Climate Change Vulnerabilities and Freshwater Challenges: The Case of the Most Vulnerable Small Island Developing States

Muhammad Zia ur Rahman Hashmi, Shahbaz Mehmood

Global Change Impact Studies Centre (GCISC), Islamabad, Pakistan

Abstract

Climate change has now been accepted as a blatant reality which is mainly human induced and is widely recognized as the greatest challenge ever faced by mankind. Small Island Developing States (SIDSs) have little contribution among all nations in terms of greenhouse gasses emission responsible for climatic change. Even then, they are believed to be the places which will be hit first and will be the most affected from the adverse impacts of climate change and some places could experience irrecoverable physical damage. This paper specifically focuses on these highly vulnerable nations on the earth. It presents a crisp review on their major vulnerabilities (especially related to water resources sector) under climate change impacts and major factors that make them vulnerable. Also, it brings forward different plausible adaptation measures specifically suitable for SIDSs nations as identified by previous similar studies.

Key words: Climate Change; Vulnerability; Sea Level Rise; Small Island; Adaptation

Corresponding author's email: mhas074@aucklanduni.ac.nz

INTRODUCTION

Climate change has now been accepted as a blatant reality which is mainly human induced and is widely recognized as the greatest challenge ever faced by mankind (King, 2004). The UN Secretary General Ban Kimoon said in a keynote speech at a gathering of the 39th Plenary Assembly of the World Federation of United Nations Associations, "It is, simply greatest collective challenge we face as a human family". Figure 1 presents observed changes in global surface temperature during last century as reported by Intergovernmental Panel on Climate Change (IPCC) which reveals temperature changes in the range -0.6 to +2.5 ^{0}C in different parts of the world with the average global temperature change being +0.6 ^{0}C. Grid boxes where the trend is significant at the 10% level, are indicated by a + sign. Major impacts of climate change include changes in the pattern of precipitation resulting in floods and droughts, increased snow/ice melting and sea level rise. Recognizing it as a "greatest collective challenge", scientists all over the world are striving to devise means for proper assessment of anticipated climate change impacts to work out mitigation and adaptation strategies, especially for the most vulnerable countries around the world including the Small Island Developing States (SIDSs).

The United Nations Department of Economic and Social Affairs enlists 51 countries and territories as SIDSs that form the Alliance of Small Island States (AOSIS) in the United Nations. These island nations are spread around the world in three major concentration zones, i) AIMS (Africa, Indian Ocean, Mediterranean and South China Sea); ii) the Caribbean; and iii) the Pacific (as shown in Figure 2). Their characteristic features: population, Area, Coast line length and Maximum Elevation. SIDSs are among the least responsible of all nations in terms of greenhouse gasses emissions that are believed to be causing climate change. On the other hand, SIDSs are believed to be the first and the most affected nations from the adverse impacts of climatic change. In some cases, the physical damage could reach irrecoverable limits making them practically uninhabitable (Kelman, 2014). Due to this reason, these are considered to be the most vulnerable human settlements on earth and require the help and special attention of the global community. As per latest available data total population living in Small Island Developing States is 63.2 million which is approximately 1% of the total world population today. Economically, SIDSs have a combined gross domestic product (GDP) of $575.3 billion which is slightly less than 1% of the global GDP. Most of SIDSs have Exclusive Economic Zones (EEZs) i.e. sea zone, larger than their land area due to skewed land to sea ratios. For example, EEZ of Nauru is nearly 15,000 times of its land area size, whereas EEZ of Samoa is eight times its land area. In terms of nature of the terrain, many SIDSs have mostly low-lying flat land areas (e.g. Maldives) while some have a varied terrain, including mountainous areas e.g. Haiti (UNFCCC, 2005). In terms of population density, SIDSs are generally densely populated. However, large differences are there between different SIDSs countries in this regard ranging from Papua New Guinea, with a population density of about 1 person per Km^2 of land area to Singapore with nearly 5,000 persons per Km^2 (World Bank, 2012). Table 1 presents a concise summary of some important demographic and physical features of SIDSs. Nearly 90% of SIDSs members are in the tropics with extreme weather events such as tropical storms, cyclones and hurricanes being their prominent weather features. Also, drastic changes in rainfall, floods and droughts are among the prevailing weather pattern there. This paper specifically focuses on the vulnerabilities of the SIDSs to climate change impacts especially to their water resources as the existence these generally resource-poor small island states is seriously threatened by it in the near to long term future.

