Bank by one metre sea level rise (17.5 million) and that of UNEP by 1.5 metre sea level rise (17 million) is similar (Table 3).

4.1. Impact on Freshwater

Freshwater is getting contaminated as salinity intrusion is causing reduction of freshwater. Water salinity as well as soil salinity along the coast will be increase with the rise in sea levels, destroying normal characteristics of coastal soil and water (Figure 3). Soil Resources Development Institute (*SRDI*, 1998a) produced a water salinity map for the period of 1967 and 1997 (figure.3) which shows that the problem has already started.

Figure 3: Water Salinity Map of Bangladesh

Shrimp farmers of Bangladesh mainly cultivate Indian Tiger Shrimp (**Penaeus** monodon). Water salinity required for maximum growth of this species is 5-25 ppt (Chanratchakool, 2003). It cannot be cultivated in fresh water. The salinity intrusion in the freshwater zone of the coastal area has provided an opportunity to shrimp farmers to cultivate tiger shrimp.



Source: SRDI, 1998a

Table 4: Shrimp Farm Area in Satkhira, Khulna and Bagerhat District

Year	Shrimp Farm Area (Ha)
1975	1,330
1987	67,650
2004	115,900

source: Ittefaq, 2004

A comparative study between Soil Salinity map of SRDI (1998b, 1998c) for the period of 1973 and 1997 depicts that salinity intrusion in soil is much higher than water salinity. A sea level rise of 1m will expand the soil and water salinity area at a much faster rate.

Shrimp farming, which emerged as an important industry in Bangladesh, started from the input of saline water into fresh land which was previously used for agricultural production. The soil quality of fresh land is degraded due to the addition of saline water which affects vegetation, aquaculture, ecology as well as health of people of Bangladesh (*Rahman et al.,* 2013).

There are 60 shrimp hatcheries and 124 shrimp processing plants in the coastal zone (Haque, 2003) and the hatcheries are located at Teknaf, Ukhia and Sadar Thana of Cox's Bazar district of Bangladesh (*Sarwar*, 2005). The shrimp farm areas in the year 2004 were 87 times more than that of the year 1975 (Table 4); this is another indicator of salinity intrusion in the coastal zone. From such types of data of the past years, it can be inferred that salinity intrusion has contaminated the freshwater in Bangladesh and has degraded land quality due to which farmers are unable to grow any agricultural crops in their fields and are losing their land. SLR, which causes salinity intrusion, has a huge impact on freshwater and this leads to a loss in agriculture output and biodiversity.

4.2. Impact on Ecosystem

The Sundarbans is the largest mangrove forest in the world, covering 6,500 sq. km (FAO, 2003; Cited in Islam & Haque, 2004) covering part of Khulna, Satkhira and Bagerhat district (Iftekhar & Islam, 2004). The Sundarbans will be completely lost with one metre sea level rise (*World Bank*, 2000) (Table 5). This will be a great loss of heritage, biodiversity, fishery resources, life and livelihoods. Salinity intrusion has led to cause the death of "top-dying" of Sundari, the major tree species of the Sundarbans (*Huq*, 1995).

Table 5: Fate of the Sundarbans with Different Sea Level Rise (SLR)

SLR (m)	Inundation of Sundarbans (%)
0.10	15
0.25	40
0.45	75
0.60	100
1.00	Total destruction

Source: World Bank, 2000

The area of the Sundarbans varies each year because of soil erosion or land accretion. The site is home to a number of unique and globally or nationally endangered species of plants like rare Sundari, Gewa, Passur, animals like endangered Royal Bengal Tiger, vulnerable Pallas, Fishing Eagle and Masked Fin foot, and critically endangered River Terrapin, all listed in the IUCN Red Book, rare species of shark and very rich avifauna. Many fish species such as *Peneaus monodon, Macrobrachium rosenbergii, Lates calcarifer, Metapeneaus monoceros and Pangaisus pangaisus* depend for spawning and juvenile feeding on the Sundarbans aquatic habitat (*Rabbiosi*, 2003).

Table 6: Protected areas in the coastal zone of Bangladesh

Type	Name	Area (ha)	Location	Will 1m SLR affect?
Reserved Forest	-	885,043	Bagerhat, Barguna, Bhola, Chittagong, Cox's Bazar, Feni, Khulna, Lakshmipur, Noakhali, Patuakhali, Satkhira	Yes
National Park	Himchari	1,729	Cox's Bazar	No
	Nijhum Dweep	4,232	Hatiya, Noakhali	Yes
Eco-park	Sitakunda	808	Chittagong	No
Wildlife Sanctuaries	Sundarban East	31,227	Bagerhat	Yes
	Sundarban South	36,970	Khulna	Yes
	Sundarban West	71,502	Satkhira	Yes
	Char Kukri Mukri	2,017	Bhola	Yes
	Chunati	7,761	Chittagong	No
Game Reserve	Teknaf	11,615	Cox's Bazar	No
Ramsar Site	The Sundarbans	601,700	Bagerhat, Satkhira, Khulna	Yes
Environmental Critical Areas	Sonadia	4,916	Cox's Bazar	Yes
	Teknaf beach	10,465	Cox's Bazar	Yes
	St. Martin Island	590	Cox's Bazar	Yes
World Heritage Site	Wildlife Sanctuaries of the Sundarbans		Bagerhat, Satkhira, Khulna	Yes
	Shaat Gombuz Mosque	0.16	Bagerhat	Yes
Marine Reserve		69,800	Bay of Bengal	Yes
Fish Sanctuaries		15,614	Barisal, Bagerhat, Bhola, Patuakhali, Narail, Khulna, Jessore, Lakshmipur, Feni	Yes

