Emerging issues

Sea-Level-Rise: Causes, Consequences & Countries At Risk A Global Overview

By Golam Kibria, Ph.D; April 2012

Key points

Sea-level-rise (SLR) is the average increase in the level of world's oceans. SLR is one of the most catastrophic consequences of global warming/climate change. SLR will cause forced migrations, of which small island and poor developing countries are particularly susceptible. Regions at most risk include heavily populated deltaic regions in South, Southeast and East Asia (Bangladesh, China, India, Indonesia, Myanmar, Philippines, Thailand, and Vietnam), and small islands (Kiribati, Maldives and Tuvalu). SLR will cause a number of ecological and socioeconomics impact in particular on coastal systems including (a) saltwater intrusion into freshwater aquifers, deltas and estuaries (e.g. chloride contamination of freshwater aquifers), (b) salinization of agricultural land and rice production (e.g. inundation of rice land and rice production in Vietnam, Myanmar, Egypt, Bangladesh), (c) losses of wetlands (Vietnam, Jamaica, Belize), (d) loss of biodiversity (e.g. a 28 cm SLR will cause a decline of 96% tiger habitat in Sundarbans or Shundorbôn Bangladesh), (e) increase in human health risk (e.g. increase in cholera outbreak and hypertension), (f) inundation of low-lying coastal regions (e.g. densely populated South, Southeast and East Asia are highly threatened), (g) displacement of people (e.g. globally 72-187 million people will be displaced & most of them are from South, Southeast and East Asia and (h) impact on coastal infrastructure (e.g. commercial and residential buildings, air ports, ports, hospitals, schools which are close to the coast are at greater risk). Coast defences, flood warning system, planned retreat, elevated storm shelters, growing salt tolerant rice, rearing euryhaline fish species is some of the adaptation options that can be taken to reduce impacts from sea-level-rise.

Contents

1. Introduction

Sea-level-rise (SLR) is the average increase in the level of world's oceans. It (SLR) is a response to increasing concentrations of greenhouse gases in the atmosphere [1,2,3]. However, the changes in sea level do not occur uniformly around the globe. Satellite altimetry (instrument for determining elevation) shows that sea level is not rising uniformly, for example, in some regions (e.g. western Pacific); sea level has risen up to three times faster than the global mean since 1993. Spatial patterns in sea-level trends mainly result from non-uniform ocean warming and salinity variations [4]. Nevertheless, changes in regional sea levels can also result from continental drifts (movement, formation, or re-formation of continents). For instance, land in some river deltas subside by several millimetres per year because of collapse of sediments. In these cases, a rising sea level intensifies the existing regional effects. In other regions, a rise in sea level remains unnoticed because the land is rising to the same extent or even more than the sea level itself [5]. The Relative sea-level rise occurs where there is a local increase of change in the level of the ocean relative to the elevation of the adjacent land, which might be due to ocean rise and/or land level subsidence [1,6].

2. Causes of Sea Level Rise

There are two ways in which global warming is causing sea levels to rise are: (a) thermal expansion and (b) the melting of glaciers, ice caps etc. Global warming or increases in temperatures (due to increase in the concentrations of greenhouse gases) cause the oceans to warm and expand in volume inducing a rise in the sea levels. Furthermore, warmer climate facilitates melting of glaciers, ice caps and ice sheets causing further addition of water to the oceans (Table 1). In fact, the major cause of SLR is the thermal expansion of the oceans which contributes substantially in recent time (1993-2003) (see Table 1)

Table 1: *Observed rates of sea level rise (SLR) and estimated contributions from different sources during 1961-2003 [1].*

Source of sea level rise	Rate of sea level rise (mm/year): 1961-2003	Rate of sea level rise (mm/year): 1993-2003
Thermal expansion of oceans	0.42	1.6
Melting of Glaciers and ice caps	0.50	0.77
Melting of Greenland ice sheets	0.05	0.21
Melting of Antarctic ice sheets	0.14	0.21
Climate contributions to SLR	1.11	2.79
Observed total SLR	1.8±0.55	3.1±0.7

Thermal expansion refers to the increase in volume (and decrease in density) that results from warming water. A warming of the ocean leads to an expansion of the ocean volume and hence increases in sea level.

[1,6,7,8]. For example, thermal expansion accounts for about 25% of the observed SLR since 1960 and about 50% from 1993 to 2003. The glaciers and Greenland and West Antarctica mass loss due to melting of ice sheets contributed to SLR was around 30% and <15% of the global SLR between 1993 and 2009 respectively [4].

3. Current Sea Level Rise

It was observed that global sea level rose at an average of 1.8 mm per year (1961-2003) (estimated from tide gauge measurements), and the rate was 3.1 mm per year during 1993 to 2003, which was faster compared to 1961-2003 (measured by high precision altimeter satellites) (see Table 1) [4, 9]. According to IPCC (2007) [1], the global sea level may rise from 18 to 59 cm by 2100. A recent trajectory by Jevrejeva et al. 2012 [8] shows that global SLR will be in the range of 0.57 to 1.10 m by 2100 (Figures 1). It means that sea levels will rise higher and faster than the IPCC (2007) [1] prediction made just five years ago. The rise of sea levels in the case of Bangladesh is estimated to be higher than the global sea-level rise as observed at three coastal stations (Hiron point, Char Changa and Cox's Bazaar of Bangladesh) for the last 22 years, which were 4, 6 and 7.8 mm/year respectively [10]. Figure 2 shows the SLR projections beyond 2100 as follows: 1 to 2 m by 2200 (Figure 2) and 1.84 to 5.48 m by 2500 (Figure 2) [11,12]

Ericson et al. 2006 [11] made an assessment of contemporary effective sea level rise (ESLR) of 40 deltas across the world. The estimated ESLR ranged from 0.5 to 12.5 mm/ year with the three highest ESLR were for densely populated and agriculturally active deltas in south Asia including Bangladesh, India (see Figure 3). Based on assessment made by Ericson et al. 2006 [11], the mean ESLR from Asia, North America, Africa, South America, Europe, Africa and Oceanic were 4.6, 4.5, 4.4, 3.5, 2.6, and 1.0 mm/yr respectively (i.e. highest ESLR from Asia and lowest from Oceania) (see Figure 3).

