Impacts of Sea-Level Rise on Coastal Zones of Mauritius: Insights following Calculation of a Coastal Vulnerability Index

Yashna Devi Beeharry[1], Girish Bekaroo[2*], Chandradeo Bokhoree[1], Michael Robert Phillips[3]
[1] University of Technology, Mauritius, La Tour Koenig, Pointe aux Sables, Republic of Mauritius
[2] Middlesex University (Mauritius Branch Campus), Vacoas, Republic of Mauritius
[3] College of the North Atlantic - Qatar, Qa

***Abstract*— Whilst climate change has been regarded as a growing concern in recent years due the disruptive and detrimental effects experienced across the globe, one of its most compelling and threatening evidence is Sea Level Rise (SLR). This phenomenon is more prominent in Small Island Developing States (SIDS) and such islands are already facing escalating associated environmental threats, causing social and economic disruptions as well as insecurities. Amongst the SIDS, the coastal areas of Mauritius are considered among the most vulnerable to SLR, where statistics showed that between the years 1987 and 2007, an annual increase of 2.1mm in the sea level has been observed around Mauritius. Although SLR has various associated impacts, limited work has been undertaken to assess the coastal vulnerability of the impacts of SLR for Mauritius and to compute the Coastal Vulnerability Index (CVI) of the island. Taking cognizance of this limitation, the purpose of this paper is to quantify, prioritize and critically assess the vulnerability of key impacts of sea level rise on the coastal areas of Mauritius following computation of a CVI. In this process, five key research questions are answered towards calculating the CVI of the island to eventually conceptualize a framework with the aim to reduce the adverse impacts of SLR on coastal zones of Mauritius. Findings of this study aim at the advancement of resilience and increased sustainability of coastal areas to the impacts of SLR.**

Keywords*— Coastal Vulnerability Index, Sea-Level Rise, Mauritius, Coastal Zone, Coastal Resilience, Vulnerability Assessment.

I. INTRODUCTION

Due to their rich prevailing ecosystem and services, coastal zones have been recognized as the most exploited areas around the world (Semedescu & Fîntîneru, 2013; Incera & Fernández, 2015; Beeharry, Makoondlall-Chadee, & Bokhoree, 2014) and have undergone numerous developments during recent years thereby positively impacting the society and economy of several countries (Lakshmi & Rajagopalan, 2000). These regions have been considered as the most dynamic environments within which human activities interact with economy, ecology, and geomorphology (Fabbri, 1998; Coelho, Silva, Veloso-Gomes, & Taveira-Pinto, 2009). Whilst providing shelter to a range of habitats and resources including sand minerals, hydrocarbons and aquatic living organisms (Masria, Negm, Iskander, & Saavedra, 2014), coastal zones also regulate the environment by being a sink for pollution resulting from land based activities and development (Hung & Hsu, 2004). However, due to associated effects of climate change, such regions are known to be particularly vulnerable to Sea-Level Rise (SLR) (FitzGerald, Fenster, Argow, & Buynevich, 2008). SLR is the observed increase in the level of the global sea due to a change in the ocean volume (Mimura, 2013). During the previous century, the global level of the sea increased by 1.8 millimetres annually (Douglas B. C., 1997) and this has made people living within the coastal zones homeless. Additionally, it was estimated in 2007 that by the year 2100, the sea would rise by an approximate 60 centimetres as a result of the warming of the ocean and melting of the polar ice (IPCC, 2007). However, owing to the accelerated decline in the mass of the glaciers, it has recently been identified that the expected SLR would be 1 metre or more by 2100 (Allison, Alley, Fricker, Thomas, & Warner, 2009; Rignot, et al., 2008; Velicogna, 2009). This increase is expected to have significant effects on the coastal regions and neighbouring land areas including damage to infrastructure (e.g., hotels and jetties), risk to inhabitants due to flooding, loss of biodiversity and adverse impacts on agricultural products located within coastal zones (Nicholls & Cazenave, 2010).

Among the areas affected, Small Island Developing States (SIDS) are highly vulnerable to SLR and the effects of climate change though being the least contributors to greenhouse gases (IPCC, 2014). As a SIDS, the Island of Mauritius is very susceptible to SLR and the effects of climate change (UN-OHRLLS, 2015; Bekaroo, Bokhoree, & Pattinson, 2016).

The coastal areas of the Island of Mauritius are considered among the most vulnerable to SLR, causing far-ranging effects on the prevailing environment and economic activities as well as health of the society. Recent statistics showed that between the years 1987 and 2007, an annual increase of 2.1mm in the sea level was recorded around Mauritius thus confirming the rising sea level (Mauritius Meteorological Services, 2017). Consequently, different adverse effects have been reported where the principal one being land loss through submergence of lowlands in addition to loss of wetlands (Ragoonaden, 1997). Furthermore, beach erosion is a known threat to the coastal infrastructure of the island affecting coastal roads and hotels principally (Ragoonaden, 1997).

Due to the significant effects of SLR on SIDS, there have been apprehensions concerning management responses (Leonard, et al., 2016; Turvey, 2007). In this endeavour, coastal vulnerability tools are essential in identifying and assessing all the potential drivers of change that could be slowed down or eradicated (Schröter, et al., 2005) in view of protecting the coastal zones for longer and sustained uses (Cicin-Sain & Belfiore, 2005). Moreover, vulnerability assessment has been recognised to improve understanding on the adaptive capacity of a system on a long-term basis, while also being an initiative towards the development of policies and their implementation (Füssel & Klein, 2006; Duong & Ngo, 2016). Additionally, studies have revealed that assessing the vulnerability of coastal zones enable understanding climate projection, level of risks being exposed to and resilience for adaption of society (Heenan, et al., 2015; Herron, Bohn, Roy, & Evans, 2016). However, even though the island of Mauritius as a SIDS is amongst the most vulnerable countries to SLR (Pelling & Uitto, 2001) and the effects of climate change (Allison, et al., 2009), limited work has been conducted regarding coastal vulnerability assessment of the impacts of SLR and so far, no Coastal Vulnerability Index (CVI) has been computed. As such, the purpose of this paper is to quantify, prioritize and critically assess the vulnerability of key impacts of sea-level rise on the coastal areas of Mauritius through the computation of a CVI. Based on insights revealed following calculation of the CVI, a framework is also proposed aiming to decrease the impacts of SLR on coastal zones of Mauritius. The sustainability assessment is focused on data collection through a survey and the use of an Analytic Hierarchy Process (AHP) to ensure that the tool encompasses both qualitative and quantitative aspects of SLR in the coastal regions. Additionally, an evaluative framework has been concurrently carried out for classification purposes. The findings enlightened within this study are essential to help climate and environmental policy makers, regulatory bodies, and researchers to better understand the impacts of SLR on the coastal areas of Mauritius and SIDS to better design solutions towards minimizing associated impacts.

II. Impacts of Sea-Level Rise and associated influences

SLR is principally caused by the warming of the ocean, melting of glaciers and land ice (Church, Wilson, Woodworth, & Aarup, 2007), all because of the emissions emanated from human activities (Nicholls & Cazenave, 2010). This phenomenon has various impacts within coastal areas and the major ones include coastal erosion, flooding, inundation, salt-water intrusion to groundwater resources and salt-water intrusion to river/estuary (Gornitz, 1990; Snoussi, Ouchani, & Niazi, 2008) (Gornitz, 1990). These impacts are highly influenced either by physical or human actions. The physical influences occur naturally because of weather processes or induced by other climatic changes and exacerbate the impacts of SLR. On the other hand, human influences relate to human activities in the form of infrastructural development within coastal areas. The key impacts of SLR along with their associated human and natural influences are discussed as follows:

A. *Coastal Erosion*

The shoreline is considered as the most dynamic interface (Mann & Westphal, 2016) due to the convergence of natural and anthropogenic processes including influence of waves, tides, sedimentation, and human developmental activities (James & Saito, 2007). Whilst being highly active, this area possesses numerous and complex land use changes being greatly influenced by the sea (Marfai, 2011). Over the years, the shoreline has been highly influenced by the sea processes: from the dynamics of waves, surges, oceanic circulations, currents, tides and sea level rise (Palha, Mendes, Fortes, Brito-Melo, & Sarmento, 2010; Irish, Resio, & Ratcliff, 2008; Cooper & Pilkey, 2004; Kuriyama & Banno, 2016). That is why coastal erosion has been viewed as one of the main physical changes, which are representatives of the shoreline evolution temporally (Boruff, Enrich, & Cutter, 2004). Moreover, since the past decades, it has also been observed that coastal erosion has been amplified both by natural and human influences.

Natural influences include the rate of sea level rise (Anderson, Fletcher, Barbee, Frazer, & Romine, 2015) and geomorphological processes. The geomorphological processes relate to the continual process of the Earth's surface to generate sediments which are eroded during the natural process of weathering (Bird, 2011). Additionally, the steeper the slope, the easier it is for gravity to initiate a landslide, thus increasing the likelihood of coastal erosion (Bromhead & Ibsen, 2006). Furthermore, in certain instances, due to natural processes such as storms, there is an increase in wave height that induce the strength of waves along the coastline thus affecting coastal erosion (Ruggiero, Komar, McDougal, Marra, & Beach, 2001). Another natural influence is tidal range, which relates to the vertical distance during the rising and falling of tides and this varies from time to time and from place to place. This rise and fall lead to the exposure of the coasts to different types of wave energy thus eroding the area at various instances (Xue, 2005).

On the other hand, a couple of human influences have also been amplifying coastal erosion. The first one is engineered frontage, which refers to any infrastructural development in terms of building, any other infrastructure, in addition to coastal protection structures that have been made because of human influences (Cheong, et al., 2013). The uncountable and ever growing anthropogenic developments in terms of engineered structures have direct impacts on coastal erosion (Hsu, Lin, & Tseng, 2007) through reduction of sediment supply (Syvitski, Vörösmarty, Kettner, & Green, 2005) and disturbances in normal river flow regulation (Hupp, Pierce, & Noe, 2009).

B. Flooding

During flooding, dry areas become wet momentarily owing to tides, heavy rainfalls, or accumulation of surface waters from any source (USGS, 2016; Flick, Chadwick, Briscoe, & Harper, 2012). This phenomenon has been considered as one of the most powerful forces on Earth (Carrera, Standardi, Bosello, & Mysiak, 2015) and has adversely impacted human health and caused many deaths (Ohl & Tapsell, 2000). During the last 10 years of the 20th century, more than 1.4 billion people were affected, and 100,000 persons died because of floods across the world (The International Disaster Database, 2016). Moreover, it has been projected that flooding is expected to be more frequent and severe in many regions around the world, especially in the tropics and in the Western Europe (Hirabayashi, et al., 2013). This exacerbation is also expected to be felt within coastal zones across the world thereby resulting in major catastrophic losses (Nicholls & Cazenave, 2010). This is particularly due to the influence of both natural and human factors.