Source: Islam, 2004

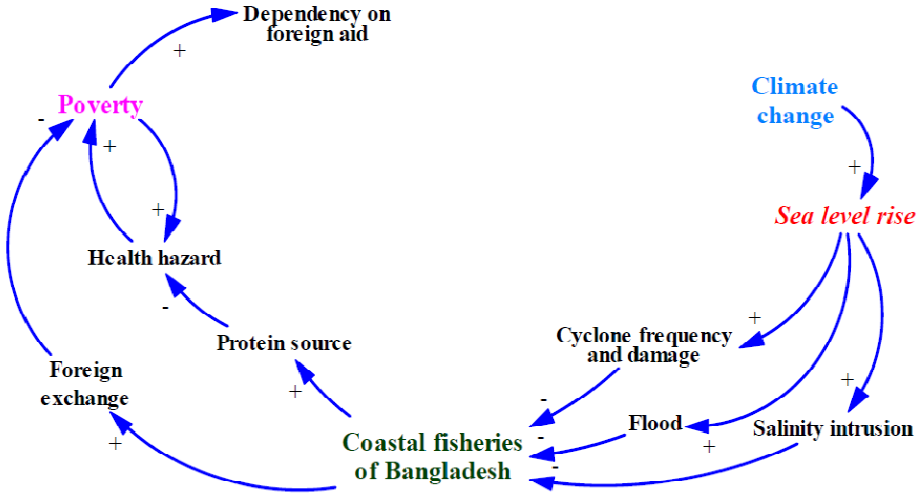
Table 6 depicts how the protected areas will be affected by sea level rise of 1m. About seven species of fishes, two species of amphibians, seven species of reptiles, eight species of birds and eight species of mammals living in these protected areas are at risk (*Islam*, 2004). Excluding Himchari National Park, Sitakunda Eco-park, Chunati Wildlife Sanctuaries and Teknaf Game Reserve, all the protected areas in the coastal zone will be inundated by one metre sea level rise, destroying the area

and its animal inhabitants and valuable natural resources. Sea level rise will decrease the availability of light for corals, affecting the photosynthesis process. Decreased rates of photosynthesis will decrease the growth of corals, causing destruction of St. Martin's island, the only highly productive coral island of the country.

4.3. Impact on Fisheries and Aquaculture

The main protein source for coastal people of Bangladesh is fisheries and the consumption of fish stands at about 60-80% (*Alam* & *Thomson*, 2001; *World Bank* 2000). The rise in sea level has a significant impact on fish habitat and their breeding ground as this would change the location of river estuary which ultimately affects fisheries (Figure 4).

Figure 4: Causal Loop Diagram of Sea Level Rise Impacts on Coastal Fisheries Sector



Source: Haraldsson, 2004

Figure 4 prominently shows that climate change is inducing a change in sea level which is leading to cyclone frequency and damage, salinity intrusion, and flooding. These factors are affecting fisheries in Bangladesh. The decline in coastal fisheries would cause protein scarcity among the people which will affect their health. In addition to the health issue, another sector which will be affected is the food industry, affecting the earning and livelihood of people of Bangladesh. The decline in coastal fisheries will hinder Bangladesh's ability to earn foreign exchange as the frozen food industry is dependent on coastal fisheries. And due to the fall in economic conditions as well as health hazards, aid will be required from foreign sources. Another example which shows the impact of SLR on aquaculture is that of Penaeid prawns which breed and develop in brackish water. But due to the rise in sea levels, their habitat is in danger (*Sarwar*, 2005).

Even the shrimp farms are likely to be completely inundated by a rise of 1m sea level (*Huq*, 1995). While looking at the state of environment and biodiversity of Bangladesh, many areas of great concerns can be identified. The IUCN Red List of Threatened Species 2012 (Version 2012.2) identifies as