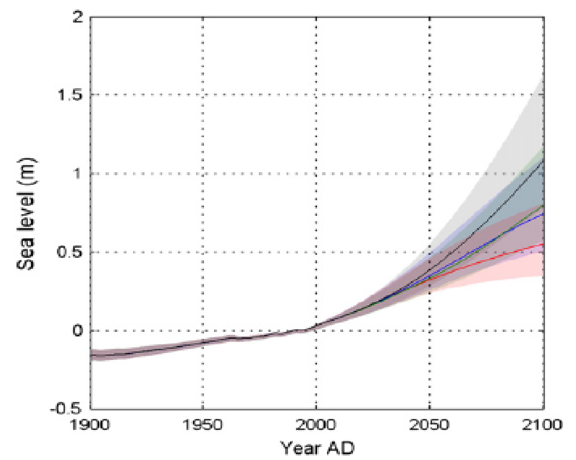

Figure 1: *Sea level projections by 2100 with Representative Concentration Pathways (RCP) scenarios; red = very low greenhouse gas concentrations; blue= medium low greenhouse gas concentrations, black= high greenhouse gas concentrations. Shadows with similar colour around sea level projections are upper (95%) and low (5%) confidence levels [from 8; page 17].*

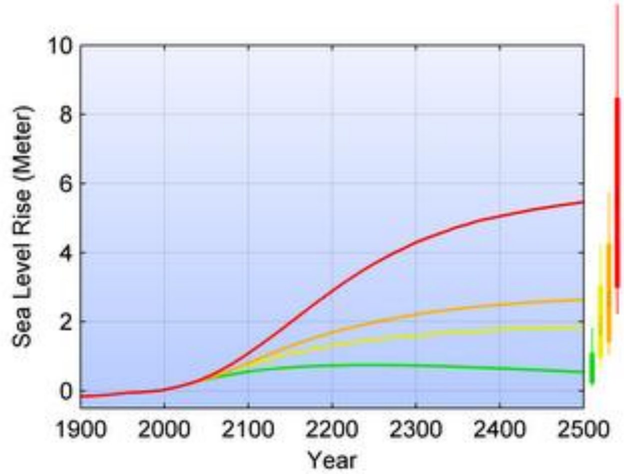

Figure 2: *The graph shows how sea levels will change for four different pathways for human development and greenhouse gas pollution. The green, yellow and orange lines correspond to scenarios where it takes 10, 30, or 70 years before emissions are stabilized. The red line can be considered to represent business as usual where greenhouse gas emissions are increasing over time [from 12].*

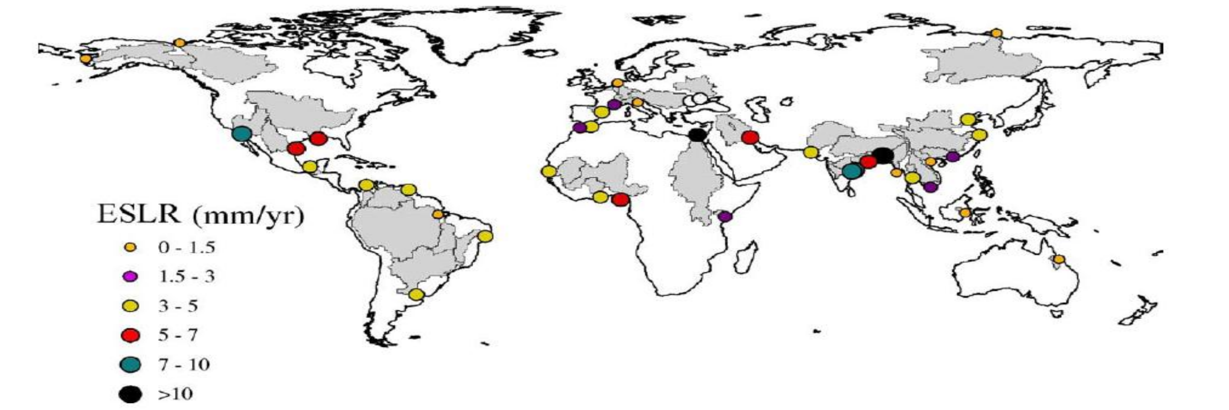

Figure 3: *Global distribution of effective sea level rise (ESLR) under baseline conditions of 40 deltas. This figure represents contemporary conditions. ESLR shows that highest ESLR are for deltas in south Asia (densely populated, agriculturally active and strongly regulated drainage basins). ESLR is defined as the rate of apparent sea-level change relative to the delta surface [from 11; page 75].*

4. Consequences of Sea Level Rise

Rising sea levels is one of the most catastrophic consequences of global warming/climate change which are a major threat to coastal habitats and communities worldwide. SLR will cause forced migrations, of which small island and poor developing countries are particularly susceptible. Regions at most risk include heavily populated deltaic regions, small islands (especially coral atolls), and sandy coasts backed by major coastal developments [13,14]. SLR will cause a number of ecological and socioeconomics impact in particular on coastal systems and coastal areas as listed below [3,8,15,16]:

- Saltwater intrusion into freshwater aquifers, deltas and estuaries
- Increase coastal erosion
- Increase the heights of waves
- Higher storm-surge flooding
- Inundation of low-lying coastal regions
- Salinization of freshwater and agricultural land
- Decline in soil quality
- Changes in surface and groundwater quality
- Impacts on primary production (agriculture and aquaculture and fisheries)
- Loss of biotic resources
- Increased loss of coastal habitats
- Wetland losses or damages
- Increased loss of property
- Damage to coastal infrastructure and assets
- Loss of tourism, recreation, and transportation functions
- Affect on human health
- Forced displacement/migration or climate refugees
- Potential loss of life