Amongst the natural factors, it was revealed that even a slight increase in the sea level is expected to double the frequency of flooding (Spencer, et al., 2016). Furthermore, the frequency, severity and duration of coastal flooding are expected to increase with SLR (Sweet, Park, Marra, Zervas, & Gill, 2014). Whether a coastal area is steep or flat, it also linked to the susceptibility of it to being flooded where surfaces with gentle slopes are more rapidly flooded than steeper ones (Dawson, et al., 2009). In addition, a previous study has demonstrated that strong winds generate higher waves, which consequently cause flooding (Wadey, Brown, Haigh, Dolphin, & Wisse, 2015). Moreover, because of the ebb and flows of tides, flooding occurs temporarily in low lying areas, more specifically during high tide events and during new or full moon (Wassmann, Hien, Hoanh, & Tuong, 2004). Flooding due to tidal range has shown to impair the natural drainage systems in low-lying areas (Douglas, et al., 2008). On the other hand, an important human influence has been in the form of coastal developments or engineered frontage. These have showed to disturb the natural resilience of prevailing ecosystems, thus increasing the vulnerability of coastal zones to flooding (Brody, Zahran, Maghelal, Grover, & Highfield, 2007). Moreover, the degradation of natural protections has been directly linked to an increase in flooding particularly due to erosion of land and because of lesser trees that retain water (Depietri, Renaud, & Kallis, 2012). Also, within many coastal areas around the world, there have been accruing construction of coastal protection structures by human beings for several purposes; not only to cater for human activities but also for protection (WWF, 2017). However, these structures have often been constructed in flood prone areas without proper planning (Airoldi, et al., 2005), thus increasing the vulnerability to floods due to compromise of natural resiliency (Dolan & Walker, 2006).

C. Inundation

Inundation occurs because of storm surges, sea level rise and tsunami. Storm surge relates to any rise of water caused by storms and tropical cyclones during which pressure and speed of these phenomena cause water to rise above the normal level (McInnes, Hoeke, Walsh, O'Grady, & Hubbert, 2016). A series of giant waves caused by earthquakes and volcanic eruptions below the sea cause tsunamis (San Pedro, Babonneau, Gutscher, & Cattaneo, 2016) and associated waves gradually gain in height during inland travel and the depth of the ocean decreases (Levin & Nosov, 2016). Inland inundation arises within solid land during the event of moderate to intense rainfalls (Gao, Meng, Zhang, & Bosart, 2009) or the melting of snowpack that causes a surplus of water inland (Ahluwalia, et al., 2016). It has been demonstrated that over time, inundation induces changes in the position of the coastline thus affecting natural habitats and human infrastructures (Addo, Larbi, Amisigo, & Ofori-Danson, 2011; Ashton, Donnelly, & Evans, 2008). Additionally, inundation amplifies coastal erosion and consequently transport submerged sediment beyond the shore, thus allowing storm waves to occur further inland (Passeri, et al., 2015). Therefore, inundation as a result of SLR is expected to cause numerous detrimental effects to social and environmental aspects of the coastal zones throughout the world, especially within SIDS (Neumann & Livesay, 2001).

Among the natural influences, rate of SLR is a significant issue for coastal populations that are vulnerable to inundations (Nguyen & Woodroffe, 2015). Moreover, within coastal zones, an accelerated level of SLR induce the frequency and intensity of storms thereby impacting storm surges (Harvey & Nicholls, 2008). Similar to coastal erosion and flooding, coastal slope influences inundation whereby gently sloped surfaces are more rapidly flooded than steeper ones. Additionally, the ebb and flow of tides influence inundation such that during high tides, more water is present thus causing submerged coastal zones (Michael, Mulligan, & Harvey, 2005). Concurrently, human activities such as altered natural protection and poorly planned construction of protection structures have a direct impact on the vulnerability of coastal zones to inundation (Airoldi, et al., 2005), thus threatening these areas (Snoussi, Ouchani, & Niazi, 2008).

D. Saltwater Intrusion to Groundwater Resources

Saltwater intrusion is considered as a major environmental issue within coastal ecosystems (Barlow P. , 2003). There exists a natural movement of freshwater towards the sea. This prevents saltwater from influencing coastal aquifers that maintain a balance between the proportion of freshwater and saltwater within coastal zones and below land surface (Barlow P. , 2003; Lee, 2015). This interface is known as a transition zone whereby there is a mixture of fresh and sea water (Werner, et al., 2012). However, because of the need to pump groundwater for human consumption, there can be a fluctuation in the amount of freshwater, thus disrupting the normal level that enables the maintenance of the balance between fresh and sea water (Paniconi, Khlaifi, Giacomelli, & Tarhouni, 2001). This situation is prevalent in circumstances where the amount of water being withdrawn is faster than the rate at which it is being replenished. Consequently, seawater intrudes inland, thereby impacting the groundwater resources (Demirbas, Sakarya, & Onder, 2010). This is because seawater comprises salt and has a high density than that of freshwater (National snow and ice data center, , 2016). During this condition, freshwater becomes contaminated with seawater and leading to the movement of saltwater into areas of freshwater found inland such as marshes, lakes among others (El Moujabber, Samra, Darwish, & Atallah, 2006; Barlow & Reichard, 2010). Consequently, the normal ecosystem of the freshwater systems become disrupted as the living organisms thriving there cannot adapt to the new levels of salt (Neubauer, 2013). Plant life is the most affected when saltwater intrudes freshwater systems to the extent of causing loss of plants which may eventually lead to cascading effects on living organisms dependent on the vegetation (Felisa, Ciriello, & Federico, 2013).

In instances where groundwater resources are located near the coast and the level of groundwater diminishes, there will be an automatic movement of seawater inland. The type of aquifer in terms of permeability of the soil, presence of fractures in the bedrock and sloppy areas are more susceptible to intrusion of saltwater (Datta, Vennalakanti, & Dhar, 2009; Smith, 2004). Moreover, saltwater intrusion occurs because of hydraulic conductivity as saltwater is denser than freshwater thus moving inland naturally with higher pressure (Luyun, Momii, & Nakagawa, 2011). Regarding the human influences, whenever groundwater retreats either for pumping purposes for human consumption or for altered land uses, such diversion of natural waterways will obviously cause a disruption in the natural equilibrium between freshwater and seawater thus causing intrusion (Cheng, Halhal, Naji, & Ouazar, 2000).

E. Saltwater Intrusion to River/Estuary

Similarly, to groundwater resources, saltwater can also intrude rivers and estuaries as a result of same phenomenon discussed previously (DeLaune, Jugsujinda, Peterson, & Patrick, 2003). Among the environmental issues prevailing within coastal zones, salt-water intrusion is considered as a major stress that causes displacement of freshwater-saltwater interface and favours the infiltration of saline water to rivers or estuaries (Barlow P. , 2003; Yuan, Zhu, & Wang, 2013). This impact of SLR is known to be amplified by different factors. The physical and human parameters that influence saltwater intrusion to groundwater resources and to river/estuary differ, except for the rate of sea level rise. Other than this factor, among the physical parameters that influence saltwater intrusion to river/estuary are tidal range, water depth at downstream and discharge. Whenever there is a change in the tidal range due to ebbs and flows of tides, an increase in speed of waves occurs thereby causing a rise in the level of saltwater (Cai, Savenije, Yang, Ou, & Lei, 2012). This also leads to the inland movement of saline water to the river and estuaries. Furthermore, depending upon the volume of water available in land (river or estuaries), the amount of discharge downstream varies. Again, this alters the balance of freshwater and seawater. As for discharge, it pertains to the volume of water that flows through a river channel within a given amount of time (Farina, Alvisi, & Franchini, 2017). The volume of water flow varies depending on numerous factors such as wet or dry seasons, among others (Conant, 2004) and these factors negatively impact the balance between freshwater and seawater. Similarly, there are different human influence parameters that affect saltwater intrusion to rivers and estuaries. During the occurrence of a change in the river flow such as a change in the volume of water, engineered frontage as well as altered land use pattern in terms of developmental activities, there is a disruption in the amount of water naturally present, thus causing saltwater to move inland (Zalidis, Stamatiadis, Takavakoglou, Eskridge, & Misopolinos, 2002; Ma, Wang, & Edmunds, 2005).

F. Summary of Impacts of SLR and Associated Influences

As discussed in the previous sections, each impact of SLR has associated natural or physical as well as human influences and these are summarized in Table 1 as follows:

1. Coastal erosion	
Physical Parameters	**Human Influence Parameters**
♦ Rate of sea level rise ♦ Geomorphology ♦ Coastal Slope ♦ Wave height ♦ Rate of shoreline changes ♦ Tidal Range	♦ Reduction of sediment supply ♦ River flow regulation ♦ Engineered frontage ♦ Natural protection Degradation ♦ Coastal Protection Structures
2. Flooding	

Physical Parameters	Human Influence Parameters
♦ Rate of sea level rise ♦ Coastal Slope ♦ Wave height ♦ Tidal Range	♦ Engineered Frontage ♦ Natural Protection Degradation ♦ Coastal Protection Structures
3. **Inundation**	
Physical Parameters	**Human Influence Parameters**
♦ Rate of sea level rise ♦ Coastal Slope ♦ Tidal Range	♦ Natural protection degradation ♦ Coastal protection structures
4. Saltwater intrusion to groundwater resources	
Physical Parameters	**Human Influence Parameters**
♦ Rate of Sea Level Rise ♦ Proximity to Coast ♦ Type of Aquifer ♦ Hydraulic Conductivity ♦ Depth to Groundwater ♦ Level Above Sea	♦ Groundwater Consumption ♦ Land Use Pattern
5. Saltwater intrusion to river/estuary	
Physical Parameters	**Human Influence Parameters**
♦ Rate of Sea Level Rise ♦ Tidal Range ♦ Water Depth at Downstream ♦ Discharge	♦ River Flow Regulation ♦ Engineered Frontage ♦ Land Use Pattern

Table 1 – Associated physical and human influences of impacts of SLR

III. RESEARCH FRAMEWORK

Whilst the island of Mauritius is amongst the most vulnerable countries to SLR (Pelling & Uitto, 2001) and that this phenomenon is responsible for different impacts as discussed in the previous section, it becomes essential to investigate and assess how vulnerable these impacts are to the coastal areas of the island. However, limited work has been conducted in this area and because of this gap; different questions are yet to be investigated. These questions are given in Table 2.

ID	Research Question
RQ1	How does the significance of each identified impact of SLR vary amongst key coastal areas in Mauritius?
RQ2	How can the impacts of SLR be ranked in terms of significance for the island of Mauritius?
RQ3	How can the studied coastal areas of the island be ranked in terms of vulnerability of the impacts of SLR?
RQ4	What are the implications of the overall coastal vulnerability of the coastal areas of Mauritius to the impacts of SLR?
RQ5	What approach could be adopted in order to reduce coastal vulnerability of the studied areas to the impacts of SLR in order to foster a win-win sustainable approach?