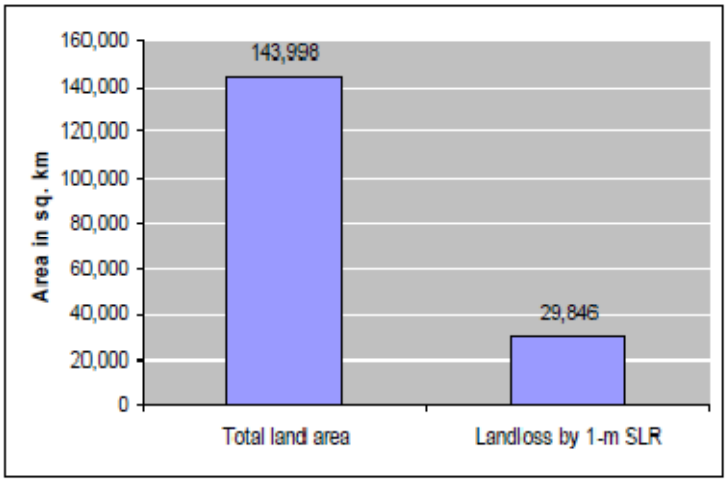
many as 124 species of all categories from Bangladesh which are categorized as threatened. Out of the 124 species found in Bangladesh, 34 are mammals, 31 birds, 22 reptiles, 17 fish and 17 plant species, besides a few others which are also threatened in Bangladesh. The list has further categorized the extent of threats to different levels. It is found that at least 15 animals and 5 plant species are critically endangered in Bangladesh, while as many as 31 animal and 4 plant species are categorized as endangered. It also listed 61 animal species and 8 plant species as vulnerable, while 69 animal and 5 plant species are termed as near threatened in Bangladesh.

4.4. Impact on Land Area

The rise in sea level will impose its impacts on Bangladesh in the coastal areas and through coastal areas, the whole of Bangladesh. Sea level rise initiates erosion by raising water level as it washes out top soil of the coast which makes the coastal region steeper. In addition to this, the backwater effect is accelerated by sea level rise that will also cause erosion. Most vulnerable shore types to sea level rise are sholay, sandy and silty shore (*Kont et al.,* 1997) and as the coastal areas of Bangladesh are formed of silty and sandy soils, it makes them vulnerable to sea level rise. This is supported by (Vellinga, 1988) who states that a sea level rise of 1.0 metre will cause an erosion of a sandy shore in the order of 100-500 metre. The rate of erosion due to rise in sea level along Bangladesh coast is high. The forecasted land erosion will lead to displacement of coastal population.

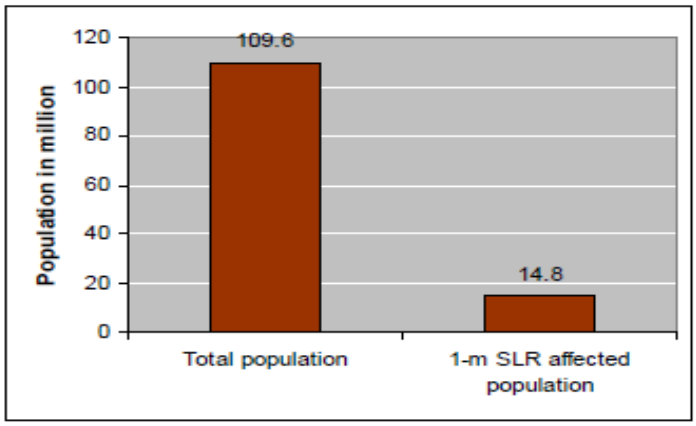
About 2,500, 8,000 and 14,000 km^2 of land (with a corresponding percentage of 2%, 5% and 10% with respect to the total land area of the country) will be lost due to SLR of 0.1m, 0.3m and 1.0m respectively (Ali, 2000) whereas the loss estimated by IPCC (2001) reports 29,846 km^2 area of land will be lost and 14.8 million people will be landless by 1 m SLR (Figure 5 & 6).

Figure 5: Total Area and Potential Land Loss by 1m SLR



Source: IPCC, 2001

Figure 6: Total Population and 1m SLR Affected Population



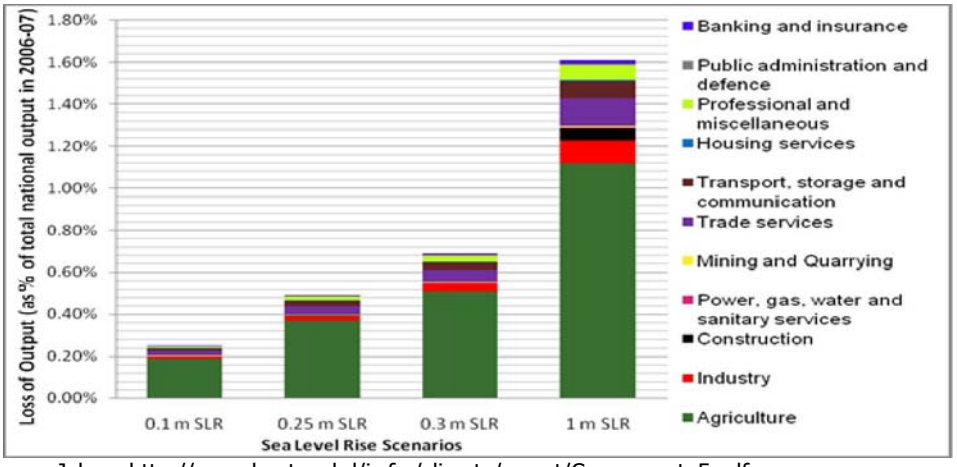
Source: IPCC, 2001

4.5. Impact on Agriculture

SLR causes salinity intrusion which will decrease agricultural production due to the lack of freshwater and soil degradation. Salinity also diminishes the germination rate of some plants (*Ashraf et al.,* 2002) which affects the agriculture sector. The negative impact on agriculture can be observed by the investigation done by Ali (2005) on the decline of rice production in a village of Satkhira district of Bangladesh which shows that rice production in 2003 was 1,151 metric tonnes less than the year 1985, corresponding to a loss of 69 per cent. Out of the total decreased production, 77 per cent was due to conversion of rice field into shrimp pond and 23 per cent was because of yield loss (*Ali*, 2005).