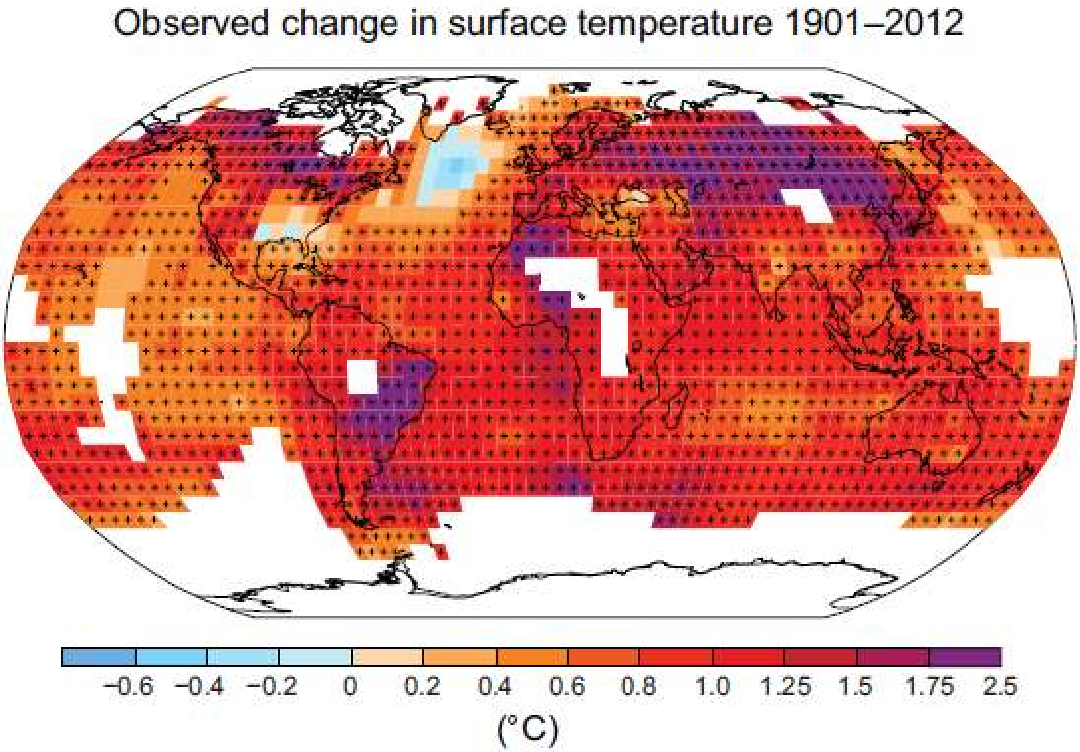
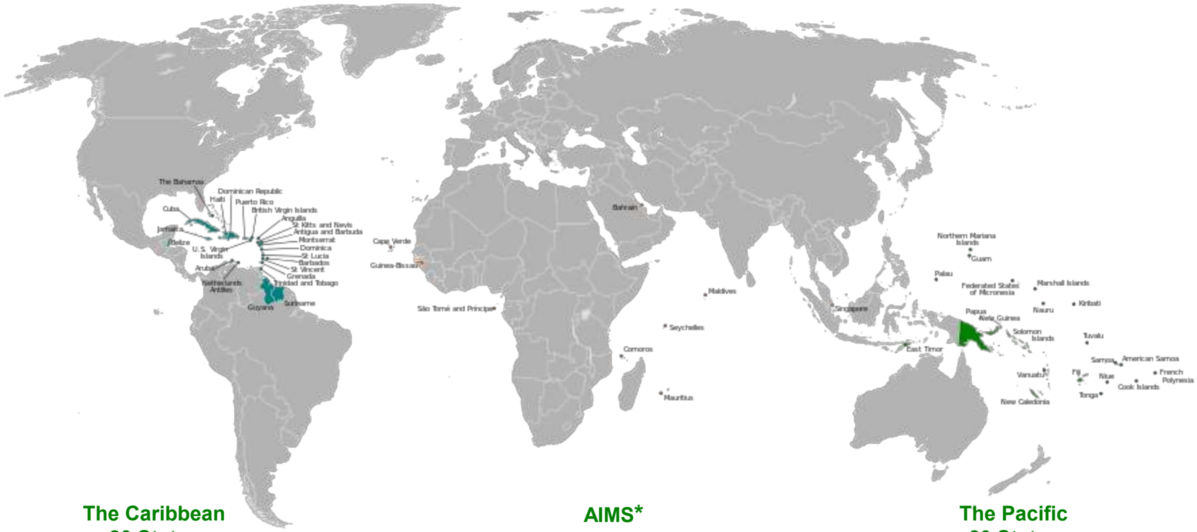


Figure 1: Observed changes in global surface temperature during last century (IPCC, 2013), white colored polygons show areas with no data

MATERIALS AND METHODS

Climate Change and its Impacts in SIDSs

Considering the geographic location of SIDSs (surrounded by sea) and land-sea interactions being the main governing factor, inter-annual natural variation in precipitation for SIDSs is higher as compared to other countries. This higher rate of variation may result in various forms of extreme hydrological events, such as droughts and floods. These extreme events can exhibit adverse impacts of various levels including subjecting natural systems and infrastructure to serious damages. Current and future climate change is going to exacerbate the situation in SIDSs through rising temperatures on land and sea surfaces, tropical/extra-tropical cyclones, sea-level rise and varying rainfall patterns. Recognizing the need for a special attention required for SIDSs in terms of detection and attribution of climate change and its likely impacts to formulate suitable adaptation strategies, a specific chapter on 'Small Island States' was included by IPCC in its Third Assessment Report published in 2001, for the first time. The current IPCC assessment report (AR5) also has a dedicated chapter for SIDSs which says, "Rather their high diversity in both physical and human attributes and their response to climate-related drivers means that climate change impacts, vulnerability and adaptation will be variable from one island region to another and between countries in the same region" (IPCC, 2013).



The Caribbean
23 States
Total Area: 632 1000 Km^2
Total population 40.3 Million

AIMS*
8 States
Total Area: 47 1000 Km^2
Total population 8.9 Million

The Pacific
20 States
Total Area: 567 1000 Km^2
Total population 9.5 Million

***(Africa, Indian Ocean, Mediterranean and South China Sea)**

Figure 2: Geographical distribution of Small Island Developing States (SIDSs) in three zones

Table 1: Key facts related to demographic and physical features of SIDSs

Parameter	Value	Remarks
Range of Population (Million)	0.0017- 11.2	Min^m: Niue Max^m: Cuba
Number of SIDSs with Population below 10,000	2	
Range of Area (Km^2)	21- 463,000	Min^m: Nauru Max^m: Papua New Guinea
Number of SIDSs with Area less than 100 Km^2	3	
Range of Average Width (Km)	5 - 700	Min^m: Nauru Max^m: Papua New Guinea
Number of SIDSs with Width less than 10 Km	3	
Range of Coastline (Km)	24 - 6,112	Min^m: Tuvalu Max^m: Fed. State of Micronesia
Number of SIDSs with Coastline less than 100 Km	9	
Range of Maximum Height (m) above sea level	2.4 - 4,509	Min^m: Maldives Max^m: Papua New Guinea
Number of SIDSs with Max. Height less than 10 m above sea level	3	

Observed Climatic Changes

According to the IPCC AR5, the following are the main observed changes in the global climate and the associated major impacts:

- An increase of 0.6 ^{0}C in mean global temperature during the last century (During the first 12 years of this century the temperature has increased further by about 0.2 ^{0}C);
- Large variations (both, increases and decreases) of temperature and precipitation in different parts of the world;
- Significant increase in frequency and intensity of extreme climate events (floods, cyclonic storms, droughts etc.);
- Large scale melting of polar ice caps and mountain glaciers, in particular the Arctic;
- Sea level rise of 19 cm over 20th Century.