Table 2 – Research Questions

To answer RQ1 to RQ5, the CVI assessment approach designed by Ozyurt, *et al*., (2008) and Gornitz (1990) were adapted to compute and evaluate the coastal vulnerability index of key selected coastal zones of Mauritius. According to IPCC, vulnerability has been defined as '*the degree to which a system is susceptible to, or unable to cope with adverse effects of climate change, including climate variability and extremes*' (IPCC, 2001) and is '*a function of the character, magnitude and rate of climate change and variation to which a system is exposed, its sensitivity, and its adaptive capacity*' (IPCC, 2007). This definition encompasses the multitude of interaction factors resulting from the social, economic as well as environmental aspects of a particular system (Birkmann, 2006; Turner, et al., 2003). As such, coastal vulnerability relates to the degree to which the social, economic and environmental aspects of coastal zones are prone to the negative impacts of climate change. One among the most used approaches for assessing the vulnerability of coastal zones is through a CVI (Gornitz, 1990). The aim of CVI is geared towards the adaptation to the effects of climate change and is also a means of identifying how exposed and sensitive a system is in terms of character, magnitude and rate of the impacts of climate change (Maina, et al., 2016). By using this approach, a quantitative value or an index is computed, which could be used to identify areas that are more at risk based on drivers under consideration. In other words, CVI tools are essential for identifying and assessing potential drivers of change that could be slowed down or eradicated in view of protecting the coastal zones for longer and sustained use.

Based on the CVI approach developed by Gornitz (1991), key impacts pertaining to vulnerability of coastal zones had to be identified as a first step (Gornitz, 1990; NASA, 2015). In many instances, these impacts were caused by anthropogenic factors and are amplified by SLR, whilst also being irreversible. For the selection of impacts related to the vulnerability of coastal zones to SLR, the ones listed in Table 1 were selected due to their suitability to the coastal zones of Mauritius being a SIDS. The assessment of these five impacts in terms of their physical and human influences is also important to weigh these influences on the five impacts as per the approach used by Gornitz (1990). As such, in this study, these impacts were evaluated in terms of their physical and human influences from human value judgement in the form of an expert survey conducted within different coastal regions. The selection of these coastal regions in addition to the expert survey and the approach used to compute the CVI are described as follows:

A. Selection of Coastal Regions

The island of Mauritius is situated about 2,000 km off the southeast coast of the African continent within the Indian Ocean. This island has been known for its excellent economic success, particularly in the tourism sector with a receipt of Rs. 44,304 million for the year 2014 (Chuhan-Pole & Angwafo, 2011; Statistics Mauritius, 2014). As an international tourist destination, the coastal regions are well utilized by inhabitants, workers (e.g., fishermen, hawkers, among others.), local visitors, foreign visitors, amongst others (Beeharry, Bekaroo, Bokhoree, Phillips, & Jory, 2017). Among the coastal areas around Mauritius, seven were selected for this study due to their prevailing high number of activities and number of people, both Mauritians and foreigners who make use of those zones (Beach Authority, 2015). These selected coastal regions (representative of high socio-economic significance areas) are:

1. Flic-en-Flac

Flic-en-Flac is located on the western coast of Mauritius in the Black River district. In the past, Flic-en-Flac was a small fishing village but since the late 1980s, the public beach of Flic-en-Flac has undergone rapid development with the establishment of high standard as well as multi-national hotels, wide range of restaurants and shops. As of year 2011, the population of Flic-en-Flac was 2,127 inhabitants (Statistics Mauritius, 2014). Moreover, along this coastal area, 14 hotels have been built, in addition to 3,112 apartments on top of many houses (Statistics Mauritius, 2014). The Flic-en-Flac beach is of an extent of 17.0 Hectares (Beach Authority, 2015).

2. Tamarin

This coastal zone is located next to Flic-en-Flac and is situated in the Black River district. The public beach of Tamarin is of an extent of 2.1859 Hectares with a sea frontage of 410 meters (Beach Authority, 2015). Tamarin is a residential village and is considered a lesser touristic resort area than Flic-en-Flac. There are two hotels within this coastal region and Tamarin is well known for surfing activities across the world (Statistics Mauritius, 2014). Moreover, there are numerous fishing activities that are operated in the seas of Tamarin with the highest number of registered fishermen in this area (Statistics Mauritius, 2014).

3. Port Louis Harbour

Located in the capital of Mauritius, Port Louis Harbour is the only maritime area and route, accounting for 99% of the overall volume of the island's external trade (Cohen, 2009). During the past few years, several developmental activities have taken place, converting the harbour into a modern port with an array of facilities as well as significant waterfront advances (Khosrow-Pour, 2008). The harbour has three terminals that are used for bulk, fishing vessels, reefer, cruise, naval, research, tankers and containers (IBL Maritime, 2012). It is strategically located in the Indian Ocean, which links a number of shipping routes to Africa, Asia and Europe (Yao, El-Masry, Khandelwal, & Sacerdoti, 2005). This coastal region also comprises of the Caudan Waterfront, which encompasses touristic and commercial areas for Mauritians as well as tourists (Government of Mauritius, 2013). To enable these developments, part of the sea in Port Louis was reclaimed and this forms a major part of the harbour (Kervern & Martial, 2013).

4. Belle Mare

Belle mare is situated in the district of Flacq on the Eastern part of Mauritius. The public beach of Belle Mare is divided in four main areas with a main one extending up to 17.4 hectares (Beach Authority, 2015). Moreover, the main beach of Belle Mare has a sea frontage of 1500 metres and is one of the most popular beaches for Mauritians as well as for tourists (Beach Authority, 2015). The public beach of Belle Mare hosts nine hotels offering a total number of 1,305 rooms and 2,727 bed places (Statistics Mauritius, 2016).

5. Blue Bay

Blue Bay beach extends to 4.8361 Hectares and has a sea frontage of 400 meters (Statistics Mauritius, 2016). In 1997, Blue Bay was declared as a national park as it is a wetland consisting of unique and remarkable coral garden. Later in 2008, Blue Bay was designated as a Ramsar Site of international importance as it hosts a rich fauna of corals and flora of marine species (Ramsar Convention on Wetlands, 2016). It possesses 38 coral species representing 28 genera and 15 families with a diverse ecosystem of mangroves, seagrass meadows and macro algae (Ramsar Convention on Wetlands, 2016). Moreover, it is the habitat of some 732 fish species, endangered turtles and is a suitable place for nursing of juvenile species (Government of Mauritius, 2013). One of the major aspects of the Blue Bay Marine Park is the presence of a brain coral which is more than 1000 years old and is of a diameter of 5 meters (EnezGreen, 2016). Furthermore, within the Blue Bay coastal zone, there are two hotels offering a capacity of up to 399 rooms (Statistics Mauritius, 2016).

6. Pereybere

Pereybere is situated in the district of Riviere du Rempart in the north of Mauritius and the beach of Pereybere is of an extent of 1.76 Hectares with a sea frontage of 108 metres (Beach Authority, 2015). This beach is also considered as one of the most popular ones mostly for swimming by Mauritians and it hosts two hotels that offer around 99 rooms (Statistics Mauritius, 2016). A major part of Pereybere was a wetland that has subsequently been reclaimed for touristic, commercial as well as residential purposes (Ministry of Environment and Sustainable Development, 2010).

7. Grand Baie

Grand Baie is located in the north-west coastline of Mauritius with an area of 5.5 km^2 and consisting of 12,111 inhabitants (Statistics Mauritius, 2014). It also consists of two main beaches accounting to a total extent of 1.30 Hectares and a sea frontage of 442 meters (Beach Authority, 2015). It is one of the most common holiday destinations within Mauritius as it the departure point for the neighbouring islands and is surrounded by a number of commercial and touristic buildings. Moreover, within the beach of Grand Baie, there are nine hotels which offer a total number of 720 rooms (Statistics Mauritius, 2015). Similar to Pereybere, a large area of the Grand Baie sea has been reclaimed on which a number of buildings have been constructed (Ministry of Environment and Sustainable Development, 2010).

Figure 1 Coastal zones under study

B. The Expert Survey

As mentioned earlier, the purpose of conducting the survey was to collect quantitative data from experts to evaluate the selected SLR-related impacts in terms of their physical and human influences. The study was carried out in the year 2019. In the survey, experts had to rate the influence on the impacts based on a Likert-5 scale where 1 represented a low contribution and 5 meant a high contribution of the variables to coastal vulnerability. In the same survey, respondents were also asked to rank the impacts in order of significance towards SLR. For selecting the experts, the non-probabilistic sampling technique of convenience was applied within different institutions and group of individuals involved in issues pertaining to coastal and marine related aspects. In the context of this study, an expert is an individual who has significant and authoritative knowledge pertaining to issues related to coastal and marine environments or has been living in the coastal area for a significant amount of time. In this study, wherever possible, only participants having at least 10 years of related experience were considered. In total, 385 participants were selected and details on these stakeholders are given in Table 3.

Participating Experts	**Number of Participants**
Officers in the fisheries sector	87
Inhabitants within coastal areas	38
Coastal surveillance officers	38
Weather observers	19
NGOs across the coastal zones	19
Staff from relevant ministries (having duties related to coastal zone management)	63
Port-management officers	19
Tourism promotion officers	19
Employees of Public utility services	38
Hotel managers	15
Restaurant owners	15
Apartment owners	15

Table 3 – Participating Experts

For data collection, a mixed approach was adopted including one to one interview and group interview, to ensure that the groups were of a maximum of 3 participants. With every participant or small group, an introduction on the study was provided and ethical consent was sought. In this introduction, the impacts and parameters were explained in addition to the various aspects pertaining to the questionnaire to ensure that consistent data is obtained. Subsequently, enough time was given for the participants to fill-in the questionnaire. Upon having completed the questionnaire, thorough verification was performed by the research team to ensure validity and reliability of the collected data. A few challenges were also faced during the data collection process where the major one was that some of the participants (e.g. fishermen and inhabitants) could not properly understand the terminologies utilized and as a solution, further clarifications and assistance were provided in the local language. Another issue was that the expert survey was quite lengthy, as the experts had to provide information regarding all the coastal regions taken into consideration for the purpose of this research study. As a process, the survey took 4 months for completion with a high response rate of 97.4%. Following data collection, same were statistically analysed and relevant hypothetical tests were conducted to ensure reliability of collected data. Furthermore, the accuracy and reliability of the data obtained from the experts could be confirmed by the similarities in the responses obtained throughout the variables and the demo sites.

C. Computing the CVI and Outcome Evaluation

Data from the survey was used to compute the CVI. The CVI computation started by determining the average weightage for each human influence and physical parameters. Using Microsoft Excel, an average value for each parameter of every impact (as in Table 1) of the coastal regions under study was calculated. Subsequently, these average values were used to prioritise the impacts by designating a rank to each impact as assigned by the experts during the survey. This step helped to analyse the significance of each impact. Once the ranking was obtained, Analytic Hierarchy Process (AHP) was applied, as it is an assessment tool that encompasses both the qualitative and quantitative aspects of such a survey (Nelitz, Boardley, & Smith, 2013).