A World Bank (2000) study suggests that increased salinity alone from a 0.3 metre sea level rise will cause a net reduction of 0.5 million metric tonnes of rice production. Salinity intrusion degrades soil quality which in turn inhibits rice production and when the rice fields are converted into shrimp ponds, total rice production declines due to decreased rice field areas. In support of this, data from the research done by Jahan[5] is taken, which shows the projected variation in the sector of agriculture and related sectors.

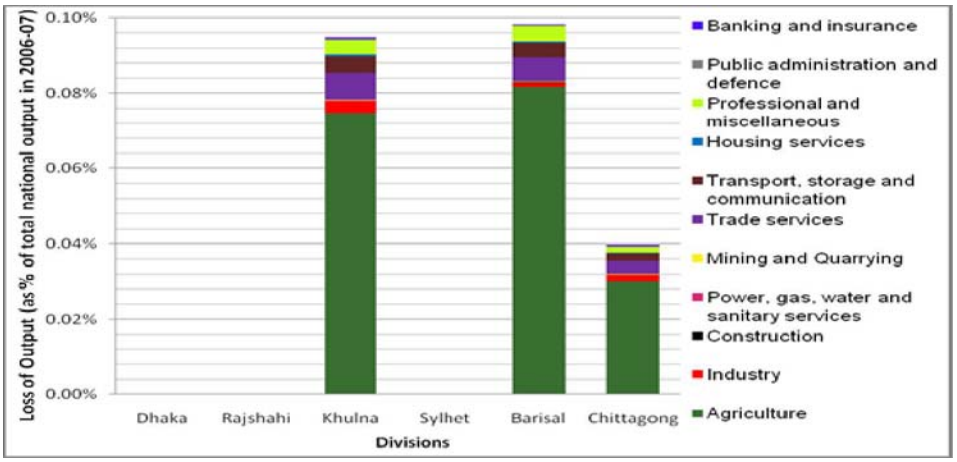
Figure 7: Change in National Output Due to Sea Level Rise Scenarios



Source: Jahan, http://www.buet.ac.bd/iwfm/climate/report/Component_5.pdf

Figure 7 shows that a 1m SLR will result in maximum loss of output in agriculture sector. SLR which is leading to loss of land, forestry and increased salinity is the main cause for the fall in agricultural output and this will automatically affect industry, trade and transport sector. Sea level rise of about 1m will lead to a reduction of about 1% income in agriculture sector and this will result in a reduction of 0.13% of income in trading sector. And due to the above results, there is a probability of remarkable loss in employment of agriculture sector due to 1m rise in sea level[6].

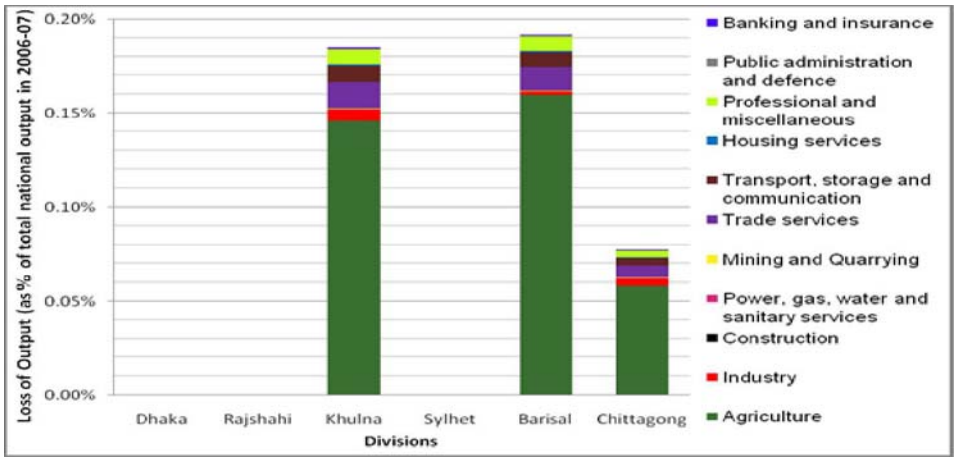
Figure 8: Change in Regional Output Due to Sea Level Rise of 0.1 m



Source: Jahan, **http://www.buet.ac.bd/iwfm/climate/report/Component_5.pdf**

Figure 8 shows that Barisal, Khulna and Chittagong are mainly affected by SLR whereas Barisal faces the maximum loss as its coastal areas face the highest risk of inundation. This inundation due to sea level rise mainly affects the agriculture sector.