In pursuit of the observed climate change in SIDSs, several studies have been carried out. For instance, some of the main findings of the analysis performed for the Caribbean region using the data of the second half of the 20th century are (Tompkins et al., 2005):

- Significant increase in the number of very warm days and nights
- Decrease in the number of very cool days & nights and extreme inter-annual temperature range
- Decrease in the maximum number of consecutive dry days
- Increasing trend of the number of heavy rainfall events
- Rise in sea temperature by 1.5 0C
- Overall decreasing trend in precipitation, with prolonged dry spells having occurred over the last few decades (Tompkins et al., 2005).

A study (Manton et al., 2001), focusing on Southeast Asia and the South Pacific finds out that:

- Significant increase in the annual number of hot days and warm nights
- Significant decreases in the annual number of cool days and cold nights
- Statistically significant increase in the frequency of hot extremes and decrease in the frequency of cold extremes
- Increasing trend of mean rainfall over the South Pacific Convergence Zone and its north east.
- The overall trend of extreme rainfall is not very clear
- Increase of 0.6 to 1.0 0C in ocean surface and island air temperatures
- Since 1970, there is a decadal increase of 0.3 to 0.5 0C in annual temperature since 1970
- The increases in surface air temperatures have been greater in the Pacific than the global rates of warming (Guinea and Unit, 2000).

Projected Climatic Changes

According to AR5 Summary for Policy Makers (SPM), the most likely range of global surface temperature change as projected for the 21st Century is 1.5 – 4.6 ^{0}C (In extreme case the temperature may increase by up to 6 ^{0}C) (Figure 3). This warming trend will not be uniform for all regions and will exhibit variability on annual to decadal scales. All the RCPs (Representative Concentration Pathways) scenarios (except for RCP 2.6), indicate that the said warming trend will continue even after the end of 21st century (IPCC, 2013).

Projections of temperature for SIDSs under SRES A1B (the medium emissions) scenario as reported in the IPCC AR4 suggest (IPCC, 2007):

- An annual increase of 1.8 to 2.3 0C in surface temperature by the year 2100 in the Caribbean, Indian Ocean and Pacific Ocean small islands regions as compared to the baseline climate of 1980-1999
- About 12% overall annual decrease in precipitation in the Caribbean while a 3-5% increase in the Indian and Pacific Oceans small island regions
- Similar projections under the comparative new RCP 4.5 scenario in the 5th Assessment Report of IPCC (AR5) indicate:
- Increase of 1.2 to 2.3 0C in surface temperature by the year 2100 as compared to a baseline climate of 1986-2005
- A decrease in precipitation of 5 to 6% in the Caribbean and Mediterranean respectively which can exhibit serious implications for agricultural productivity and water security
- There is a projected increase of 1-9% in precipitation for Indian Ocean and Pacific Ocean small islands
- There is a prominent difference in future projections for the Mediterranean islands and the tropical small islands until year 2100. For instance, frequency and intensity of temperature related extreme events (e.g. warm spells, heat waves) is likely to increase in the Mediterranean islands.

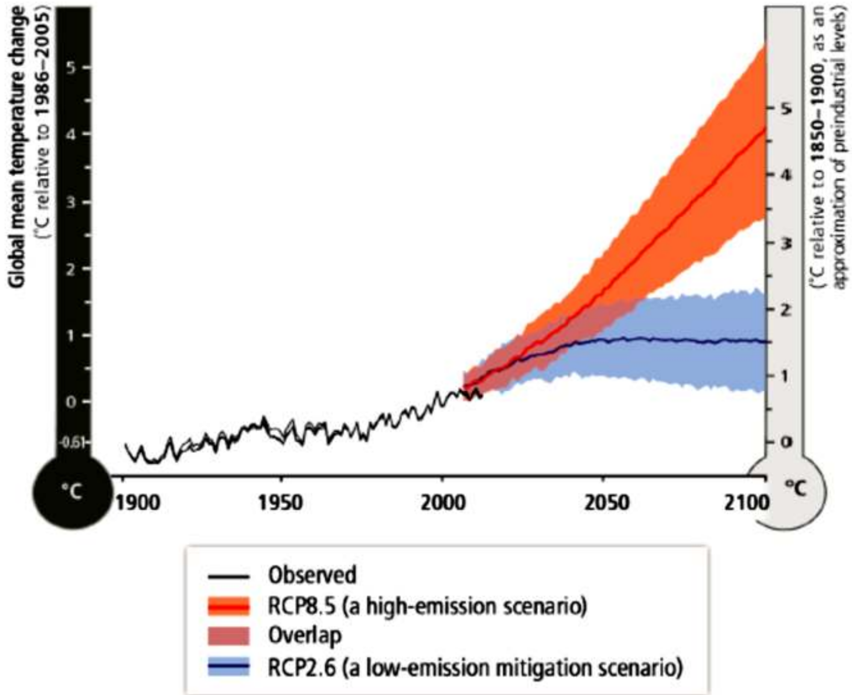


Figure 3: Future projections of global temperature rise based on RCP 2.6 (Low) and RCP 8.5 (High) scenarios (IPCC, 2013)

Sea Level Rise

Sea level rise (SLR) is the most important factor to consider when analyzing the vulnerabilities of SIDSs and the factors largely responsible for it are; i) global glacier/ice sheet melt (Greenland and Antarctica being the main source) and ii) thermal expansion, which expands existing water volume (Hemming et al., 2007). According to an estimate about the impact of SLR on the displacement of human settlements made during a research study, one-meter rise in sea level by the end of 21st century would result in displacement of around 130 million people around the world.