The AHP theory is actually a '*method of measurement that makes use of pairwise comparisons to derive a priority scale based on human experts*' judgements (Saaty, 2008). It enables the arrangement of essential components of a problem in a hierarchical structure through the application of a systematic and multi-attribute approach (Veisi, Liaghati, & Alipour, 2016). The purpose of the scale was to represent how a particular variable is more important than another by assigning an appropriate characteristic (Saaty, 2008). For determining the order of variables, a scale of numbers was considered as means of comparison (Gupta, Dangayach, Singh, & Rao, 2015). For this study, the order in which respondents perceived the parameters contributed towards the impacts was considered.

The application of AHP involved the use of a pairwise matrix consisting of two types of data, namely, a whole number (example: 5) indicating the intensity of importance and a reciprocal value in the form of a fraction (example: $^{1}/_{5}$). For the intensity of importance, the classification proposed by Saaty (2008) in Table 4 was utilized:

Intensity of importance	Definition
1	Equal importance
3	Somewhat more important
5	Much more important
7	Very much more important
9	Absolutely more important
2,4,6,8	Intermediate values

Table 4 – Intensity of Importance

In this study, an average value for the intensity of importance was computed from the data collected during the survey before applying AHP using the pairwise matrix. For instance, if parameter A is very much more important than parameter B and is rated 7 (very much more important as per Table 4), then parameter B is less important than A and is valued at $^{1}/_{7}$. The pairwise matrix allowed for the parameters in a row to be compared to that in a column.

The next step was to normalize the pairwise matrix by calculating the sum of the numbers of each column as per the data arranged in the Excel sheet. Then, each assigned value to the parameters was then divided by the sum of the column to generate a normalized score.

Subsequently, a Consistency Ratio (CR) was calculated to ensure that the ratings are consistent. This was done by:

- multiplying each column of the pair wise comparison matrix by the corresponding weight,
- dividing of sum of the row entries by the corresponding weight,
- computing the average of the values from step 2, i.e. λmax

$$Consistency\ Index = \frac{\lambda max - n}{n - 1}$$

where n is the order of matrix

$$Consistency\ Ratio = \frac{Consistency\ Indez}{Random\ Index}$$

Finally, to interpret the calculated CVI, the utilization of an evaluation framework is important. However, even though AHP has been widely used in an array of fields, its application to coastal vulnerability is limited (Chang, Liou, & Chen, 2012). As such, it was important to define the evaluation framework to be utilized because there presently exists no such framework for CVI.

For the definition of such framework, the physical as well as human influence parameters (as in Table 1) were rated as 1, thereby representing a minimum value. This minimum score was assigned to the parameters as 1 also meant a minimum value with equal importance between two variables. This same process was carried out using the maximum value that is 9 which is representative of extremely more important variable as compared to another one (9 being higher than 1 in terms of importance), to obtain the maximum CVI. These two data sets (obtained from the minimum and maximum values) were multiplied and the obtained CVI was used to determine the minimum possible CVI that can be calculated. These lowest and highest CVI values have then been used to calculate percentiles between the following:

i. 0.25,
ii. between 0.25 and 0.50 and
iii. 0.50.

To calculate percentile, the first step was to rank the data set in ascending order. *y* % (percentile required) was multiplied by the total number of values and if the value obtained was not a whole number, it was rounded off to the nearest whole number. Then, the arranged set was counted until the whole number obtained in the previous step is reached. The percentiles and defined CVIs utilized are as per Table 5:

Percentile	CVI representing coastal areas of Mauritius of high socio-economic significance	
0.25	Less than 0.217	**LOW**
Between 0.25 and 0.50	0.217 – 0.342	**MEDIUM**
Between 0.50 and 0.75	0.342 – 0.468	**HIGH**
0.75	Greater than 0.468	**VERY HIGH**

Table 5 – Evaluation framework with CVI range based on percentiles

While calculating the CVI, one loophole encountered was that there is no suitable systematic means for its calculation. It was therefore considered essential to come up with a means of calculating the CVI. Hence, the aggregation of a number of statistical calculations based on literature search.

IV. Results and Discussion

Using the methodology described in the previous section, the CVIs for each impact of SLR were established for the selected coastal regions. These results are given in **Error! Reference source not found.** and are further discussed as follows to answer RQ1 to RQ4:

	CVI						
Impact	**Flic en Flac**	**Belle Mare**	**Blue Bay**	**Grand Baie**	**Pereybere**	**Port Louis Harbour**	**Tamarin**
Coastal Erosion	0.325	0.315	0.309	0.369	0.354	0.278	0.306
Flooding	0.455	0.432	0.406	0.502	0.478	0.502	0.479
Inundation	0.559	0.756	0.709	0.670	0.715	0.689	0.670
Saltwater Intrusion to Groundwater Resources	0.547	0.452	0.476	0.458	0.556	0.572	0.456
Saltwater Intrusion to River/Estuary	0.530	0.570	0.573	0.570	0.639	0.635	0.537

Table 6 – CVI of the studied coastal areas detailed as per impacts

A. *Significance of the impacts of SLR*

The impacts of SLR were found to be of varying significance among the regions (RQ1) and each impact is further discussed as follows:

Coastal Erosion

This impact of SLR has been observed along different beaches in Mauritius and increased erosion rates have also been reported at key beaches around the island in the last decade (Baird & Associates Coastal Engineers Ltd, 2003; UNDP, 2015). Furthermore, 21 beaches were confirmed to be experiencing erosion and this represents 23% of the beaches on the island (UNDP, 2015). Additionally, sea level has risen by an average of 5.5 mm since 2011 and this indeed has an effect on coastal erosion across Mauritius (Mauritius Meteorological Services, 2016). This is because when rate of SLR increases, the sea generates waves of higher energy and of increased height which consequently induces them to move further up the beach and in turn bring back sand offshore (Leatherman, Zhang, & Douglas, 2000; Romine, Fletcher, Frazer, & Anderson, 2016). Moreover, the increase in sea level is expected to lead to a reduction in the distance between the area pertaining to coastal population and the sea. Subsequently, this will cause an increasing in the risk of exposure of people to coastal hazards.

In the survey, this impact of SLR was positively recognized by the participants where coastal erosion for five areas were classified at medium level except for Grand Baie and Pereybere categorized as high level based on expert opinions. According to the experts, the reason for coastal erosion in Grand Baie was principally because of prevailing coastal development and engineered frontage, where although this region is considered as a wetland area, several unplanned or poorly planned development took place during the previous decade. After Pereybere, Flic-en-Flac was found to be particularly vulnerable to coastal erosion. In view of decreasing erosion within this area and as coastal protection structures, gabions were placed alongside the beach in the 1990s, which were however destroyed by waves thereby leading to unproductive results towards coastal erosion (Duvat, 2009). Among the other regions, Belle Mare beach was ranked as the fourth most vulnerable area to coastal erosion. This coastal area is situated in the eastern part of Mauritius with a number of hotels in the region and one of the key anthropogenic contributors of coastal erosion is the construction of sea walls by hotels (UNESCO, 1994). Furthermore, a previous study has also highlighted that the construction of sea walls has already caused a retreat of 5 to 8 meters of the coastline in Belle Mare (UNESCO, 1994). On the other hand, Port Louis Harbour was ranked as the least eroded coastal zone as this region has been reclaimed for the construction of infrastructural development, notably the Waterfront. This human development has left the region with a very limited area of beach that is very unlikely to erode at an alarming rate according to the participants.

Flooding

One of the physical impacts of climate change which has already been observed in Mauritius is the increasing probabilities of damaging floods (Chen, et al., 2017). SLR is considered as the starting point for the generation of high waves (Karim & Mimura, 2008), which have had negative as well as irreversible flooding impacts on the coastal zones of Mauritius (Hinkel, et al., 2014). Among the areas studied, Grand Baie, Port Louis Harbour, Tamarin and Pereybere were found to be very highly vulnerable to flooding. According to the experts, this very high vulnerability was because of the topographical characteristics of Tamarin as well as the reclamation of Port Louis Harbour. Additionally, Grand Baie and Pereybere are natural wetlands, which have been mostly backfilled for engineered frontage development. Wetlands with the prevailing ecosystems in terms of vegetation help to subside by absorbing/storing the surplus water (Mitsch & Gosselink, 2000), thus acting as a giant sponge (Bullock & Acreman, 2003). Moreover, the presence of vegetation help to slow down the speed of water from the floods, thus considerably reducing the damaging associated effects inland (Jia, Ma, & Wei, 2011). The giant sponge and speed reduction effects of wetlands towards floods have proven to lower flood heights as well as decrease erosion (Uluocha & Okeke, 2004). Reclamation of wetlands is a known factor to increase vulnerability to flooding as the reclaimed area have reduced storage capacity whenever the level of water rises, especially during rainfall (Temmerman, Govers, Wartel, & Meire, 2004). Consequently, an inland propagation of water occurs as the surplus water finds a way to move out (Temmerman, De Vries, & Bouma, Coastal marsh die-off and reduced attenuation of coastal floods:a model analysis, 2012). Also, a reclaimed wetland has a lower content of natural wetland sedimentation which leads to flooding whenever there is an increase in sea level (Skagen, Burris, & Granfors, 2016). It has been estimated that 20% of the prevailing wetlands in Flic-en-Flac and in the north of the island, namely Grand Baie and Pereybere, have been respectively reclaimed and this is also why these regions are amongst the most vulnerable ones to flooding (Ministry of Environment and Sustainable Development, 2010). On the other hand, the expert survey revealed that the topographical characteristics of Tamarin make it highly vulnerable to flooding. In the region of Tamarin, there is a mountain range and a river, and these two natural features are channel routes for water to flow from land to sea. In addition, part of Tamarin is at a same level as the sea, that is there is no significant coastal slope. As such, these natural characteristics favor the movement of waves in land while also allowing water retention, thus making Tamarin prone to flooding.

Inundation
As discussed earlier, inundation occurs because of storm surge, tsunami and SLR. Amongst these factors, storm surge occurring as a result of storms are very rare in Mauritius. Also, during the previous years, the occurrence of cyclones are low near Mauritius as the last tropical cyclone since 2017 in Mauritius dated back to 2007 (Mauritius Meteorological Services, 2016). Furthermore, the occurrence of tsunami to cause inundation in Mauritius is considered as minimal, where except that in 2004, the coastal zones of Mauritius were slightly inundated due to the deadly tsunami (Mauritius Meteorological Services, 2016). As such, for the coastal zones of Mauritius, the most influential factor that cause inundation are SLR and torrential rainfalls. SLR usually occurs at a constant rate (Vermeer & Rahmstorf, 2009) and this therefore implies that low-lying areas especially coastal zones and SIDS are inundated and are expected to disappear as a result of SLR (Ng & Mendelsohn, 2005). Another important cause is torrential rainfall resulting in subsequent accumulation of water. Since the past few years, Mauritius has been receiving recurring torrential rainfall, that is, 100 millimeters of rain in less than 12 hours (Mauritius Meteorological Services, 2016). These torrential rainfalls unfortunately lead to accumulation of water (Carswell, 2012) and contribute to inundation, especially in areas where human development such as coastal protection structures has obstructed the natural flow of water back to the sea, underground or within reclaimed wetland areas.