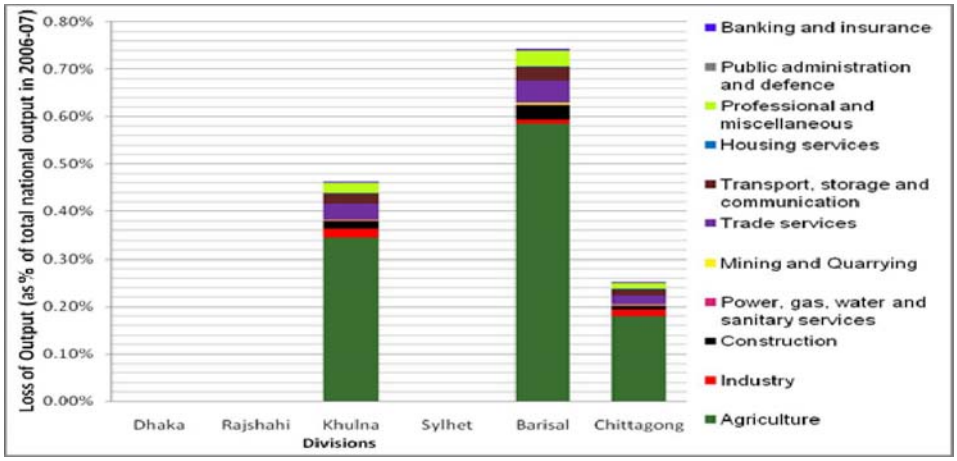
Figure 9: Change in Regional Output Due to Sea Level Rise of 0.25 m



Source: Jahan, http://www.buet.ac.bd/iwfm/climate/report/Component_5.pdf

Figure 9 shows regional damage due to 0.25m rise in sea level. Its shows that Barisal faces maximum damage in agriculture which is more than 0.15% as compared to Khulna and Chittagong. Trade, professional service and transport sector are also affected and industry sector of Khulna is damaged by the 0.25 m rise in sea level.

Figure 10: Change in Regional Output Due to 1 m Sea Level Rise



Source: Jahan, http://www.buet.ac.bd/iwfm/climate/report/Component_5.pdf)

Figure 10 shows regional loss due to 1 m sea level rise and highest loss is observed at Barisal division, the loss is significantly higher than previous 0.7%. Khulna and Chittagong also facing loss of output in this scenario. This 1 m rise in sea level will reduce 1.3% of Barisal's income from agricultural sector. Sea level rise would also affect the employment of agricultural sector in the coastal regions. In addition to agriculture sector, loss of output is evident for trade, transport, professional service, industry and construction sector.

Table 7: Effect of 1 m Sea Level Rise on Agriculture (major crops)

Crop	Area affected (Ha)	Total for Bangladesh (%)
Aman (Monsoon) rice	1,280,000	21
Aus (Summer) rice	40,000	12
Boro (Winter) rice	102,000	8
Jute	13,800	2

Source: Huq, 1995

The coastal zone is very important for rice, pulses, oil seeds and vegetables production, which will fall gradually, with increase in salinity in the zone. But as the production of pulses and oil seeds are comparatively in landward part of Bangladesh where salinity is very low, the production is still in high volume. Even then, the salinity intrusion due to rise in sea level will decrease the agricultural production (Table 7). Miller (2004) stated that high projected rise in sea level of about 0.88 m (35 inches) would flood agricultural lowlands and deltas in parts of Bangladesh.

4.6. Impact on Economy

SLR is impacting the economy of Bangladesh as the food production and tourism sectors are largely affected Table 8.

Table 8: National damage estimation for sea level rise

Direct Impact		Sea Level Rise Scenario			
		0.1 m SLR	0.25 m SLR	0.3 m SLR	1 m SLR
National damage (in million BDT)		14779.07	28833.64	40160.86	93412.9
Total area inundated due to SLR (in sq. Km)		2500	6300	8000	25000
Affected Sectors (damage in million BDT)	Agriculture	14779.07	28833.64	40160.86	87002.14
	Industry	N/A	N/A	N/A	23 (salt industry of Cox's Bazar)
	Construction	N/A	N/A	N/A	6387.76
Regional inundated area (in sq km)	Khulna	1001.18	2522.98	3203.78	7616.13
	Barisal	1090.13	2747.13	3488.42	13297
	Chittagong	408.69	1029.89	1307.8	4086.87

Source: Ali, 2000; Agrawala *et al.,*2003; Islam, 2004; Sarwar, 2005; Rahman, 2011

The analysis from this data on national damage is increasing every time, with the inundated area of agriculture, whereas, industry and construction has shown the consequence of SLR with 1m SLR. A sea level rise of 1 m will damage the salt mills of Cox's Bazar and will also cause some infrastructural damage. The region of inundation is also consistent with the rise of sea level. It should be mentioned that SLR scenarios are predicted using hypothetical values and data on damage to all the

possible sectors are not available in monetary terms, though data on direct damage to agriculture sector is available (Sarwar *et al.,* 2005).