The following section discusses in more details of the main consequences of sea-levels- rise on water resources, agriculture and fisheries production, wetlands/mangroves and biodiversity, human health, coastal flooding, population exposure and displacement and infrastructure:

4.1: Impacts on Water Resources

Saline intrusion caused by rising sea-level (an invasion of seawater into freshwater and brackish areas) would cause the most significant impact on coastal groundwater resources in particular shallow sandy aquifers along low-lying coasts. Seawater movement into a coastal aquifer may be initiated by the breakdown of the natural barrier system (mangroves or sand ridges). As sea levels rise, the saline water will be able to overcome natural barriers thus allowing saline water to move into low lying areas of freshwater and ultimately into coastal fresh water aquifers. Saline intrusion has already affected many coastal aquifers such as aquifers in Los Angeles (USA) and localities along the Mediterranean coast including 60% of Spanish coastal aquifers [17,18,19, 20,21]. In the Netherlands, a 0.5 m SLR per century would increase the salinity in all low-lying regions which are closer to the sea. Similarly, if SLR becomes greater than 48 cm over the next 100 years several freshwater aquifers in Florida would be vulnerable to chloride contamination. It is also projected that SLR would cause loses of permanent freshwater reserve in Israel [reviewed by Chang et al. 2011 [22]. Freshwater aquifers in coastal areas are used for drinking water. Therefore, saltwater intrusion due to SLR would thus be a serious problem both at regional and global level since 80% of the world's population live along the coast and utilize local aquifers for their water supply.

Furthermore, SLR is projected to increase the frequency of storm surges resulting to inundate thousands of kilometres of coast lines along the world's oceans (see section 4.5). As a consequence, the saline water can flow down submerged and storm-damaged water supply wells. This will cause to contaminate both boreholes in inundated low-lying areas as well as the surrounding coastal aquifers [23]. The United Nations Environment Programme [24] projected that extensive low-lying areas in coastal Bangladesh (22,000 km^2) are vulnerable to inundation by a surge of only 1.5 metre. This has the potential to affect thousands of water supply wells in these areas that supply fresh water to approximately 17 million people. In the United States, storm surge (Hurricane Katrina in 2005) contaminated a number of bores in south eastern Louisiana [25].

4.2: Impacts on Agriculture and Fisheries Production

SLR would cause loss of agricultural land due to flooding of lands and intrusion of seawater into freshwater aquifers, as a result agriculture in low-lying coastal area or adjacent to deltas may be affected. For example, agriculture farming in low-lying areas of Egypt, Bangladesh, Indonesia, China, the Netherlands, Florida and some island states could be affected [7,26,27]. Significant rice land would be inundated in many countries, most notably in Southeast Asia, South Asia, East Asia [28], in particular in Vietnam, Egypt, Myanmar and Bangladesh (Table 2). Rice is a major staple crop of half of world's population and may results in food security crisis in those regions/countries if SLR increases in line of projections. Some of Asia's most important rice growing areas is located in low lying deltas in Vietnam, where more than 50% of the rice is grown alone in the Mekong River and another 7% in the Red River delta - all of which would be affected by sea-level-rises [29, 30,31,32]. A 1.5 meter of sea level rise in Bangladesh may flood about 16% of the country's land area (22,000 square kilometres) of which southern subregions are more vulnerable where rice production could be unsuitable [33]. A 32 and 88 cm SLR would significantly reduce paddy production in Bagerhat, Khulna and Satkhira districts of Bangladesh whereas shrimp production (*Penaeus monodon*) will significantly increase in these areas [see 34; see Table 3].

Table 2: *The consequent effects of sea level rise (SLR) on loss of rice acreage (land) in major rice producing/consumption countries or regions (% of rice cropland lost to inundation) [35]. m=metre; SLR=sea level rise. Note: highlighted countries will be most affected*

	1m SLR	2m SLR	3m SLR
Bangladesh	0.54	1.25	2.77
Brazil	-	-	-
Central Africa	-	-	-
Central America	-	-	-
China	0.03	0.05	0.07
Egypt	1.72	2.23	2.76
India	0.02	0.04	0.08
Indonesia	0.18	0.34	0.60
Japan	0.3	0.82	1.62
Korea, DPR	0.03	0.06	0.14
Myanmar	0.85	1.41	2.49
Pakistan	0.01	0.02	0.04
Philippines	0.12	0.19	0.32
South America	0.03	0.06	0.09
Taiwan	0.12	0.35	0.84
Thailand	0.12	0.35	0.84
USA	0.001	0.003	0.003
Vietnam	5.53	9.5	13.28
West Africa	0.02	0.03	0.05

Table 3. *Paddy and shrimp production under different sea-level- rise scenarios in southern Bangladesh [34].*

Paddy production (kg/capita/year					**Shrimp production (ton/year)**			
District	Base year (2005)	SLR 32 cm (2050)	SLR 88 cm (2100)		District	Base year (2005)	SLR 32 cm (2050)	SLR 88 cm (2100)
Bagerhat	287	77	5		Bagerhat	10,740	27,265	50,502
Khulna	123	52	14		Khulna	21,032	34,290	33,649
Satkhira	298	161	70		Satkhira	7,414	17,245	45,946
Average	**236**	**96**	**30**		**Average**	**13,062**	**26,267**	**43,365**
Decreasing rice production due to SLR-----→					Increasing shrimp production due to SLR----→			

SLR= sea-level rise

The rising sea level would most likely damage or destroy many coastal ecosystems including mangroves and salt marshes. These ecosystems are essential habitat for wild fish stocks and a source of natural seed for aquaculture. On the contrary, sea level rise would expand areas suitable for brackish water fish farming or aquaculture [7].