IPCC AR5 reports with a high level of confidence that the rate of sea level rise (SLR) has shown a much higher increase since the middle of the 19th century as compared to that for the previous two millennia. More precisely:

- Global mean SLR during 1901-2010 period was 0.19 m (likely range 0.17 to 0.21m) (Figure 4)
- The rate of global mean SLR during the most of the 20th Century period, was between 1.3 to 1.7 mm yr^{-1}. After 1993 it fluctuated between 2.8 to 3.6 mm yr^{-1} (IPCC, 2013).
- In the tropical region of western Pacific which is home to a large number of small islanders, during the period 1993-2009 the rates of SLR are found to be four times higher than the global average (approximately 12 mm yr^{-1}) (Becker et al., 2011).

According to the latest IPCC projections, the global mean SLR for 2081–2100 (taking 1986–2005 period as baseline) with the combined effect of all contributing factors is likely to be 0.26 to 0.82m for the four IPCC RCP scenarios (Fig. 5). Based on the RCP8.5 scenario, SLR projection for end of the 21st century is 0.52 to 0.98 m, (at a rate of 8 to 16 mm yr^{-1} for last 20 years). These given SLR projections are based on a combination of CMIP5 climate models' simulations, some process-based models and review of literature on the magnitude/volume of glacier and ice sheet melt (IPCC, 2013).

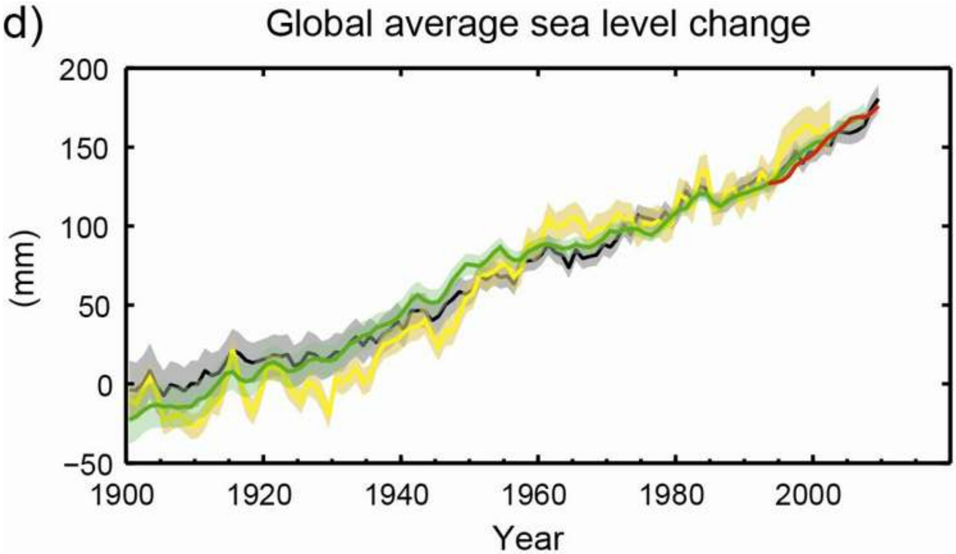


Figure 4: Historical changes in global average sea level during the 20th century (IPCC, 2013)

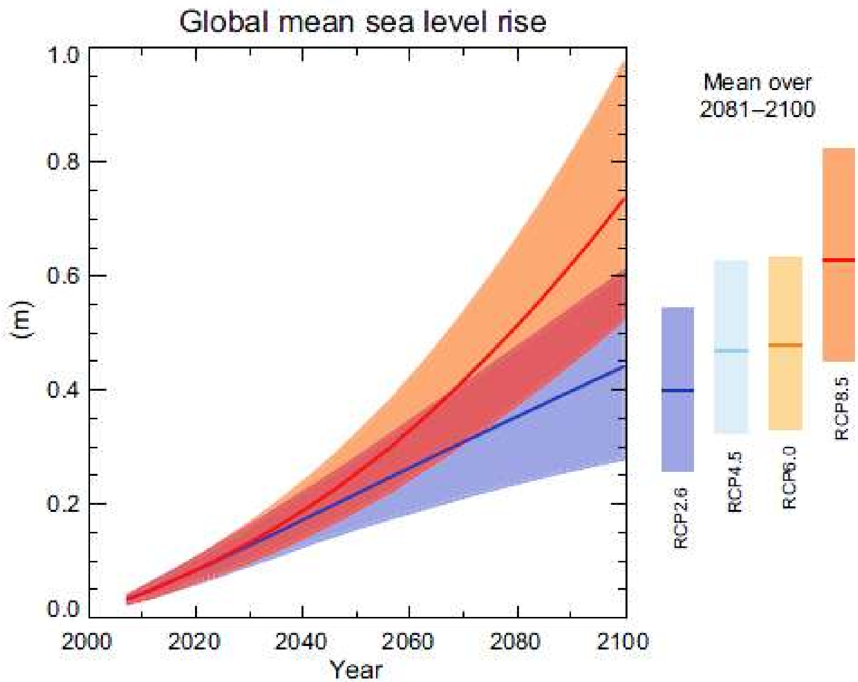


Figure 5: Projections of global mean sea level rise during the 21st century under different IPCC scenarios (IPCC, 2013)

Projections of Sea level rise for the small islands regions are higher than the global SLR projections given in the previous paragraph. For the RCP4.5, projected SLR by year 2100 relative to 1986-2005 baseline ranges from 0.5 to 0.6 m in the Indian Ocean, Caribbean and the Pacific and 0.4 to 0.5 m in the North Indian Ocean and Mediterranean (IPCC, 2013).