Regional damages due to extreme events/scenarios are calculated from national damage figures multiplied by regional share of damage for respective regions where, regional share of damage for a region is equal to the ratio of area affected in that region for a certain scenario to the national affected area for that scenario. This is shown in Table 9 for Khulna, Barisal and Chittagong regions in agriculture sector and the damage is consistent with the SLR.

Table 9: Regional Dam age for SLR of 0.1m, 0.25m, 0.3m and 1.0m (in million BDT)

	Share of Damage & Damage to sectors	National	Damage in Regions (Divisions) in million BDT		
			Khulna	Barisal	Chittagong
SLR 0.1 m	Share of Damage	1.00	0.40	0.44	0.16
	Agriculture	14779.07	5911.63	6502.79	2364.65
SLR 0.25 m	Share of Damage	1.00	0.40	0.44	0.16
	Agriculture	28833.64	11533.46	12686.80	4613.38
SLR 0.3 m	Share of Damage	1.00	0.40	0.44	0.16
	Agriculture	40160.86	16064.34	17670.78	6425.74
SLR 1.0 m	Share of Damage	1.00	0.31	0.53	0.16
	Agriculture	87002.14	26970.66	46111.13	13920.34

Source: Jahan, http://www.buet.ac.bd/iwfm/climate/report/Component_5.pdf

4.7. Impact on Health

The decreasing volume of freshwater due to rise in sea level will force people to drink contaminated water leading to cholera, diarrhoea and other water borne diseases. In addition to this, the increased salinity in the coastal zone will decrease food production in the area, causing malnutrition among coastal population (Sarwar, 2005). Cholera (Vibrio Cholera) is the most common in the coastal area of Bangladesh because it withstand the salinity ranging from 2.5 ppt to 30 ppt (Borroto, 1998). Average salinity of sea water is 35 ppt or 3.5%. Most of the salt present in the sea water is sodium chloride (NaCl) that breaks up into Na+ and Cl- ion when dissolved in water. For this reason, coastal area is a breeding ground of cholera disease.

Colwell and Huq (2001) stated that most of the major epidemics (Cholera) that have occurred during the last 50 years originated in the coastal regions. Also, the contamination outbreaks of cholera often occur after flooding, as the water supply becomes contaminated (Eco-health Glossary, 2005). Thus, sea level rise not only increases flood risk, but also increase the risk of cholera outbreak too.. Also, the impact on coastal fisheries due to SLR affects the protein source of people which results in poor health and other health hazards.

4.8. Impacts on Tourism

Tourism in coastal areas of Bangladesh is also being affected by the rise in sea levels. Kuakata beach in Patuakhali district, Patenga beach in Chittagong district and Cox's Bazar beach in Cox's Bazar district are attractive tourist areas of the country. Cox's Bazar sea beach is the world's largest unbroken sandy beach, stretching to an area of 145 km (Hossain and Lin, 2001 p.21), which attracts tourists. Out of 18 tourist areas identified by Bangladesh Parjatan Corporation (BPC), five spots, namely Chittagong, Cox's Bazar, Kuakata, Khulna and the Sundarbans are located in the coastal zone (Tanzler, 2012).

Bangladesh tourism sector will be hugely affected due to rise in sea levels as the coastal zone will be adversely affected and hence result in economic loss. Tourism sector of Kuakata will suffer the most because all the facilities are very close to the coastline and the area is more vulnerable in comparison to Cox's Bazar and Chittagong. Tourism industry serves the nation with economic development at the national as well as the local level, thereby strengthening the nation as a whole.