4.3: Impacts on Wetlands/Mangroves and Biodiversity

Coastal wetlands (salt marshes, mangroves and intertidal areas) are sensitive to sea-level rise since they are closely linked to sea level. They provide flood and storm protection, waste assimilation, nutrient cycling functions, food production (nursery areas for fisheries), nature conservation (habitat for wildlife) and other ecosystems services. It has been projected that most losses of coastal wetlands may occur from a rise of 0.2 m sea level. A 1m SLR may cause significant losses (25-46%) of the world's coastal wetlands [36] (see Figure 4). Coastal wetlands in the Atlantic coast of North and Central America, the Mediterranean, the Baltic and the Caribbean are most vulnerable or threatened (see Figure 5). It is projected that by the 2080s, most of the wetlands around the Mediterranean and Baltic may be lost [36]. Dasgupta et al. 2009 [26] assessed the vulnerability of SLR to wetlands of 84 developing countries, the results of which show that 28% wetlands in Vietnam, Jamica and Belize would be inundated by a 1m SLR. Other developing countries, where wetlands will also be most affected are Qatar (21.75%), The Bahamas (17.75%), Uruguay (15.14%), Mexico (14.85%), Benin (13.78%) and Taiwan (11.70%) [26].

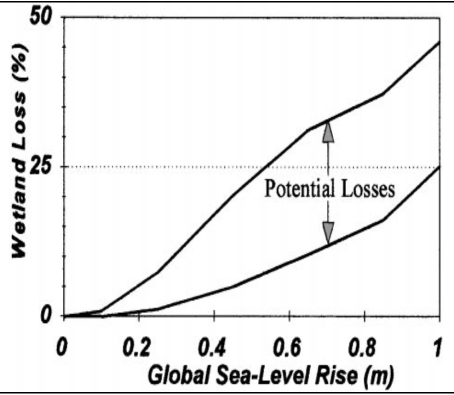

Figure 4: *The range of possible response surfaces for wetland loss as a function of global sea-level rise over a century. Note: that there is no consideration of subsidence or other loss factors [from 36, page S82].*

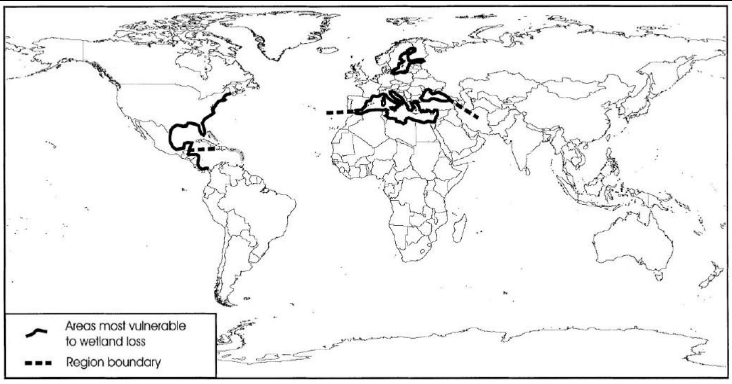

Figure 5: *Areas most vulnerable to coastal wetland loss. The regions where wetland losses may exceed 65% due to the HADCM2 scenario by the 2080s [from 36, page S82]. HADCM2= the second generation the Hadley Centre coupled model ensemble simulations. HADCM2 assumed a growth of CO_2 concentrations from 354 ppmv (1990) to 731 ppmv (2080)*

The Sundarbans mangroves in Bangladesh are projected to be most vulnerable to SLR. The Sundarbans (Bengali: Shundorbôn; *sundar= "beautiful" and bon= "forest*") is the largest single block of tidal halophytic (*a plant that grows in waters of high salinity*) mangrove forest in the world. It is a UNESCO World Heritage site covering parts of India and Bangladesh (total 860,000 ha; Bangladesh portion is 600,000 ha). A 10, 25, 45, 60 cm SLR will inundate 15%, 40%, 75%, 100% of the Sundarbans. A 1m SLR may cause complete losses of the Sundarbans resulting loss of heritage, biodiversity, and fisheries. The SLR may also impacts on mangrove tress, for example, the most important Sundari tress, *Heritiera fomes* may be replaced by less important trees such as Goran, *Ceriops decandra* and Keora, *Sonneratia apetala*. Nursing and breeding grounds of many estuarine fish and migratory species may also be affected [37,38]. Sundarbans is the home of iconic Royal Bengal Tigers (*Panthera tigris tigris*) and a recent research reveals that a 28 cm SLR will cause a decline of 96% tiger habitat [39] (see also Figure 6). In addition, the distribution and habitat of the important cetaceans (aquatic mammals including such as dolphins) in Sudarbans, the Ganges river dolphin, *Platanista gangetica gangetica* preferring lower salinity may also be affected [40].

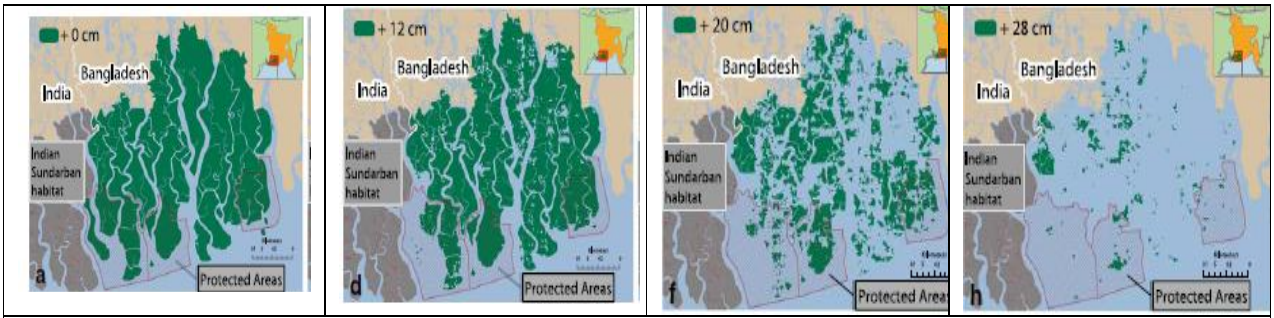

Figure 6: *Predicted tiger habitat loss in the Bangladeshi Sundarbans under increasing sea levels. The land area that lies above the predicted sea level is shown in green. SLR impacts are only shown for the Sundarbans and not the surrounding land area [from 39, page 294]. Note: Tiger Protected areas will be completely submerged with the rise of as little as 28 cm sea-level (last image).*