Global ice melting resulting from rising temperature (arguably at a faster rate in glacier/ice-rich mountainous regions) plays a major role in SLR hence contributing to the vulnerability of SIDSs. The total volume of the ice in all the 171, 000 glaciers spread in different parts of the world (other than the Greenland and Antarctic ice sheets) by a recent study through a methodology comprising of both the direct satellite observations and modeling is almost 170,000 km^3 (21,000 Km^3). Melting of all this glacier volume would cause a global SLR of almost 17 inches (43 centimeters) (Huss and Farinotti, 2012). Furthermore, according to an estimate made by IPCC in 2007, a global SLR of about 7m would occur as a result of melting of whole of the Greenland ice sheet. Hence, the combined effect of melting of all the ice contained in 171,000 glaciers and Greenland ice sheet would cause a total global SLR of about 7.43 m. According to IPCC, after the year 2100 thermal expansion would be the main cause of global mean SLR which is likely to continue for many centuries (Figure 6). Currently, there are only few global model simulations available that simulate the period after year 2100. These simulations show that two centuries after year 2100, the global mean SLR above the pre-industrial sea level would be less than 1 m and 1 to more than 3m for radiative forcing equivalent to RCP2.6 and RCP8.5 respectively.

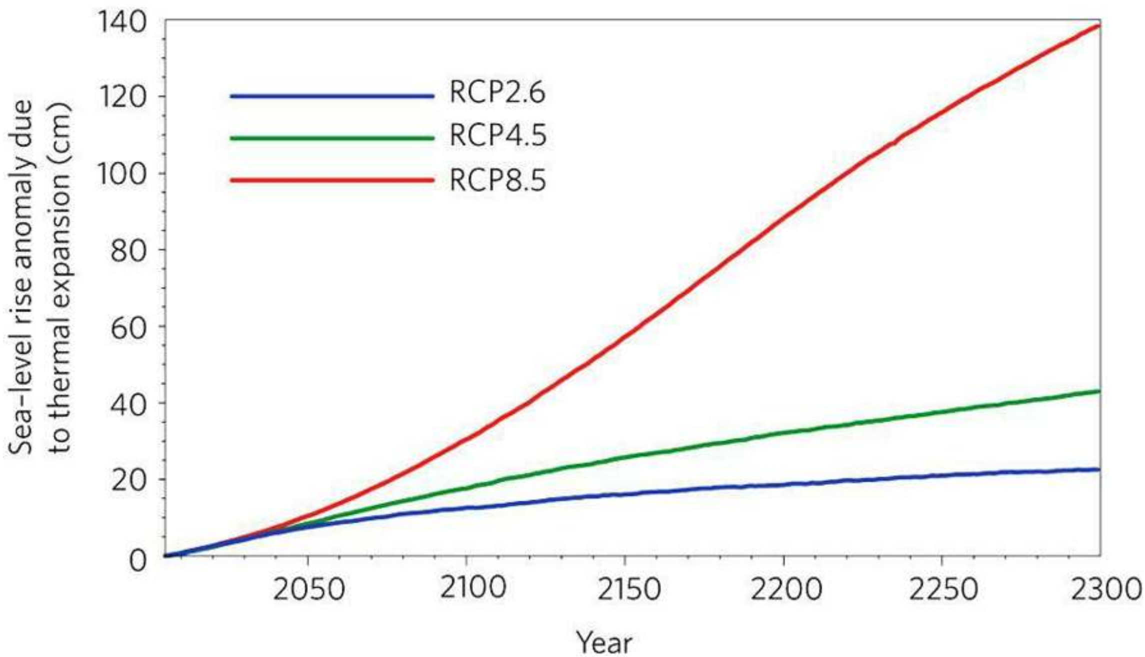


Figure 6: Projections of SLR beyond 21st century due to thermal expansion under three RCP scenarios

Major Freshwater Challenges

As reported by many studies, there is a decreasing trend of per capita freshwater availability globally. This situation is more alarming for SIDSs having small surface areas, limited natural, technical and financial resources and being more vulnerable to climate change impacts than larger continental countries. Some of the major fresh water challenges under the impacts of climate change posed to SIDSs are as under;

- Threats to supplies of fresh water in relatively small watersheds
- Sea water intrusion into freshwater resources
- Health related issues in SIDSs caused by poor water quality and limited water quantity
- Lacking ample freshwater storage and efficient distribution system causing clean water access problem.
- Inadequate action to safeguard watershed areas and groundwater resources
- Threat of freshwater contamination due to untreated human, livestock and industrial waste and agricultural chemicals
- Climate change induced extreme events e.g. droughts, flooding, storm surges, and sea-level rise.

RESULTS AND DISCUSSION

Vulnerabilities of SIDSs to climate change

By definition, 'vulnerability' is the tendency of something to be damaged. The opposite of this is 'resilience' which means the ability to resist to and/or recover from damage. According to Business Insider (2012), "Something is vulnerable to the extent that it is not resilient, and vice versa". The vulnerability of an island state is governed by the following four key factors, individually or through a complex combination of any of these;

- Small size
- Geographic isolation
- Sea level rise
- Natural and environmental disasters

Based on the above mentioned four key factors, (Kelman, 2014) determined vulnerabilities of SIDSs to different types of climate change impacts and factors (e.g. import of food items, dependence on changes in external markets) that further exacerbate the impacts of climate change. Owing to their specific climatic and certain socio-economic conditions, SIDSs are considered to be the most vulnerable to climate change along with the 12 least developed countries (LDCs) of the world. Based on the Environmental Vulnerability Index (EVI) that was developed in 2005 by the South Pacific Applied Geoscience Commission (SOPAC), the United Nations Environment Programme (UNEP) with some of their partners, a comparison of SIDSs with all countries is shown in Table 2. The EVI is estimated by means of 50 indicators that depict the vulnerability of the environment of a country to future shocks. There are 32 indicators of hazards, 8 of resistance and 10 that measure damage. The hazard indicators relate to the frequency and intensity of hazardous events. The resistance indicators refer to the inherent characteristics of a country that would tend to make it more or less able to cope with natural and anthropogenic hazards. This includes measures such as absolute size and number of shared borders. Damage indicators relate to the vulnerability that has been acquired through loss of ecological integrity or increasing levels of degradation of ecosystems. Out of the total of 50 indicators, 6 are related to weather & climate, 4 to geology, 6 to geography, 28 to ecosystem resources & services and 6 to human populations. Examination of Table 2 reveals that about 70% of the studied SIDSs fall in the categories of Highly vulnerable and Extremely vulnerable with no SIDSs country potentially resilient.