The expert opinions and resulting CVI obtained in this study reflect the vulnerability of the coastal regions to inundation. Results in **Error! Reference source not found.** show that all regions studied were very highly vulnerable to this impact of SLR. Amongst, Belle Mare was found to have the highest vulnerability to inundation followed by Pereybere. The reason why Belle Mare has the highest vulnerability according to the experts was principally because there has been a number of unplanned infrastructural development within the coastal zone, even though having coastal setback regulations. Flic-en-Flac was found to be the least vulnerable to inundation according to expert opinions. This may be explained by the fact that most of the human infrastructural development is located outside the coastal setback of 30m from the high-water mark (JICA, 2016). The purpose of the setback regulations is to ensure that there exists a buffer between a hazard prone area and any human development within the coastal zones (Choudri, Baawain, & Ahmed, 2016). Coastal setbacks enable the provision of enough space for the natural movement of the mean high-water mark inland by SLR over the lifetime of a particular infrastructural development (Knežević & Petović, 2016). This preventive measure is also considered as key for the ecological and economic roles of coastal zones (Fish, et al., 2008).

Saltwater Intrusion to Groundwater Resources
Saltwater intrusion occurs both naturally and because of human interferences (Giambastiani, Antonellini, & Stuurman, 2007). However, salt intrusion because of human interventions is considered as a major growing concern (Murgulet & Tick, 2008). According to the experts, Port Louis Harbour, Pereybere, Flic-en-Flac and Blue Bay coastal regions have a very high vulnerability while Grand Baie, Tamarin and Belle Mare have a high vulnerability to saltwater intrusion to

groundwater resources. This overall high vulnerability may be explained by the fact that in coastal regions, a large amount of groundwater is often pumped or simply because of over-exploitation of water to be used for domestic, touristic as well as agricultural purposes, which the case for Mauritius (Zuurbier, Raat, Paalman, Oosterhof, & Stuyfzand, 2016). This occurs because of the proximity of the source of groundwater to the coasts. With the need for offering luxury to tourists, the hotel industry indeed makes use of large amount of water, and this is reflected by the CVI obtained for salt-water intrusion to groundwater resources for Port Louis Harbour and Pereybere. As such, these two coastal areas were also found to have the highest vulnerability respectively. Even though many hotels in Mauritius have a desalination plant within their premises, the expert opinions have revealed that the coastal areas under study have high to very high vulnerability to salt-water intrusion. Across Mauritius, there are some 337 boreholes, out of which 110 are used for potable water, 110 used by industries while the remaining 117 are utilized for agricultural purposes (Water Resources Unit, 2001). Water pumping or development near coastal zones diminish the proportion of fresh water that flows towards the sea thus causing saltwater to intrude in groundwater resources (Zhou, 2016). This gradient induced cause the quality of freshwater to be compromised. One of the most damaging impacts of saltwater intrusion is the alteration between the saltwater and freshwater interface or more commonly known as the transition zone (Robinson, Ahmed, & Hamill, 2016). When freshwater level declines, a higher proportion of saltwater emerges thus shrinking the usual space for freshwater. In the long term, this causes the transition zone to move further inland thus leading to additional treatment of freshwater before domestic consumption (Aitchison-Earl, et al., 2003).

Saltwater Intrusion to river/estuary

Saltwater intrusion as explained earlier is a natural process but is being amplified owing to human activities (Giambastiani, Antonellini, & Stuurman, 2007; Rani, Satyanarayana, & Bhaskaran, 2015). The movement of saline water affects water quality thus rendering water from rivers or estuaries unsafe or unsuitable for domestic, agricultural, industrial or other uses (Magritsky D, S, & Skripnik, 2016). Based on the opinions of experts, it could be deduced that saltwater intrusion to river/estuary is more prominent in Pereybere followed by Port Louis Harbour and Blue Bay. These may be explained by the fact that Pereybere and Port Louis Harbour have a high demand for water supply and that the inflow of rivers diminishes consequently, thus causing a disruption in the normal river flow regulation. The demand for water supply relates to the number of hotels and apartments within the region. There is hence a need to ensure proper continuous water supply to the tourism industry. As for Port Louis Harbour, there is a high demand for water for domestic as well as industrial consumption. Also, these two regions have known a number of developmental activities, thus altering engineered frontage, whereby major alteration to normal river flows have occurred to either cater for tourists' demands or the construction of other amenities. Moreover, the other reason is SLR which impedes the normal movement of sea water and fresh water (Anderson & Al-Thani, 2016) is that Mauritius is a SIDS and is highly affected by the effects of climate change. On the other hand, Flic-en-Flac is least vulnerability to saltwater intrusion to river/estuary.

B. Ranking the Vulnerability of Impacts of SLR

In order to answer RQ2 and to rank the studied impacts of SLR in terms of significance for the island of Mauritius, the computed CVI for each impact given in **Error! Reference source not found.** was averaged. The resulting average and the rank for each impact of SLR is given in Table 7.

Impact	Overall Vulnerability	Ranking
Inundation	0.681	1
Saltwater Intrusion To River/Estuary	0.579	2
Saltwater Intrusion To Groundwater Resources	0.502	3
Flooding	0.465	4
Coastal Erosion	0.322	5

Table 7 – Overall Rank of Impact of SLR

Results in Table 7 show that Mauritius is most vulnerable to inundation, and all studied coastal regions were found to be very highly vulnerable to this impact. Inundation has also been considered as one of the most often occurring event within the coastal zones and has been associated with financial and human losses (Gasper, Blohm, & Ruth, 2011; Amarnath, 2014), as also highlighted by the participants. Moreover, it is expected that the risk of inundation will be worsened in the future due to climate change and SLR (Reuveny, 2007) and this exacerbation will be felt within coastal zones to result in major catastrophic losses (Nicholls & Cazenave, 2010). Following inundation, saltwater intrusion to river/estuary, saltwater intrusion to groundwater resources were ranked as second and third most significant impact of SLR respectively. Similar to inundation, all studied coastal areas were found to be very highly vulnerable to saltwater intrusion to river/estuary. As discussed earlier, saltwater intrusion to river/estuary and that of groundwater resources in Mauritius occurs particularly because of the need to pump groundwater for human consumption, causing a fluctuation in the amount of freshwater which disrupts the balance between fresh and sea water (Paniconi, Khlaifi, Giacomelli, & Tarhouni, 2001). This situation is prevalent in circumstances where the amount of water being withdrawn is faster than the rate at which it is being replenished, thus causing seawater to intrude inland and this eventually impacts groundwater resources (Demirbas, Sakarya, & Onder, 2010). Furthermore, the participants also highlighted that with the increase in sea level, more saline water is expected to intrude to rivers, estuaries or groundwater resources when the normal flows or levels are disrupted as a result of human activities/needs. On the fourth position, flooding was found to have a very high impact on the coastal zones in Mauritius. According to the experts, this high vulnerability index was particularly due to the increasing rate of SLR during recent years because of climate change (Boori, Vozenilek, & Choudhary, 2015). Finally, the expert survey revealed that the vulnerability of the coastal zones of Mauritius to coastal erosion is medium. This could be explained by the fact that beaches by nature are not stable landforms (Carson & Athens, 2007), which have different response capabilities to supply of sediments, hydrodynamics processes and sea level rise (FitzGerald, Fenster, Argow, & Buynevich, 2008; Davidson-Arnott, 2005). The participants affirmed that this also reflects the case of the coastal zones of Mauritius which have different sand structures and responses to natural processes. Another reason behind the varied vulnerability to coastal erosion of the areas under study is also because of the presence of man-made developments which have been carried out by ensuring that coastal setbacks have been respected or not. It is to be pointed out that in Mauritius one of the requirements of the building land use permit within coastal zones is the compliance to a defined coastal setback of 30 metres (JICA, 2016; Ministry of Housing and Lands, 2004). Overall, the expert survey revealed that the coastal areas of Mauritius are very vulnerable to most of the impacts of SLR besides coastal erosion.

C. *Ranking the Vulnerability of Coastal Areas Investigated*

The overall CVI of the coastal areas studied were averaged in order to answer RQ3 and the results are given in Table 8.

Demo site	CVI	Ranking
Pereybere	0.548	1
Port Louis Harbour	0.535	2
Grand Baie	0.514	3
Belle Mare	0.505	4
Blue Bay	0.495	5
Tamarin	0.490	6
Flic-en-Flac	0.483	7

Table 8 –CVI of coastal areas studied and their rank

Based on the views of the experts, it could be deduced that all the coastal areas investigated have a very high vulnerability to the impacts of SLR. Amongst the different coastal zones studied, Pereybere was found to have the highest overall vulnerability to the impacts of SLR. This could be because of the sea frontage of Pereybere being 108 metres and within this coastal area, there are many human development activities: apartments, restaurants, shopping complex among others. Also, according to the experts, a large area of Pereybere has been reclaimed which means that the natural characteristics have been altered thus limiting the normal topographical changes. This area was found to be very highly vulnerable to the impacts of SLR besides coastal erosion. On the other hand, the least vulnerable coastal zone to the impacts of SLR was found to be Flic-en-Flac which is located on the western part of Mauritius. Part of Flic-en-Flac also has been back filled for human activities and the coastal zone is of an extent of 17.0 Hectares. For this region, the slightly lower vulnerability index was due to lower values for coastal erosion and flooding following calculation.

D. *CVI of Selected Coastal Areas of Mauritius*

The overall CVI score of the selected coastal areas of Mauritius under study was found to be 0.510 (RQ4) and this translates to a very high vulnerability to effects of SLR using the adopted methodology in this study. This also implies that sea-level rise is a serious concern to Mauritius as well as its associated impacts. Amongst the key findings, this research study revealed that the coastal areas of Mauritius are very highly vulnerable to all impacts of sea-level rise besides coastal erosion, found to be of medium vulnerability. Also, among the key impacts to SLR, the most significant ones to the studied coastal areas of Mauritius were inundation and saltwater intrusion to river/estuary respectively. These two coastal impacts have been caused by the ever-increasing man-made activities within the coastal zones of Mauritius and have further been amplified by the effects of climate change. The Intergovernmental Panel on Climate Change has identified that inundation and saltwater intrusion to river/estuary as a result of sea level rise, climate change are serious threat to low lying areas and SIDS (IPCC, 2001) and this is also reflected in findings of this study. Also, all the coastal areas studied were found to be of very highly vulnerability based on the computed CVI, as shown in Table 8. Furthermore, according to the participants of the study, the impacts of SLR are already being felt within the island and these impacts are expected to further amplify over the coming years. This also means that further effort is needed so as to individually address each impact of SLR so as to adapt and mitigate this growing concern of Mauritius along with SIDS.