Despite threats from SLR, coastal wetlands including mangroves may be able to adapt by growing upward or landward if sea-level rise occurs slowly with sufficient space for expansion, and if environmental conditions are tolerable or met [41,42]. In general, mangroves show greater plasticity in wood, bark and leaves structure as it can adapt to a wide gradient of water salinity, flooding level and water logging period [43]. According to Gilman et al. 2006 [41], there are three general scenarios for mangrove response to relative sea level rise as highlighted below: (see Figure 7)

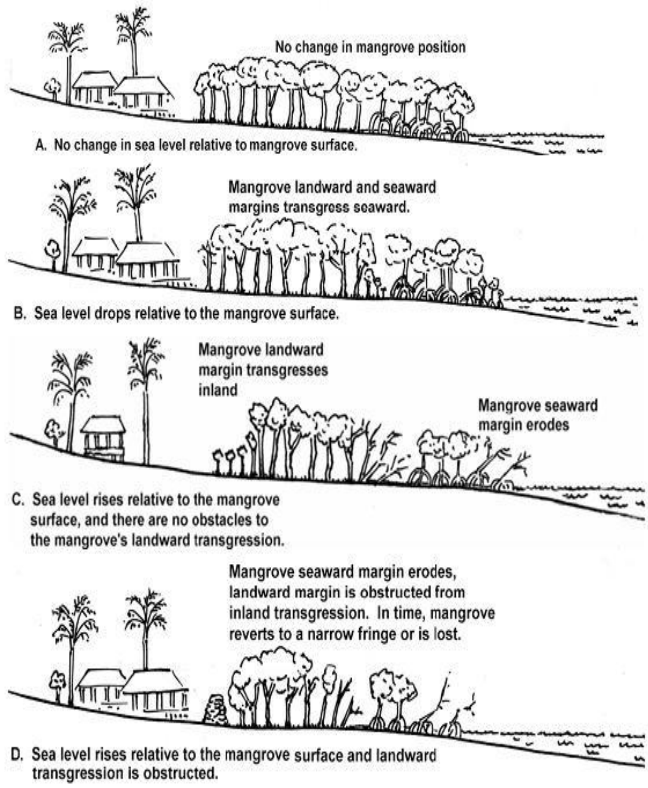

Figure 7: *Different scenarios for generalized mangrove responses to sea level rise [from 44].*

- **If there is no change in relative sea level** (the mangrove margins will remain in the same location) (Figure 7A)
- **If relative sea level is lowering**: (seaward movement of mangrove) (Figure 7B)
- **If relative sea level is rising:** [if unobstructed, mangrove species zones migrate towards inland in order to maintain their preferred environmental conditions, such as period, frequency and depth of inundation and salinity (Figure 7C). However, if there are obstacles to landward migration such as seawalls and other shoreline protection structures, some sites will revert to a narrow mangrove fringe or experience extirpation of the mangrove community (Figure 7D).

4.4: Impacts on Human Health

Increasing salinity of natural drinking water sources (e.g. freshwater aquifers) (see section 4.1) has been or will be one of the many problems from public health perspectives that can affect many countries including low-income countries. This problem will be exacerbated by projected rising of sea-levels. Though in some developed countries, de-salination plants are used to partly remove salt and other minerals from water sources; however this is unlikely to be a sustainable option for low-income countries affected by high salinity. Low-income countries cannot afford to have de-saline plants. Usually small quantities of salt are essential for regulating fluid balance of the human body; however consumption of salt higher than the recommended levels is associated with adverse health effects such as hypertension (high blood pressure) and stroke. There is a strong association between dietary salt intake and high blood pressure. Increased salinity exposure of coastal populations in Bangladesh through drinking, cooking and bathing caused hypertension, miscarriage among pregnant women, skin disease, acute respiratory disease, acute respiratory infections and diarrheal diseases (reviewed by Vines et al. 2011 [45] *[note: the recommended dietary intake of salt (sodium chloride) has been set at 5 g/day* [46] *and for drinking water, the maximum allowable concentration is 250 mg/L))* [47].

SLR can increase the risk of cholera in many countries including Bangladesh since cholera bacterium, *Vibrio cholerae* survive longer in salinity range from 2.5 ppt to 30 ppt and need sodium ion (Na+) for growth [48]. Cholera has a sea stage during which copepods (tiny animal called zooplankton) act as host organisms. It (cholera-carrying copepods) lives in salt or brackish waters [49]. During the last 50 years or so the major cholera epidemics that have occurred originated in coastal region [50] therefore SLR may increase the risk of cholera outbreak in those coastal areas where SLR is projected to increase [51].

4.5: Impacts on Coastal Flooding and Inundation

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Global warming (=warmer ocean) is likely to intensify cyclone activity and heighten storm surges. This would cause greater surges to move further inland, threatening larger areas [52]. Moreover, the rising sea levels will raise flood levels. Since SLR will increase the frequency of high water events therefore it would cause flooding of low elevated coastal zones and potential inundation of thousands of kilometres. The number of people to be flooded in a typical year by storm surges may increase 6 and 14-times with a 0.5m SLR and 1.0m SLR respectively. In addition, the number of people to be affected by coastal flooding in the future will further increase due to growing coastal populations and net coastward migration of people across the globe (reviewed by Nicholls 2004) [53]. For example, densely populated and economically less developed regions in South Asia, Southeast Asia and East Asia are highly threatened due to SLR (Figure 8). Africa is also threatened due to rapid population growth in coastal area; in particular, Egypt and Mozambique in Africa are two "hotspots" for potential impacts from SLR. It is projected that small islands in the Pacific, Caribbean and Indian Oceans are also vulnerable to SLR (see Figure 8). Island nations such as the Maldives or Tuvalu could be completely submerged or abandoned during the 21st century [54, 55]. Globally, 1054.99 million km land may be inundated by a 1 m SLR (see Table 4). A sea-level rise of 1 m and 1.5 m (without dike measures) will put 17,000 square kilometres (11.52%) and 22,000 (15%) square kilometres respectively permanently under flooded water in Bangladesh (see Figure 9).