Table 2: Comparison of Environmental vulnerability of SIDSs with all countries in terms of EVI scores

Level of Vulnerability	No. of All Countries of the World including SIDSs	No. of SIDSs	SIDSs as % of Total
Extremely Vulnerable	35	17	49%
Highly Vulnerable	62	17	27%
Vulnerable	81	10	12%
At Risk	43	3	7%
Resilient	14	-	-
Total	**235**	**47***	

*** 4 SIDSs have been left out due to non-availability of adequate data.**

A comprehensive study by (Hay, 2013), that taken into consideration about 12,983 islands (size greater than 2.5 hectares) of the Pacific Ocean including the Philippines and Hawaiian Islands, reveals that an SLR of 1 to 6 meters would cause a significant number of islands to entirely submerge under water. Although, SIDSs have different kinds of economies and there exists a significant deviation in their geographical, physical, climatic, social, political and cultural characteristics, they do share certain characteristics that makes them almost equally vulnerable to climate change, climate variability and especially to sea-level rise. The following are some of the major indicators of SIDSs vulnerabilities:

- Strong possibility of submersion of large areas of land under the sea, where most of the population is located;
- Irrespective of their geographic location, besides sea level rise, SIDSs are also extremely vulnerable to tropical storms: typhoons, hurricanes etc.;
- Deterioration of coastal conditions, (e.g. erosion of beaches, and coral bleaching) resulting in loss of local resources (e.g. fish production, mangroves etc.) that support the livelihood of island communities;
- By mid-21st Century, fresh water resources in many SIDSs in the Caribbean and the Pacific are projected to decline considerably during low-rainfall periods;
- Some impacts of Climate change (e.g. coral bleaching and reduced beach areas due to sea level rise) will negatively impact the all-important tourism industry in these Island States.

Some Special Cases of SIDSs Vulnerability

A few special cases are presented below as examples of the extent of SIDSs vulnerabilities to the adverse impacts of climate change:

Sea Level Rise

- On average the Maldives is 1.3 meters above sea level (masl) and 80 per cent of its land area is below 1 meter amsl and is highly susceptible to rising sea level. As per President Mohamed Nasheed of the Maldives just three feet of SLR would submerge the Maldives and make them uninhabitable. Mr. Abdullahi Majeed (Madives) made the following statement on 11 December 2003, Milan, Italy (COP 9 Round-Table);
- "In April 1987, Maldives experienced unusual high waves causing extensive damage to the islands. Two thirds of the whole Maldives, including the capital island, Malé, was inundated for two days causing extensive damage to the infrastructure. Male International Airport, the only gateway to the Maldives, was closed for two days, causing delays in receiving the relief assistance from the international community, cancellation of tourist arrivals and lot more."
- In the Papua New Guinea, about 20-50 per cent of the land area is below mean sea level and is highly prone to SLR, as in the case of Maldives.
- The level of vulnerability of each SIDS to SLR in terms of percent of endangered population living in a coastal zone of elevation less than 10 masl can be seen in Figure 7. Examination of this figure reveals that many SIDSs have more than 50% population and almost all of the SIDSs have at least 10% population living within 10 masl elevation zone making them highly vulnerable to rise in sea level.

Hence, the low-lying flat (the highest island elevation (HIE) ≤ 10 meter above sea level) islands are expected to suffer the most. These include Marshal Islands (HIE = 10 masl), Tuvalu (HIE = 4.6 masl) and Maldives (HIE = 2.4 masl) (Annexture I). As an example of mode of the sea level rise impact, IPCC TAR indicates that an SLR of 80 cm is enough to submerge about 66% of the Marshall Islands and Kiribati, while a SLR of 90 cm could inundate about 85% of Maldives' capital, Male (Pernetta, 1989).

Like in many other countries around the world, the economic and social development in SIDSs is heavily dependent on availability of freshwater. For example, in the Mauritius, Bahamas and Barbados, the groundwater is a key resource for sustaining their economy and is believed to be badly affected by sea water intrusion (UNFCCC, 2005). Following are few examples of freshwater related vulnerabilities of some SIDSs:

- According to a 2013 list of the most water stressed counries released by World Resources Institute (WRI), ten out of the top 20 countries are SIDSs.
- In the AIMS, Mauritius is projected to become a "water-stressed" country, and Comoros a "water-scarce" country by year 2025;
- In the Seychelles (the AIMS), due to severe water shortage in 1998 (believed to be due to extreme El Niño event), their major industries including brewing and fish-canning were badly effected;
- Mahé in the Seychelles (the AIMS) threatening water shortages may give rise to the spread of a wilt disease in certain tree species that are important for proper functioning of ecosystems and watershed management;
- In the Comoros (the AIMS), the islands of Grande Comore, Mohéli and Anjouan are threatened by sea water intrusion into many of the coastal boreholes providing water supplies;
- Pacific islands, being largely dependent upon rain-fed agriculture are particularly vulnerable (in terms of their economies and peoples' livelihoods) to drought and rainfall variability especially under looming enhanced climate variability and change;
- A number of the Caribbean island countries are facing "water stress" as their, annual per capita freshwater availability is already below the 1,000 m^3 threshold. Also, the Caribbean faced a worse drought in 2009–2010.