V. Adapting to the Impacts of SLR: A Conceptual Framework

All the coastal zones under study were found to be very highly vulnerable to the impacts of SLR and as such, it is of utmost importance to address this prevailing issue across the coastal areas of Mauritius. Decreasing the coastal vulnerability should be a cooperative effort involving all stakeholders. Due to the high vulnerability of the studied areas, urgent and proactive actions that span temporally towards longer term effective solutions are to be put into place. because of the complex nature of adapting to the impacts of SLR, a framework is more relevant towards fostering a win-win sustainable approach. However, limited studies have been carried out in view of designing a proper framework to reduce coastal vulnerability to the impacts of SLR (Helm, 2014; Prato, 2008), more specifically in the context of Mauritius as a SIDS. Hence, as part of this study, a conceptual framework is being proposed in view of decreasing the coastal vulnerability in Mauritius (RQ5) as illustrated in Figure 2. This framework provides a simplistic view for understanding the way forward to decrease the impacts of SLR on the coastal zones of Mauritius focussed on two essential components: actions and outcomes.

Actions denote measures that should be implemented by key stakeholders in the endeavour to reduce the vulnerability of the studied coastal areas to the impacts of SLR and are represented in the left part of the framework. Among the key actions, it is highly recommended that coastal users (mostly those owning development within the coastal areas such as hotel owners) and policymakers work together to a more cohesive and balanced strategy so as to identify means of how to adapt and mitigate the causes of vulnerability. In the first instance, coastal users need to take cognizance of the severity of this issue, how to address this concern and to improve awareness among this group of users. Lack of awareness among key users has often been an issue related to such phenomenon associated to climate change (Muttarak & Lutz, 2014) and education could play a key role towards helping people become more resilient to vulnerability and preparing them to take necessary actions towards adapting to the impacts (Tong, Shaw, & Takeuchi, 2012). Potential measures to improve awareness would be educational campaigns within educational institutions in coastal areas or through different types of media (e.g. social media, print media or broadcast media). In addition, collaboration needs to be strengthened among key stakeholders (e.g. government, inhabitants and hotel owners) such that actions taken effectively help to reduce the vulnerability of the studied coastal areas to the impacts of SLR. Strengthened collaboration is crucial for ensuring that particular groups do not hinder authentic actions initiated by other stakeholders, while also guaranteeing that all coastal users are in a win-win situation. Furthermore, a proper legal framework is recommended to maintain the current aspects of the coastal zones and ensuring that any forthcoming development be sustainable, thus minimizing the vulnerability of the coastal zones mostly from an anthropogenic aspect. For this, the Environmental Protection Act (2002) in Mauritius could be improved by devising an elaborated component solely on protecting the coastal zones in a sustainable manner. This will help to ensure that proper measures are to be taken in order to deal with the adaptive capacity as well as considering the exposure of the coastal zones of Mauritius both for existing infrastructure and for new ones. Concomitantly, the legal framework has to include and enforce the existing international legal framework for coastal adaptation, such as the Kyoto protocol which has specific provisions related to adaptation measures pertaining to specific policies precisely for small island countries (UNFCCC, 2017). Finally, a monitoring and control process has to be established towards ensuring goal of effectively reducing the vulnerability of SLR impacts. For this, iterative process improvement methods such as the Plan-Do-Check-Act (PDCA) cycle could be implemented by regulatory bodies in the endeavour to manage actions. Periodic in-depth assessment of the coastal zones should be conducted in order to obtain updated vulnerability scores for different coastal areas and for this, the methodology used in this paper could be considered. Such assessment should encompass various stakeholders who are well versed with the coastal zones of Mauritius in addition to underlying issues faced by such areas. Based on vulnerability indices obtained, specific objectives could be defined (e.g. lower CVI of Flic-en-Flac pertaining to flooding to 3.0) in addition to the action plan for different stakeholders. The action plan should also focus on achieving specific outcomes (as in the right part of the framework). Then, while the actions are being taken by stakeholders based on the plan devised, monitoring techniques could be put in place to detect any deviations from objectives. In case of deviations, corrective as well as legal measures could be undertaken towards ensuring that the objectives are met.

Outcomes are the desired end-result of the proposed framework, notably a win-win approach that capture vulnerable critical impacts well focused on SLR adaptation, mitigation and interdisciplinary analysis of existing infrastructure within those areas and focusing on environmental, social as well as economic aspects (Makino, 2018; Kalaugher, Bornman, Clark, & Beukes, 2013). In the case of adopting such a framework, the coastal zones of Mauritius may be safeguarded from anthropogenic causes of SLR. Additionally, with strict and continuous efforts from relevant stakeholders as well as from coastal users together with proper legal enforcement, in the long run the coastal zones around the island will be altered. This will lead towards a protected environment which will be able to foster the current as well as future development thus ensuring that the people’s well-being is catered and more importantly leading towards an enhanced economy. Furthermore, this framework will help towards achieving sustainable development thus ensuring that the coastal zones of Mauritius continue to be economically valuable and that the prevailing biodiversity provide benefits to the society while preserving the ecological value leading to a win-win sustainable approach.

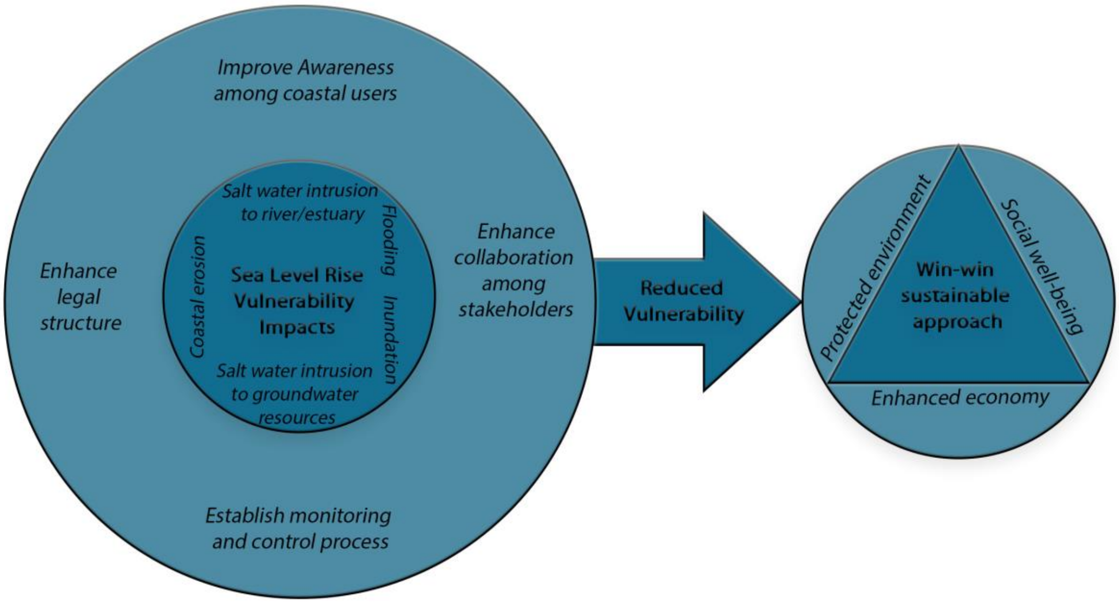

Figure 2 - A Framework for Adapting to Impacts of Sea-Level Rise

VI. Conclusion

This paper attempted to quantify, prioritize and critically assess the vulnerability of key impacts of SLR on the coastal areas of Mauritius, through the investigation of four research questions. To achieve this purpose, the CVI assessment approach designed by Ozyurt, et al., (2008) and Gornitz (1990) were adapted in order to compute and evaluate the coastal vulnerability index of 7 key coastal areas of Mauritius. While making use of this approach, an expert survey involving 385 participants in Mauritius helped to evaluate the impacts of SLR in terms of their physical and human influences. As key findings, the CVI score of the seven highest socio-economic significant coastal zones under study in Mauritius was found to be 0.510, meaning that the coastal areas of Mauritius are very highly vulnerable to the impacts of SLR. Furthermore, all coastal regions investigated were found to be very highly vulnerable to these impacts. Amongst, inundation, saltwater intrusion to river and estuary respectively were found to be of more significance to the island whilst coastal erosion was found as the least vulnerable impact. Furthermore, Pereybere was found to be the most vulnerable coastal area to the effects of SLR whereas Flic-en-Flac was revealed as the least vulnerable one amongst the studied areas. Overall, findings from this study are considered as essential as it has enabled the specific calculation of the SLR impacts on the coastal zones in Mauritius in terms of human and physical parameters, while also enabling quantification and prioritization of vulnerabilities. Moreover, the framework proposed in this paper can be among the solutions towards decreasing the impacts of SLR on coastal zones of Mauritius, although its impact could be further assessed as future works.

VII. References

Addo, K., Larbi, L., Amisigo, B., & Ofori-Danson, P. (2011). Impacts of Coastal Inundation Due to Climate Change in a CLUSTER of Urban Coastal Communities in Ghana, West Africa. *Remote Sensing, 3*, 2029 -2050.

Ahluwalia, R., Rai, S., Gupta, A., Dobhal, D., Tiwari, R., Garg, P., & Kesharwani, K. (2016). Towards the understanding of the flash flood through isotope approach in Kedarnath valley in June 2013, Central Himalaya, India. *Natual Hazards, 82* (1), 321 - 332.

Airoldi, L., Abbiati, M., Beck, M. W., Hawkins, S. J., Jonsson, P. R., Martin, D., . . . Åberg, P. (2005). An ecological perspective on the deployment and design of low-crested and other hard coastal defence structures. *Coastal engineering, 52*(10), 1073-1087.

Aitchison-Earl, P., Ettema, M., Hanson, C., Hayward, S., Larking, R., Sanders, R., . . . Veltman, A. (2003). *Coastal aquifer saltwater intrusion assessment guidelines.* Timaru: Environment Canterbury.

Allison, E. H., Perry, A. L., Badjeck, M., Neil Adger, W., Brown, K., Conway, D., . . . Dulvy, N. K. (2009). Vulnerability of national economies to the impacts of climate change on fisheries. *Fish and fisheries, 10*(2), 173 - 196.

Allison, I., Alley, R. B., Fricker, H. A., Thomas, R. H., & Warner, R. C. (2009). Ice sheet mass balance and sea level. *Antarctic science, 21*(5), 413 - 426.

Amarnath, G. (2014). An algorithm for rapid flood inundation mapping from optical data using a reflectance differencing technique. *Journal of flood risk management, 7* (3), 239 - 250.

Anderson, F., & Al-Thani, N. (2016). Effect of Sea Level Rise and Groundwater Withdrawal on Seawater Intrusion in the Gulf Coast Aquifer: Implications for Agriculture. *Journal of Geoscience and Environment Protection, 4*(4), 116.

Anderson, T. R., Fletcher, C. H., Barbee, M. M., Frazer, L. ,., & Romine, B. M. (2015). Doubling of coastal erosion under rising sea level by mid-century in Hawaii. *Natural Hazards, 78*(1), 75 - 103.