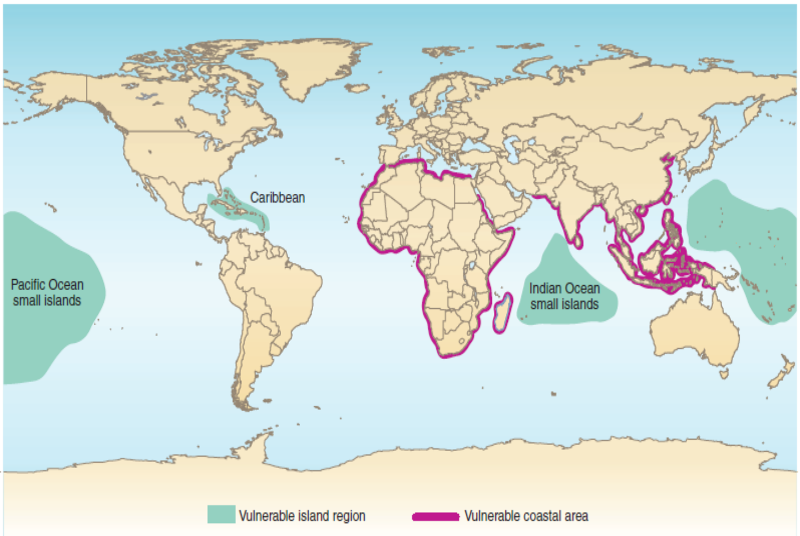

Figure 8: *Regions vulnerable to coastal flooding caused by future relative or climate-induced sea-level-rise. At highest risk are coastal zones with dense populations, low elevations, appreciable rates of subsidence, and/or inadequate adaptive capacity [from 54; page 1519]. Note: South Asia, East Asia and Southeast Asia are highly vulnerable due to SLR.*

Table 4: *Total surface area inundated and population at risk at global and regional scale due to sea level rise [56]. SLR= sea level rise; m= metre*

		Inundation area (1000 km)
Global	Global	1m SLR: 1054.99 2m SLR: 1312.97
Asia	South Asia	1m SLR: 26.67 2m SLR: 43.38
	East Asia	1m SLR: 15.25 2m SLR: 26.13
	South East Asia and northern Australia	1m SLR: 347. 8 2m SLR: 426.24
South America	Amazon Delta Region	1m SLR: 163.55 2m SLR: 189.67
North America	Southeastern USA	1m SLR: 62.28 2m SLR: 104.51
Europe	The Mediterranean	1m SLR: 18.69 2m SLR: 25.76
	Northwestern Europe	1m SLR: 34.70 2m SLR: 41.97

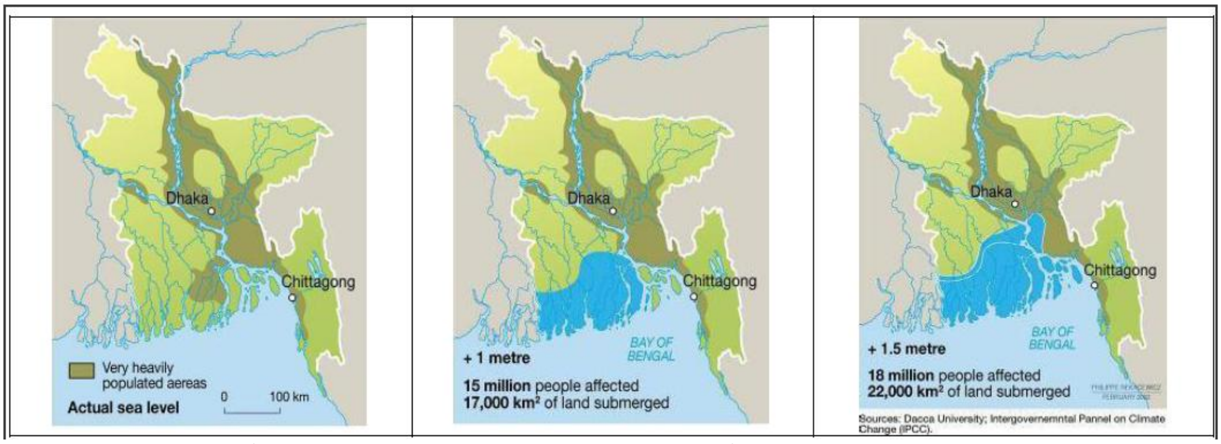

Figure 9: *Potential impact of sea-level rise (1 metre and 1.5 metre) on Bangladesh [from 57]*

4.6: Impacts on Population Displacement, Exposure and Climate Refugees

Sea level rise could displace many shore-based populations and the real risk of the forced displacement is in the range 72-187 million by 2100. Most of threatened people are from East Asia, Southeast Asia and South Asia (53-125 million from these three regions by 2100) (Figure 9, Table 5). 1.2-2.2 million people from the Caribbean, Indian Ocean and the Pacific Ocean will also be displaced. Current defences in north and west Europe and the North American Atlantic coast will protect these regions from a 0.5 SLR [58, see also Figures 12 and 13]. A SLR of just 200 mm (20 cm) could create 740,000 homeless people in Nigeria. Maldives, Tuvalu, and other low-lying countries are among the areas that are at the highest level of risk due to SLR. According to UN's environmental panel estimates that at current rates, sea level would be high enough to make the Maldives uninhabitable by 2100. The country Kiribati (an island in the central pacific) is now negotiating to buy land in Fiji to relocate and move islanders under threat from rising sea levels since the country is sinking. This would be the first climate-induced relocation of a country [59]. Kiribati's President Anote Tong considers that the rising sea is a threat to the very existence of his nations where ninety thousand people living on thirty-three islands and atolls. The country is only about two meters above sea level [14]. Pernett 1992 [60] forecasted that many Pacific island nations are vulnerable to sea-level rise and some of which may cease to exist due to SLR (see Table 6). A one metre sea level rise would submerge Maldives and would force about 311,000 people to leave the Maldives [61]. Moreover, a sea-level rise of just 400 mm (40 cm) in the Bay of Bengal would put 11 percent of the Bangladesh's coastal land underwater, creating 7 to 10 million climate refugees [62]. Table 7 shows that population of a number of port cities will be exposed as a consequence of sea-