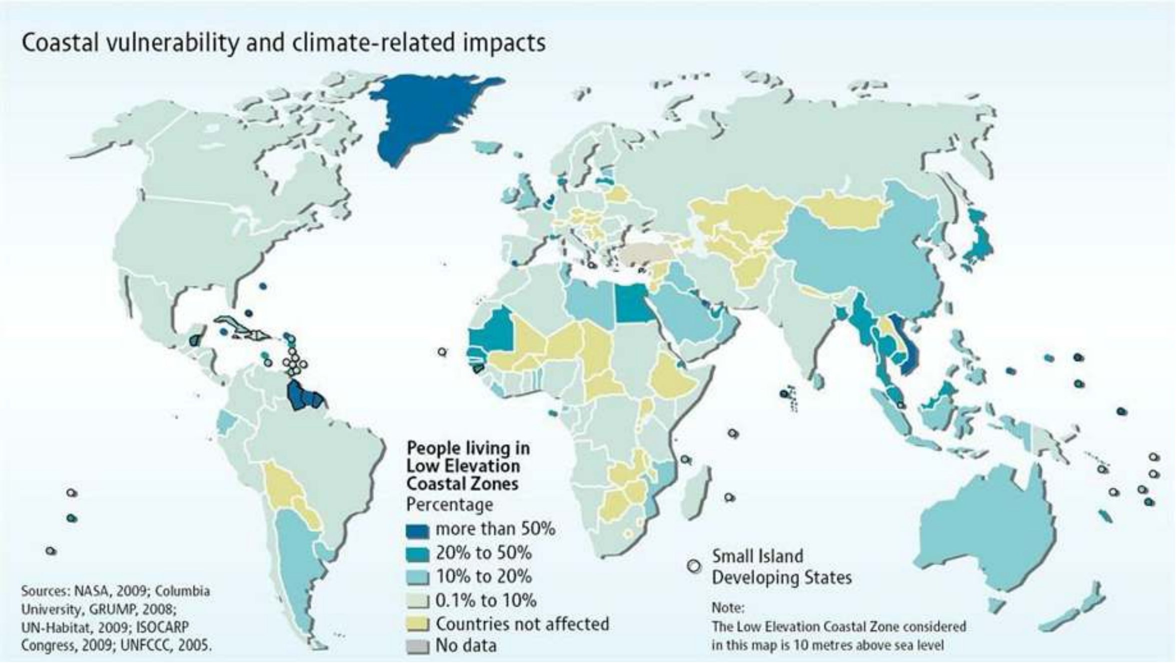


Figure 7: Vulnerability of SIDSs to SLR in terms of %age of population living in low elevation zone (> 10 masl)

Extreme Events

- In the Seychelles (the AIMS), about 80% of the infrastructure and population are under the threat of extreme weather events such as tropical storms, cyclones and hurricanes, being very close to the coast;
- Barbados and other similar islands are facing a serious threat to their large import activities through sea of the life sustaining goods (food, fuel etc.) as the frequency of cyclones and hurricanes is likely to increase;
- Palau has been experiencing severe drought periods during El Niño Southern Oscillation events;
- The entire South Pacific region has been experiencing an increase in the frequency and intensity of tropical cyclones and other climate-related extreme events since 1990s.

Highly Vulnerable SIDSs

Acording to IPCC Third Assessment Report (TAR) released in 2001, "Many small island states—especially the atoll nations of the Pacific and Indian Oceans—are among the most vulnerable to climate change, seasonal-to-interannual climate variability, and sea-level rise". However, Kiribati, the Federated States of Micronesia, Marshall Islands, Tuvalu, Cook Islands and Tonga (in the Pacific); Nevis and Antigua (in the Caribbean); and Maldives (in the AIMS) are more vulnerable then rest of SIDSs. In the study published by two types of vulnerability indices (defined by UN Secretary General, 2010) scores i.e. economic and environmental, of SIDSs (for which the required data were available) are compared with average scores of these indices calculated for all LDCs. According to the analysis presented in (Hay, 2013), generally, most of SIDSs are economically and environmentally more vulnerable than an average vulnerable LDC. Specifically, Solomon Islands, São Tomé and Príncipe, Comoros, Maldives, Vanuatu and Samoa are the most vulnerable of all SIDSs as these are in LDCs list and have environmental and econimic vulnerability above an average vulnerable LDC.

Adaptation strategies suitable for SIDSs for their sustainable development

The most relevant adaptation options for an island nation usually depend upon type of that island, nature of the hazards it is prone to, its exposure and vulnerability. As the AR5 chapter on SIDSs points out, climate change adaptation measures prove the most successful for small islands when the local community is on board and other development activities, such as disaster risk reduction is running in parallel.

As discussed in (Forbes et al., 2013), the suitability of different adaptation options for different island types e.g. an ecosystem-based mangrove conservation/restoration which best suits the continental and volcanic high islands and atolls but raised carbonate atolls may not get much benefit from such measures. Another adaptation option is known as Coastal setback (a minimum distance from the shoreline within which no development is allowed), a globally recognized adaptive measure and applicable to all island types, but it best suits the high carbonate islands such as Niue and Bermuda where infrastructure facilities built on a high elevation can be damaged by a major tropical cyclone. United Nation Environmental program (UNEP) Regional Office for Latin America and Caribbean in collaboration with CARICOM (the CARIbbean COMmunity) published special report in 2008 focusing on trends of climate change and variability, its impacts on Caribbean SIDSs and the efforts being done to address these impacts. In this report, Caribbean SIDSs have been provided very useful guidelines about developing national climate change agendas, adaptation strategies to deal with climate change impacts. It also guides about how to implement the Kyoto Protocol and joint global efforts after that (UNEP, 2008). As examples of initiatives already taken by the SIDSs over the past decade for resilience against observed and near future climate change and to address climate change through a variety of means include; 38 SIDS have ratified the United Nations Framework Convention on Climate Change, and a range of regional activities and partnerships have been developed such as the South Pacific Sea Level and Climate Monitoring Project, the Pacific Islands Global Ocean Observing System (PI-GOOS), the Pacific Climate Change Portal, and the Caribbean Community Climate Change Centre (CCCCC). Rainwater Harvesting is widely practiced and encouraged in many SIDS as rainfall is quite regular. It is common for households to incorporate rainwater storage tanks and cisterns to supplement their supplies at the household level, which puts an onus on the individual to maintain the system in a safe state. This requires investment in broad scale education and awareness-raising on the household level as well as on suitable technology. Groundwater Recharge allows for the safe collection and transmission of rainwater into the underlying aquifer and is appropriate for areas dependent on shallow rain fed groundwater supplies. This is common in Barbados and Trinidad, where water extracted from recharged aquifers is often of an acceptable quality. Based on the specific needs of SIDSs and practicability of different adaptation options, in our opinion the following measures will go a long way in countering the negative impacts of Climate Change in SIDSs:

- Enhanced international cooperation for providing technical and financial support considering specific needs of SIDSs, in particular to ensure their food and water security;
- Maintenance and restoration of coastal landform by controlling land erosion through construction of dikes etc., wherever appropriate;
- Improving existing mangrove forests and developing new mangrove plantations to protect against storm surges and inundation of coastal infrastructure by cyclones etc.;
- Protection of the available soil through improved management;
- Introduction of appropriate building codes and settlement patterns to protect against the increasing risk of climate related disasters;
- International arrangements to shift population from some of the most vulnerable SIDSs to other countries and resettle them properly;
- Strengthen capacity of SIDSs in monitoring, early warning and responding to natural and environmental hazards, in particular climate change-induced drought and sea level rise;
- Developing robust and long term water management strategies including storage facilities, catchment management, water treatment and distribution;
- Implement freshwater resources strategies that take account of the possible constraints to water supply from low groundwater recharge in times of drought, salt-water intrusion, and inundation as a result of climate change and sea-level rise.

CONCLUSION

This paper aimed to explore climate change, vulnerabilities and possible adaptation strategies for SIDSs. Climate change is a major challenge for SIDSs and more threatening to them than rest of the world as they have small population sizes, limited resources, isolation from the mainland countries, high exposure to natural disasters, and heavy dependence on import of essential goods mainly through sea. In terms of current and future climate change, SIDSs are no exception to what is happening globally and are experiencing rising temperatures and associated changes in other climatic features.

In summary, the projected climate change is likely to aggravate the current climate-related stresses in various SIDSs, particularly;

- Projected higher temperatures are likely to give rise to the water related health issues for already vulnerable island life.
- Temperature projections related to SIDSs also show more occurrences of extreme events (e.g. heat waves) which may affect both humans and sea life.
- Changes in seasonal rainfall patterns may take the form of more frequent and more intense droughts and floods for many of the already troubled SIDSs.
- Among the climate change impacts, sea level rise (believed to be mainly caused by global ice melting and thermal sea expansion) is a major threat for SIDSs and almost all of their adaptation strategies mainly revolve around these.

REFERENCES

- King D, (2004). Climate change science: adapt, mitigate, or ignore. Science 303(5655): 176–7.
- Kelman, I. (2014). No change from climate change: vulnerability and small island developing states. The Geographical Journal 180: 120–129.
- UNFCCC (2005). Climate Change, Small Island Developing States. Issued by the CLIMATE CHANGE SECRETARIAT (UNFCCC), Bonn, Germany.
- Tompkins EL, Nicholson-Cole SA, Boyd E, Hurlston LA, Brooks Hodge G, Clarke J, Trotz N, Gray G, Varlack L. (2005). Surviving Climate Change in Small Islands - A guidebook, produced by the Tyndall Centre for Climate Change Research 37(2):132.
- Manton MJ, Della- Marta PM, Haylock MR, Hennessy KJ, Nicholls N, Chambers LE, Collins DA, Daw G, Finet A, Gunawan D, Inape K, Isobe H, Kestin TS, Lefale P, Leyu CH, Lwin T, Maitrepierre L, Ouprasitwong N, Page CM, Pahalad J, Plummer N, Salinger MJ, Suppiah R, Tran VL, Trewin B, Tibig I, Yee D. (2001). Trend in extreme daily rainfall and temperature in southeast Asia and the South Pacific: 1961–1998. International Journal of Climatology 21(3): 269–284.
- Guinea PN, Unit PIC. (2000). Cities, Seas and Storms: Managing Change in Pacific Island Economies, vol. 1. World Bank, Washington DC.
- Hemming D, lowe J, Biginton M, Betts R, Ryall D. (2007). Impacts of mean sea level rise based on current state-of-the-art modeling. Hadley Centre for Climate Prediction and Research, Exeter, UK.
- Becker M, Meyssignac B, Letetrel C, Llovel W, Cazenave A, Delcroix T. (2012). Sea level variations at tropical Pacific islands since 1950. Global and Planetary Change 80: 85-98.
- Huss M, Farinotti D. (2012). Distributed ice thickness and volume of all glaciers around the globe. Journal of Geophysical Research: Earth Surface 117(F4):1-10.
- Hay J. (2013). Small island developing states: coastal systems, global change and sustainability. Sustain Sci 8:309–326.
- Pernetta JC. (1989). Cities on oceanic islands: a case study of Male, capital of the Republic of Maldives. In Impacts of Sea Level Rise on Cities and Regions, Proceedings of the First Annual International Meeting, “Cities on Water”, Marcilio Editors, Venice, Italy. pp. 169-182.
- Forbes D, James T, Sutherland M, Nichols S. (2013). Physical basis of coastal adaptation on tropical small islands. Sustain Sci 8:327–344.
- Wetzel FT, Beissmann H, Penn DJ, Jetz W. (2013). Vulnerability of terrestrial island vertebrates to projected sea- level rise. Global Change Biology 19(7): 2058-2070.