Ashton, A. D., Donnelly, J., & Evans, R. L. (2008). A discussion of the potential impacts of climate change on the shorelines of the northeastern USA. *Mitigation and Adaptation Strategies for Global Change, 13*(7), 719 - 743.

Baird, W., & Associates Coastal Engineers Ltd. (2003). *Study on Coastal Erosion in Mauritius.* Ministry of Environment, Republic of Mauritius.

Barlow, P. (2003). *Groundwater in fresh water - salt water environments of the Atlantic* (Vol. 1262). Geological Survey USGS.

Barlow, P., & Reichard, E. (2010). Saltwater intrusion in coastal regions of North America. *Hydrogeology Journal, 18*(1), 247 -260.

Beach Authority. (2015). *List of proclaimed public beaches*. Retrieved October 9, 2015, from Beach Authority: http://beachauthority.intnet.mu/component/content/article/46.html

Beeharry, Y., Bekaroo, G., Bokhoree, C., Phillips, M., & Jory, N. (2017). Sustaining anti-littering behavior within coastal and marine environments: Through the macro-micro level lenses. *Marine Pollution Bulletin, 119*(2), 87-99.

Beeharry, Y., Makoondlall-Chadee, T., & Bokhoree, C. (2014). Policy Analysis for Performance Assessment of Integrated Coastal Zone Management Initiatives for Coastal Sustainability. *APCBEE Procedia, 9*, 30 - 35.

Bekaroo, G., Bokhoree, C., & Pattinson, C. (2016). Impacts of ICT on the natural ecosystem: A grassroot analysis for promoting socio-environmental sustainability. *Renewable and Sustainable Energy Reviews,, 57*, 1580-1595.

Bird, E. C. (2011). *Coastal geomorphology: an introduction.* John Wiley & Sons.

Birkmann, J. (2006). *Measuring vulnerability to natural hazards: towards disaster resilient societies.* United Nations University Press.

Boori, M., Vozenilek, V., & Choudhary, K. (2015). Exposer Intensity, Vulnerability Index And Landscape Change Assessment In Olomouc, Czech Republic. *The International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences, 40*(7), 771.

Boruff, B. J., Enrich, C., & Cutter, S. L. (2004). Erosion hazard vulnerability of US Coastal counties. *Journal of Coastal Research, 21*(5), 932 - 942.

Bowen, M. M., & Geyer, W. R. (2003). Salt transport and the time-dependent salt balance of a partially stratified estuary. *Journal of Geophysical Research: Oceans, 108*(C5), 1 - 15.

Brody, S. D., Zahran, S., Maghelal, P., Grover, H., & Highfield, W. E. (2007). The rising costs of floods: Examining the impact of planning and development decisions on property damage in Florida. *Journal of the American Planning Association, 73*(3), 330 - 345.

Bromhead, E. N., & Ibsen, M. L. (2006). A review of landsliding and coastal erosion damage to historic fortifications in South East England. *Landslides, 3*(4), 341.

Bullock, A., & Acreman, M. (2003). The role of wetlands in the hydrological cycle. *Hydrology and Earth System Sciences Discussions, 7*(3), 358 - 389.

Cai, H., Savenije, H. H., Yang, Q., Ou, S., & Lei, Y. (2012). Influence of river discharge and dredging on tidal wave propagation: Modaomen Estuary case. . *Journal of Hydraulic Engineering, 138*(10), 885 - 896.

Carrera, L., Standardi, G., Bosello, F., & Mysiak, J. (2015). Assessing direct and indirect economic impacts of a flood event through the integration of spatial and computable general equilibrium modelling. *Environmental modelling & Software, 63*, 109 - 122.

Carson, M. T., & Athens, J. S. (2007). Integration of coastal geomorphology, mythology, and archaeological evidence at Kualoa Beach, windward O ‘ahu, Hawaiian Islands. *The Journal of Island and Coastal Archaeology, 2*(1), 24 - 43.

Carswell, A. T. (2012). *The encyclopedia of housing* (First ed.). California: Sage.

Chang, H. K., Liou, J. C., & Chen, W. W. (2012). Protection priority in the coastal environment using a hybrid ahp-topsis method on the Miaoli coast, Taiwan. *Journal of Coastal Research, 28*(2), 369 - 374.

Chen, X., Zhang, X., Church, J. A., Watson, C. S., King, M. A., Monselesan, D., . . . Harig, C. (2017). The increasing rate of global mean sea-level rise during 1993-2014. *Nature Climate Change, 7*(7), 492 - 495.

Cheng, A. D., Halhal, D., Naji, A., & Ouazar, D. (2000). Pumping optimization in saltwater-intruded coastal aquifers. *Water resources research, 36*(8), 2155 - 2165.

Cheong, S. M., Silliman, B., Wong, P. P., Van Wesenbeeck, B., Kim, C. K., & Guannel, G. (2013). Coastal adaptation with ecological engineering. *Nature climate change, 3*(9), 787.
Choudri, B. S., Baawain, M., & Ahmed, M. (2016). An Overview of Coastal and Marine Resources and their Management in Sultanate of Oman. *Journal of Environmental Management & Tourism, 7*(1), 21.
Chuhan-Pole, P., & Angwafo, M. (2011). *Yes Africa Can - Success stories from a dynamic continent.* Washington: The World Bank.
Church, J., Wilson, S., Woodworth, P., & Aarup, T. (2007). Understanding sea level rise and variability. *Earth and Space Science News, 88*(4), 43.
Cicin-Sain, B., & Belfiore, S. (2005). Linking marine protected areas to integrated coastal and ocean management: a review of theory and practice. *Ocean & Coastal Management, 48*(11), 847 - 868.
Coelho, C., Silva, R., Veloso-Gomes, F., & Taveira-Pinto, F. (2009). Potential effects of climate change on northwest Portuguese coastal zones. *ICES Journal of Marine Science,*, 1497 - 1507.
Cohen, E. (2009). *Growing Information, Part I: Issues in Informing Science and Information Technology.* Informing Science.
Conant, B. (2004). Delineating and quantifying ground water discharge zones using streambed temperatures. *Groundwater, 42*(2), 243 - 257.
Cooper, J. A., & Pilkey, O. (2004). ea-level rise and shoreline retreat: time to abandon the Bruun Rule. *Global and planetary change, 43*(3), 157 - 171.
Datta, B., Vennalakanti, H., & Dhar, A. (2009). Modeling and control of saltwater intrusion in a coastal aquifer of Andhra Pradesh, India. *Journal of hydro-envrionment research, 3*(3), 148 - 159.
Davidson-Arnott, R. G. (2005). Conceptual model of the effects of sea level rise on sandy coasts. *Journal of Coastal Research, 21*(6), 1166-1172.
Dawson, R. J., Dickson, M. E., Nicholls, R. J., Hall, J. W., Walkden, M. J., Stansby, P., . . . Jordan, A. (2009). Integrated analysis of risks of coastal flooding and cliff erosion under scenarios of long term change. *Climatic change, 95*(1-2), 249 - 288.
DeLaune, R. D., Jugsujinda, A., Peterson, G. W., & Patrick, W. H. (2003). Impact of Mississippi River freshwater reintroduction on enhancing marsh accretionary processes in a Louisiana estuary. *Estuarine, Coastal and Shelf Science, 58*(3), 653 - 662.
Demirbas, K., Sakarya, A. A., & Onder, H. (2010). Combined simulation-optimisation of a coastal aquifer by using genetic algorithm. In *Environmental Hydraulics* (p. 661). Oxon: CRC press.
Depietri, Y., Renaud, F. G., & Kallis, G. (2012). Heat waves and floods in urban areas: a policy-oriented review of ecosystem services. *Sustainability science, 7*(1), 95 - 107.
Dolan, A. H., & Walker, I. J. (2006). Understanding vulnerability of coastal communities to climate change related risks. *Journal of Coastal Research, S1*(39), 1316 - 1323.
Douglas, B. C. (1997). Global sea rise: a redetermination. *Surveys in Geophysics*, 279 - 292.
Douglas, I., Alam, K., Maghenda, M., Mcdonnell, Y., McLean, L., & Campbell, J. (2008). Unjust waters: climate change, flooding and the urban poor in Africa. *Environment and urbanization, 20*(1), 187 - 205.
Duong, S., & Ngo, H. (2016). Dimension index method for climate change vulnerability assessment. *VNU Journal of Science: Earth and Environmental Studies, 28*(2).
Duvat, V. (2009). Beach erosion management in Small Island Developing States: Indian Ocean case studies . In *Coastal Processes.* WIT Press.
El Moujabber, M., Samra, B., Darwish, T., & Atallah, T. (2006). Comparison of different indicators for groundwater contamination by seawater intrusion on the Lebanese coast. *Water resources management, 20*(2), 161 - 180.
EnezGreen. (2016). *Blue Bay, The first marine park in Mauritius*. Retrieved June 13, 2016, from http://www.enezgreen.com/en/content/blue-bay-first-marine-park-mauritius
Fabbri, K. (1998). A methodology for supporting decision making in integrated coastal zone management. *Ocean and Coastal Management, 39*, 51-62.
Farina, G., Alvisi, S., & Franchini, M. (2017). Estimating discharge in rivers through the combined use of dimensionless isovels and point velocity measurements. *Hydrology Research, 48*(3), 616 - 633.
Felisa, G., Ciriello, V., & Federico, V. D. (2013). Saltwater Intrusion in Coastal Aquifers: a primary case study along the Adriatic coast investigated within a probabilistic framework. *Water, 5*, 1830 - 1847.
Fish, M. R., Cote, I. M., Horrocks, J. A., Mulligan, B., Watkinson, A. R., & Jones, A. P. (2008). Construction setback regulations and sea-level rise: mitigating sea turtle nesting beach loss. *Ocean & Coastal Management, 51*(4), 330 - 341.
FitzGerald, D. M., Fenster, M. S., Argow, B., & Buynevich, I. V. (2008). Coastal impacts due to sea-level rise. *Annu. Rev. Earth Planet, 36*, 601 - 647.
Flick, R., Chadwick, D., Briscoe, J., & Harper, C. (2012). “Flooding” versus “inundation”. *Transactions, American Geophysical Union, 93*(38), 361 - 372.
Füssel, H. M., & Klein, R. J. (2006). Climate change vulnerability assessments: an evolution of conceptual thinking. *Climate change*, 301 - 329.

Gao, S., Meng, Z., Zhang, F., & Bosart, L. (2009). bservational analysis of heavy rainfall mechanisms associated with severe Tropical Storm Bilis (2006) after its landfall. *Monthly weather review*, *137*(6), 1881 - 1897.

Gasper, R., Blohm, A., & Ruth, M. (2011). Social and economic impacts of climate change on the urban environment. *Current opinion in environmental sustainability, 3*(3), 150 - 157.