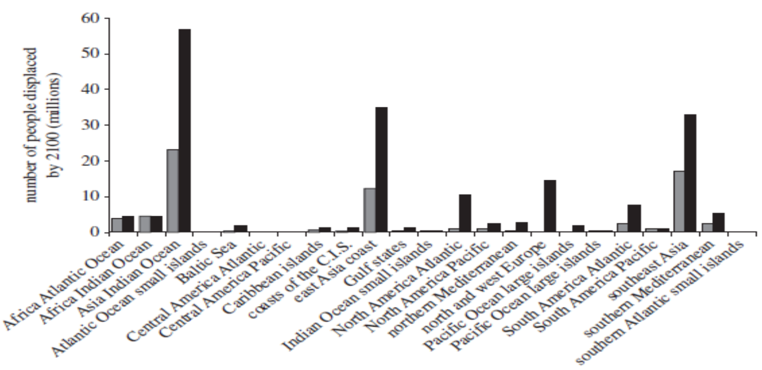

Figure 9: *The distribution of net population displacement over the twenty-first century by region assuming no protection for a 0.5m (grey bars) and a 2.0m (black bars) rise in sea level [from 58 Nicholls et al. 2012, page 173] (note: C.I.S= Commonwealth of Independent States; People from south Asia (Asia Indian ocean), southeast Asia and East Asia would be most displaced by both 0.5 and 2.m SLR)*

Table 5: *Forecasted population at risk from the sea-level-rise in 2050 (Top 20 countries) [63] (Note: population at risk are 12 in Asia, 3 in Africa, 3 in Europe, 1 North America and 1 in Latin America.*

Country	Continent	2050
India	Asia	37.2
Bangladesh	Asia	27.0
China	Asia	22.3
Indonesia	Asia	20.9
Philippines	Asia	13.8
Nigeria	Africa	9.7
Vietnam	Asia	9.5
Japan	Asia	9.1
USA	North America	8.3
Egypt	Africa	6.3
UK	Europe	5.6
Korea, Republic	Asia	5.3
Myanmar	Asia	4.6
Brazil	Latin America	4.5
Turkey	Asia	3.9
Malaysia	Asia	3.5
Germany	Europe	3.3
Italy	Europe	2.9
Mozambique	Africa	2.8
Thailand	Asia	2.6

level-rise and coastal flooding, the exposed population in top cities [based on 64, 65] are as follows: **Bangladesh-** Dhaka (11,135,000), Khulna (3,641,000), Chittagong (2,866,000); **China-** Guangzhou (10,333,000), Shanghai (5,451,000), Tianjin (3,790,000), Ningbo (3,305,000); **Côte d'Ivoire-** Abidjan (3,229,000); **Japan-** Tokyo (2,521,000); **India-** Kolkata (14,014,000), Mumbai (11,418,000); **Indonesia-** Jakarta (2,248,000);**Myanmar-** Rangoon (4,965,000); **Egypt-** Alexandria (4,375,000); **Nigeria-** Lagos (3,229,000); **Thailand-** Bangkok (5,138,000); **USA-** Miami (4,795,000), New York (2,931,000); **Vietnam-** Ho Chi Minh city (9,216,000), Hai Phòng (4,711,000).

Table 6: *Vulnerability of Pacific island countries to sea-level-rise [60].*

Profound impacts*	Severe impacts	Moderate to severe impacts	Locally sever to catastrophic impacts
Tokelau Islands Marshall Islands Tuvalu Line Islands Kiribati	Micronesia Palau Nauru French Polynesia Niue Tonga	American Samoa Fiji New Caledonia Northern Marianas Solomon islands	Vanuatu Wallis and Futuna Papua New Guinea Guam Western Samoa

Profound impacted countries are those countries that may cease to exist due to SLR

Table 7: *Coastal cities and most exposed urban populations by sea-level-rise [64,65,66,67].*

	Region	Cities
Asia	East Asia	Dandong, Guangzhou, Ningbo, Shanghai, Tianjin, Xiamen (main China), Hong Kong (China), Taipei (China), Nagoya, Niigata, Osaka, Tokyo (Japan), Seoul (Korea),
	Southeast Asia	Jakarta, Surabaya (Indonesia), Rangoon (Myanmar), Manila, Valenzuela (Philippines), Bangkok (Thailand), Hai Phòng, Ho Chi Minh City (Viet Nam)
	South Asia	Chittagong, Dhaka and Khulna (Bangladesh), Chennai, Kolkata, Mumbai, Surat, Thane (India), Karachi (Pakistan)
The Pacific	The Pacific	Kiribati, Marshal Islands, Tuvalu
North America		Miami, New York (USA)
Africa		Alexandria (Egypt), Abidjan (Côte d'Ivoire), Lagos (Nigeria)

4.7: Impacts on Proliferation of Harmful Cyanobacteria or Blue Green Algae

Cyanobacteria are now recognised as a serious water quality problem with regard to drinking water supply, recreational use and human poisoning [7]. Rising sea levels will cause an increase in salinity in coastal waters. Interestingly, there are few freshwater cyanobacteria or blue-green algal species which are quite salt tolerant (such as *Anabaena, Anabaenopsis, Microcystis* and *Nodularia)*. For example, *Microcystis aeruginosa* can tolerate salinities ranging from 0 g/L up to 10 g/ L (= 30% seawater salinity). *Anabaena, Anabaena aphanizominoides* can withstand salt levels up to 15 g/ L, while *Anabaenopsis* and toxic *Nodularia spumigena* can even tolerate salinities ranging from 0 g/ L to more than 20 g/L (reviewed by Perl and Paul 2012) [68]. The high salt tolerance capabilities of the above freshwater cyanobacteria species may indicate that there may be an expansion of harmful cyanobacteria in coastal areas as a consequence of SLR.