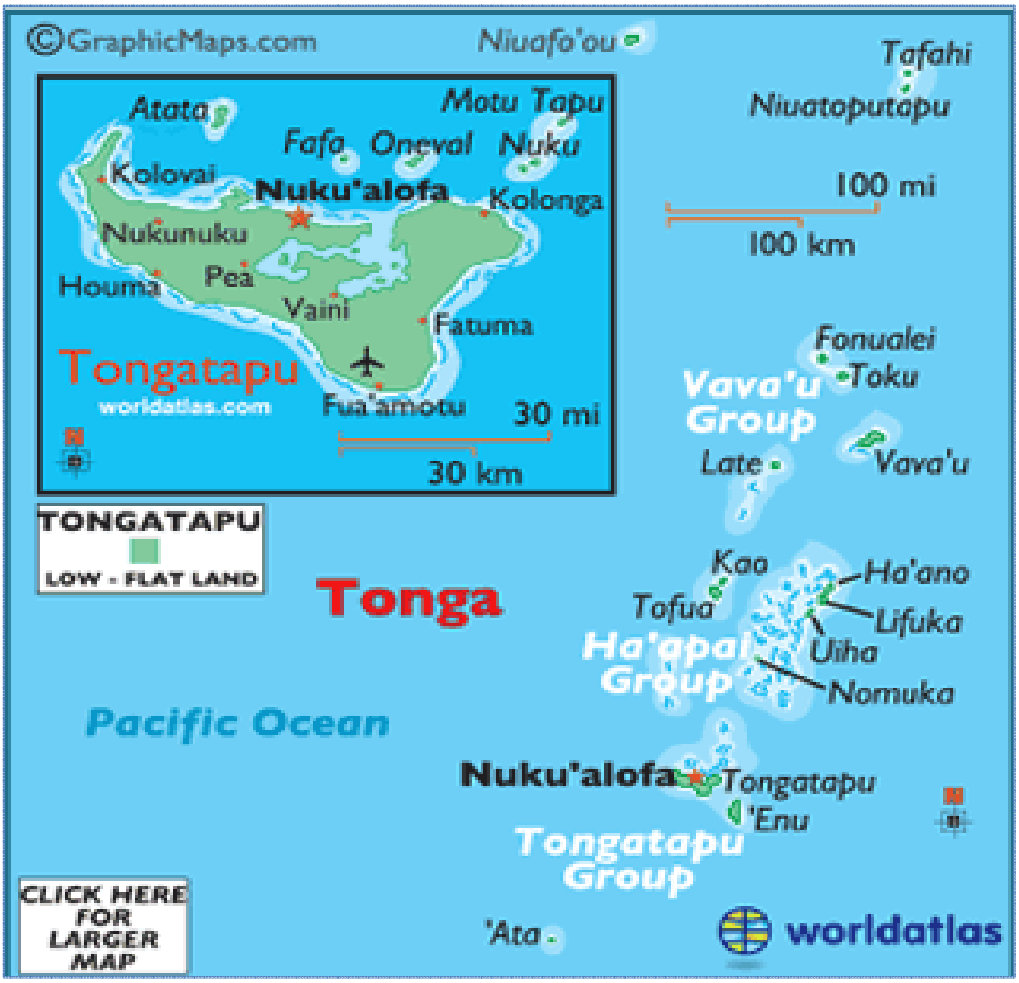
Sea level rise might also be a threat to national security of Bangladesh. For example, there is conflict between Bangladesh and India, regarding the distribution of water of the Ganges River (Swain, 1993; Nishat *et al.,* 2000) but rise in sea level leading to environmental refugees might heighten the conflict.

The rise in sea levels will affect the livelihood of the people as well as trigger above-mentioned impacts thereby adversely affecting the economy of Bangladesh.. This would also result in extreme poverty as well as untoward changes. Since people depend on agriculture, fisheries, ecosystem, and tourism for livelihood, all aspects of the country will be affected by rising sea levels.

5. Impact of Sea-Level Rise on Tonga

Tonga is located in the western South Pacific Ocean (Figure 11). The archipelago is spread over 800 sq km in a north-south direction. Tonga consists of four groups of islands: Tongatapu and Eva in the south, Haápai in the middle, Vavaú in the north and Niuafoón and Nina Toputapu in the far north. There are 172 named islands with an area of 748 km^2 and the present population of Tonga is 105,000[7]. The economy of Tonga is based on agricultural exports, tourism and fisheries. According to CIA, 2011, because of the small economic base of the islands, it remains dependent on foreign aid. Undoubtedly, the rise in sea level is affecting Tonga's population.

Figure 11: Map of Tonga



5.1. Impact on Freshwater

Most of groundwater in Tonga exists beneath the surfaces of the limestone permeable islands as freshwater lenses (Nunn, 1992). The rise in sea level will eventually lead to the reduction of freshwater in Tonga. This is likely to be a problem in a few places like in Ha'apai, in northern Tongatapu, and along the broad coastal areas. In such places, greater mixing of fresh and saline water from increased tidal ranges associated with reef overtopping will lower the level of available potable freshwater (Nunn, 1992). Extraction from wells drilled into the freshwater lens results in its depletion, as does natural outflow around its periphery. Recharge in the form of rainfall is necessary to maintain freshwater lenses (Nunn, 1992).

SLR could cause a reduction in the area of freshwater lens and salt water intrusion into the aquifer. This salinity intrusion will contaminate the freshwater sources, which will lead to a scarcity in potable water and other health hazards. The impact on the water supply of the small islands will be very severe.

5.2. Impact on Ecosystem

Sea-level rise will increase coastal erosion. Coastal erosion increases when there is an increase in water depth above the coral reef which will allow larger and more forceful waves to pass over them, reaching sandy beaches, causing erosion (Mimura *et al.,* 1997). This will lead to the loss of important resources for tourism. Ecosystems in low-lying areas, such as mud flats and mangrove swamps, may also become vulnerable to inundation, flooding, and wave action. Coastal vegetation, which is important for medical and cultural uses, and as a shelter against strong winds, will also be threatened.

5.3. Impact on Fisheries and Aquaculture

Coastal resources such as marine fisheries are vital to livelihoods of Tongans. Coral reefs, mangroves and beaches are the main environmental components of the coast which are under threat from the effects of climate change. The combination of coastal developments such as the mining of beach sand, sea level rise and extreme events caused by climate change, have led to coastal degradation (Mimura *et al.,* 1997).

5.4. Impact on Land and Population

Records suggest that there has been an increase in sea level of 14 mm/yr between 1993 and 2001. The rise in mean sea level combined with extreme weather events is likely to contribute to an increase in inundation of low lying areas[8]. Flooding and inundation will affect the population and land area. Recent estimates indicate that with 1m rise in sea levels, 10.3 km^2 of land in Tongatapu Island, Tonga, would be lost (Mimura and Pelesikoti, 1997). This would increase to 37.3 km^2 (14%) with storm surge superimposed on a 1m sea-level rise scenario (IPCC, 2001).