4.8: Impacts on Coastal Infrastructure and Assets

Commercial buildings, industrial facilities, airports, ports, hospitals, schools, and other economic and social infrastructure which are close to the coast will be at risk due to sea-level rise. For example, in Australia, between 157,000 and 247,600 existing residential buildings are at risk of inundation with a sea-level rise of 1.1 metres (Figure 10). There are a number of airports in low-lying areas in the coastal zone such as Sydney Airport. Moreover, a number of Australia's key tourism regions

Figure 10: *Estimated number of existing residential buildings at risk of inundation from a sea-level rise of 1.1 metres (including 1-in-100 year storm tide for New South Wales, Victoria and Tasmania and high tide event for other states and the Northern Territory) [from 69].*

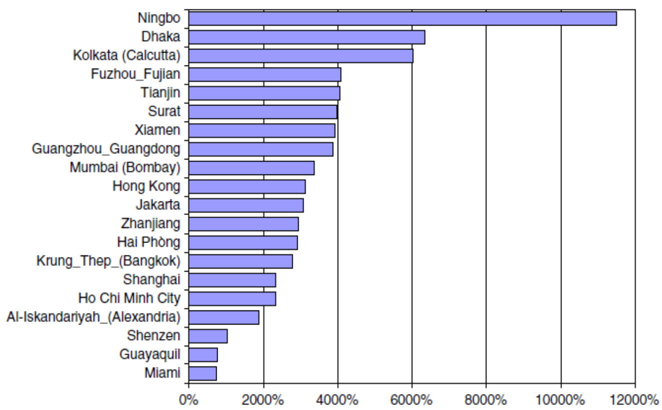

Figure 11. *Top 20 cities with the highest proportional increase in exposed assets by the 2070s compared to the current situation (2005). Cities were selected from cities with the highest exposure in 2005 [from 65, page 102].*

are at high risk due to storm surge, sea-level rise or increased cyclone intensity, notably the Great Barrier Reef, Ningaloo Reef, Kakadu and the Top End coastal wetlands. Sea-level rise may raise coastal water tables potentially impacting water supply infrastructure, such as septic tanks, sewer systems, basements, causing instability of swimming pools, tanks and some other subsurface structures. Stormwater pipes and drainage assets will also be exposed to the impacts of rising sea levels and may not be adequate to accommodate future changes in extreme rainfall and storm surge [69]. The assets (e.g. buildings, transport infrastructure, utility infrastructure, physical assets within built infrastructure, and vehicles) of three cities such as Ningbo (China), Dhaka (Bangladesh) and Kolkata (India) is projected to see more than 60 fold increase in exposure by 2070s due to SLR. This striking increase in asset exposure will be due to the large increases in wealth and population projected in these Asian cities.

5. Conclusion

More than seventy percent of the world's population lives on coastal plains and many of the nations that are most vulnerable to sea level rise do not have the resources to adapt to or prepare for it, such as small island nations, Africa, South, Southeast and East Asia). Low-lying coastal regions in developing countries such as Bangladesh, China, India, and Vietnam have especially large populations living in at-risk coastal areas such as deltas, where river systems enter the ocean. Both large island nations such as the Philippines and Indonesia and small ones such as Tuvalu, Kiribati and Vanuatu are also at severe risk because they do not have enough land at higher elevations to support displaced coastal populations. Another possibility for some island nations are the danger of losing their fresh-water supplies as sea level rise pushes saltwater into their aquifers causing contamination by salt. For these reasons, those living on several small island nations (including the Maldives in the Indian Ocean and the Marshall Islands in the Pacific) could be forced to evacuate over the 21st century. This process has already begun since Tuvalu has already buying lands in Fiji. Actions such as adaptation (as a response to sea level rise) and mitigation (reducing the emissions of green house gases) to limit the inevitable rise of sea level would be required. Coastal defences (see Figures 12 and 13), flood warning systems and planned retreat, coastal buffer zones, building houses on stilts, elevated storm shelters with emergency evacuation are some of adaptation options.

One of the adaptation measures that may be taken to counteract the losses of rice lands is to grow salt tolerant rice in affected rice areas or to grow brackish water prawn and fish in inundated areas to take advantages of the salty water. Euryhaline species (species capable of tolerating a wide range of salt water concentrations) may be selected for coastal aquaculture. Breeding of fish for higher tolerance to salinity, or shifting of stenohaline (species within a narrow range of saltwater tolerance) species into upstream would be other adaptation strategy measures that can be taken by fish farmer.

Figure 12: *The Thames Barrier is the world's second-largest movable flood barrier to prevent London from being flooded by exceptionally high tides and storm surges moving up from the sea [image source: http://en.wikipedia.org/wiki/File:Thames_Barrier_London.jpg].*

Figure 13*: The Oosterscheldekering (Eastern Scheldt storm surge barrier), between the islands Schouwen-Duiveland and Noord-Beveland, is the largest of the 13 ambitious Delta works series of dams, designed to protect the Netherlands from flooding [image source http://en.wikipedia.org/wiki/Oosterscheldekering].*

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Note: *The article is based on various sources and was compiled by Golam Kibria, Ph.D in April 2012 for http://www.sydneybashi-bangla.com (29) for community benefits. Views expressed in this article are those of the author and are not to be taken to be the views of any others including third parties. The information in this article may be assistance to you but the author donot guarantee that it is without flaw of any kind and therefore disclose any liability for any error, loss or other consequences which may arise from relying on any information in this article. All figures/diagrams/tables included in the article were acknowledged in the reference section as well as at the bottom of each figure/diagram/table and were used in good faith and intention of promoting science in particular in the third world countries such as the Asia-Pacific and Africa regions where information are not readily available or lacking on environment, climate change and chemicals impacts and as part of knowledge sharing and promotion of awareness on environment and climate change and chemical impacts. The author did not receive any financial benefits or payment or royalty for this article. This is a voluntary work to benefits the wider communities.*