Table 10: Physical impacts of sea-level rise on Tongatapu Island

Impact Categories	Values at Loss			Values at Risk		
	Land area (km^2)	Residence area (km^2)	Population	Land area (km^2)	Residence area (km^2)	Population
Present situation	0	0	0	23.3 (8.8%)	4.9	19,880 (31.3%)
SLR 1 (0.3 m rise)	3.1 (1.3%)	0.7	2,700 (4.7%)	27.9 (10.6%)	5.9	23,470 (37.0%)
SLR 2 (1.0 m rise)	10.3 (3.9%)	2.2	9,000 (14.2%)	37.3 (14.1%)	7.6	29,560 (46.6%)

Source: Mimura *et al.,* 1997

* Percentage of area and population affected are based on total values.

Table 10 shows the loss of value and risk of land area, residence area and population according to different SLR scale. About 2,700 to 9,000 people would be affected, that is 4.3 and 14.2 % of the total population of Tongatapu, respectively. The impact of sea-level rise are not limited to inundation as the danger of cyclone-induced storm surge would also increase significantly. About 20,000 people currently live in the low-lying areas that can be flooded by a storm surge of 2.8 m. If a storm surge occurs under the 0.3 m scenario, 27.9 km^2 (11 per cent of the Tongatapu Island) and

23,470 people (37 % of the Tongatapu population) would be at risk. These will increase to 37.3 sq. km (14 %) and 29,560 people (46 %) for a 1 m scenario.

5.5. Impact on Agriculture

As the sea level rises, farmland on the coast would be inundated or flooded, and the marginal areas would experience higher moisture and increased salinization, reducing their suitability for agriculture. The pressure on land will increase even further, as people may need to be relocated from inundated or swamp areas, and additional farmland needs to be converted into housing areas (Spennemann, 1988). The effects of salt water intrusion into ground water are also harmful to crops. If sea-level rise is accompanied by prolonged dry periods, food production may decrease significantly. Agriculture is the main economic sector with squash, coconuts, bananas and vanilla beans.

5.6. Impact on Economy

Tonga's economic base is small, and is mainly comprised of climate-sensitive sectors such as agriculture and fisheries. The country is also dependent on foreign aid. Coastal resources such as marine fisheries are vital to livelihoods of Tongans. Agriculture, which makes up for two-third of total export, is getting affected due to the rise in sea levels and hence the economy is getting affected. All Pacific countries will be significantly affected through the loss of outlying islands and low lying areas. Such losses will result in reduction in the extent of the exclusive economic zones and associated fisheries (Fifita, 1991). Coral reefs, mangroves and beaches are the main environmental components of the coast which are under threat from the effects of climate change. The combination of coastal developments such as the mining of beach sand, sea level rise and extreme events caused by climate change, have led to coastal degradation. The Table 11 summarizes the impact of climate change on Bangladesh and Tonga.

Table 11: Key Findings of Bangladesh and Tonga

Sl. No.	Parameter	Bangladesh	Tonga
1.	Land inundation	About 8,000 km^2 will submerge with 0.3m rise in sea level.	About 3.1 km^2 will submerge with 0.3m rise in sea level.
2.	Freshwater	Salinity is increasing day-by-day and example of shrimp farming is evident.	Salinity is increasing.
3.	Agriculture	With 0.3 m SLR, there will be a reduction of 0.5 MMT in rice production.	Salinity will lead to soil degradation. Coastal vegetation is at risk.
4.	Ecosystem	Inundation of Sunderbans is also projected with a loss of 15% of Sunderbans with 0.01m SLR.	Biodiversity is at risk including coastal vegetation.
5.	Economy	A national damage of 14779.07 million BDT is projected for 0.1 SLR	Economy will be affected due to the impacts of SLR.
6.	People affected	14.8 million People will be affected if sea level rises 1 m.	About 9,000 people would be affected with a 1.0-m rise in sea level.
7.	Fisheries and aquaculture	Decrease in the productivity.	Decrease in the productivity.
8.	Health of people	Health hazards have increased.	Health hazards have increased.

6. Conclusion

The projected impact of the sea level rise on different sectors like freshwater, biodiversity, land and agriculture and other related sectors show the severity of the problems people are facing due to the rise in sea levels. Bangladesh shows the rise of sea level evidently. The examples clearly show how the lives of people and economy are getting affected.

A comparative analysis between Bangladesh (a low lying coastal area) and Tonga (an island) is correlated to compare the vulnerability of both the regions to the impact of rising sea levels. The comparative analysis shows that, at present Bangladesh and Tonga are vulnerable to the sea level rise and there should be more attention from Governments or international agencies on Tonga or small islands to safeguard it from climate change. If the present situation continues in this direction, the impacts cannot be minimized. Adaptation strategies and mitigation measures should be taken for the protection of people before the conditions worsen.

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