Giambastiani, B., Antonellini, M. E., & Stuurman, R. J. (2007). Saltwater intrusion in the unconfined coastal aquifer of Ravenna (Italy): a numerical model. *Journal of Hydrology, 340*(1), 91 - 104.

Gornitz, V. (1990). Vulnerability of the east coast, USA to future sea level rise. *Journal of Coastal Research,* 201 - 237.

Government of Mauritius. (2013). *Fifth national assembly.* Port Louis: Republic of Mauritius.

Gupta, S., Dangayach, G. S., Singh, A. K., & Rao, P. (2015). Analytic Hierarchy Process (AHP) model for evaluating sustainable manufacturing practices in Indian electrical panel industries. *XVIII Annual International Conference of the Society of Operations Management (SOM-14)*, (pp. 208 - 216). Roorkee.

Harvey, N., & Nicholls, R. (2008). Global sea-level rise and coastal vulnerability. *Sustainability science*, *3*(1), 5 - 7.

Heenan, A., Pomeroy, R., Bell, J., Munday, P. L., Cheung, W., Logan, C., . . . David, L. (2015). A climate-informed, ecosystem approach to fisheries management. *Marine Policy, 57*, 182 - 192.

Helm, D. (2014). The European framework for energy and climate policies. *Energy policy, 64*, 29-35.

Herron, H., Bohn, B., Roy, S., & Evans, W. (2016). *Climate Change Data and Risk Assessment Methodologies for the Caribbean.* Washington D.C: Inter-American Development Bank.

Hinkel, J., Lincke, D., Vafeidis, A. T., Perrette, M., Nicholls, R. J., Tol, R. S., . . . Levermann, A. (2014). Coastal flood damage and adaptation cost under 21st century sea-level rise. *Proceedings of the National Academy of Sciences, 111*(9), 3292 - 3297.

Hirabayashi, Y., Mahendran, R., Koirala, S., Konoshima, L., Yamazaki, D., Watanabe, S., . . . Kanae, S. (2013). Global flood risk under climate change. *Nature climate, 3,* 816 - 821 .

Hsu, T. W., Lin, T. Y., & Tseng, I. F. (2007). Human impact on coastal erosion in Taiwan. *Journal of Coastal Research, 23*(4), 961 - 973.

Hung, J. J., & Hsu, C. L. (2004). Present state and historical changes of trace metal pollution in Kaoping coastal sediments, southwestern Taiwan. *Marine Pollution Bulletin, 49*(11), 986 - 998.

Hupp, C. R., Pierce, A. R., & Noe, G. B. (2009). Floodplain geomorphic processes and environmental impacts of human alteration along coastal plain rivers, USA. *Wetlands, 29*(2), 413 - 429.

IBL Maritime. (2012). *Port Facilities*. Retrieved May 30, 2016, from http://www.iblmaritime.com/en/portfacilities/

Incera, A. C., & Fernández, M. F. (2015). Tourism and income distribution: Evidence from a developed regional economy. *Tourism Management, 48*, 11 - 20.

IPCC. (2001). *Climate Change 2001: Impacts, Adaptation, and Vulnerability.* Cambridge: Cambridge University Press.

IPCC. (2001). *Climate Change 2001:Impacts, adaptation, and vulnerability.* New York: Cambridge Unviersity Press.

IPCC. (2007). *Climate change.* Cambridge: The physical science basis, contribution of working group I to the fourth assessment report of IPCC.

IPCC. (2014). Climate Change. In IPCC, *Impacts, Adaptation and Vulnerability* (p. 3). IPCC.

Irish, J., Resio, D. T., & Ratcliff, J. J. (2008). The influence of storm size on hurricane surge. *Journal of Physical Oceanography, 38*(9), 2003 - 2013.

James, P., & Saito, Y. (2007). Morphodynamics of deltas under the influence of humans. *Global and planetary change, 57* , 261 - 282.

Jia, H., Ma, H., & Wei, M. (2011). Urban wetland planning: a case study in the Beijing central region. *Ecological Complexity, 8*(2), 213 - 221.

JICA. (2016). *Guideline for climate change adaptation strategy coastal setback mauritius.* Kokusai Kogyo Co. Ltd.

Kalaugher, E., Bornman, J. F., Clark, A., & Beukes, P. (2013). An integrated biophysical and socio-economic framework for analysis of climate change adaptation strategies: the case of a New Zealand dairy farming system. *Environmental Modelling & Software, 39,* 176 - 187.

Karim, M. F., & Mimura, N. (2008). Impacts of climate change and sea-level rise on cyclonic storm surge floods in Bangladesh. *Global Environmental Change, 18*(3), 490 - 500.

Kervern, A., & Martial, Y. (2013). *Mauritius 500 Early Postcards.* Didier Millet,Csi.

Khosrow-Pour, M. (2008). *Encyclopedia of information science and technology.* IGI Global.

Knežević, J., & Petović, S. (2016). *Integrated Coastal Zone Management in Boka Kotorska Bay* (54 ed.). Cham: Springer.

Kuriyama, Y., & Banno, M. (2016). horeline change caused by the increase in wave transmission over a submerged breakwater due to sea level rise and land subsidence. *Coastal engineering, 112*, 9 - 16.

Lakshmi, R., & Rajagopalan, R. (2000). Socio-economic implications of coastal zone degradation and their mitigation: a case study from coastal villages in India. *Ocean & coastal management, 43*(8), 749 - 762.

Leatherman, S., Zhang, K., & Douglas, B. (2000). Sea level rise shown to drive coastal erosion. *EOS Transactions American Geophysical Union, 81*(6), 55 - 57.

Lee, S. (2015). Investigating the origin and dynamics of salinity in a confined aquifer system in Southeast Australia.

Leonard, P., Sutherland, R., Baldwin, R., Fedak, D., Carnes, R., & Montgomery, A. (2016). Landscape connectivity losses due to sea level rise and land use change. *Animal conservation*.

Lerczak, J. A., Geyer, W. R., & Ralston, D. K. (2009). he temporal response of the length of a partially stratified estuary to changes in river flow and tidal amplitude. *Journal of Physical Oceanography, 39*(4), 915 - 933.

Levin, B. W., & Nosov, M. A. (2016). General Information on Tsunami Waves, Seaquakes, and Other Catastrophic Phenomena in the Ocean. *Physics Tsunamis*, 1 - 34.

Luyun, R., Momii, K., & Nakagawa, K. (2011). Effects of recharge wells and flow barriers on seawater intrusion. *Groundwater, 49*(2), 239 - 249.

Ma, J. Z., Wang, X. S., & Edmunds, W. M. (2005). The characteristics of ground-water resources and their changes under the impacts of human activity in the arid Northwest China—a case study of the Shiyang River Basin. *Journal of Arid Environments, 61*(2), 277 - 295.

Magritsky D, S., S, L., & Skripnik, E. (2016). Hydrological hazards at mouths of the Northern Dvina and the Pechora rivers, Russian Federation. *Natural Hazards, 88*(1), 149 - 170.

Maina, J., Kithiia, J., Cinner, J., Neale, E., Noble, S., Charles, D., & Watson, J. (2016). Integrating social–ecological vulnerability assessments with climate forecasts to improve local climate adaptation planning for coral reef fisheries in Papua New Guinea. *Regional Environmental Change, 16*(3), 881 - 891.

Makino, K. (2018). An empirical research framework for the aesthetic appreciation of the urban environment. *City, culture and society, 13*, 1-7.

Mann, T., & Westphal, H. (2016). Multi-decadal shoreline changes on Takú Atoll, Papua New Guinea: Observational evidence of early reef island recovery after the impact of storm waves. *Geomorphology, 257*, 75 - 84.

Marfai, M. (2011). Impact of coastal inundation on ecology and agricultural land use case study in central Java, Indonesia. *Quaestiones Geographicae, 30*(3), 19 - 32.

Masria, A., Negm, A., Iskander, M., & Saavedra, O. (2014). Coastal zone issues: a case study (Egypt). *12th International conference on computing and control for the water industry, CCW12013* (pp. 1102 - 1111). ScienceDirect.

Mauritius Meteorological Services. (2016). *List of Historial Cyclones*. Retrieved June 16, 2016, from http://metservice.intnet.mu/publications/list-of-historical-cyclones.php

Mauritius Meteorological Services. (2016). *Sea level rise.* Vacoas: Mauritius Meteorological Services.

Mauritius Meteorological Services. (2017). *Climate Change.* Vacoas: Mauritius Meteorological Services.

McInnes, K., Hoeke, R., Walsh, K., O'Grady, J., & Hubbert, G. D. (2016). Application of a synthetic cyclone method for assessment of tropical cyclone storm tides in Samoa. *Natural Hazards, 80*(1), 425 - 444.

Michael, H. A., Mulligan, A. E., & Harvey, C. F. (2005). Seasonal oscillations in water exchange between aquifers and the coastal ocean. *Nature, 436*(7054), 1145.

Mimura, N. (2013). Sea-level rise caused by climate change and its implications for society. Proceedings of the Japan Academy, Series B.

Ministry of Environment and Sustainable Development. (2010). *Fourth national report on the convention on biological diversity.* Port Louis: Ministry of Environment and Sustainable Development.

Ministry of Housing and Lands. (2004). *Residential coastal development.* Port Louis: Ministry of Housing and Lands.

Mitsch, W. J., & Gosselink, J. G. (2000). The value of wetlands: importance of scale and landscape setting. *Ecological economics, 35*(1), 25 - 33.

Murgulet, D., & Tick, G. R. (2008). The extent of saltwater intrusion in southern Baldwin County, Alabama. *Environmental Geology, 55*(6), 1235 - 1245.

Muttarak, R., & Lutz, W. (2014). Is education a key to reducing vulnerability to natural disasters and hence unavoidable climate change? *Ecology and Society, 19*(1), 1 - 8.

NASA. (2015, May 12). *National Aeronautics and Space Administration*. Retrieved from Publication Abstracts: http://pubs.giss.nasa.gov/abs/go02000x.html

National snow and ice data center, . (2016). *All about sea ice*. Retrieved May 27, 2016, from http://nsidc.org/cryosphere/seaice/index.html

Nelitz, M., Boardley, S., & Smith, R. (2013). *Tools For Climate Change Vulnerability Assessments For Watersheds.*

Neubauer, S. (2013). Ecosystem responses of a tidal freshwater marsh experiencing saltwater intrusion and altered hydrology. *Estuaries and coasts, 36*(3), 491 - 507.

Neumann, J., & Livesay, N. (2001). *Coastal structures: dynamic economic modeling.* Cheltenham: Edward Elgar Publishing Ltd.

Ng, W., & Mendelsohn, R. (2005). The impact of sea level rise on Singapore. *Environment and Development Economics*, 201 - 2015.

Nguyen, T., & Woodroffe, C. (2015). ssessing relative vulnerability to sea-level rise in the western part of the Mekong River Delta in Vietnam. *Sustainability Science*, 1 - 15.

Nicholls, R. J., & Cazenave, A. (2010). Sea-level rise and its impact on coastal zones. *Science, 328*(5985), 1517 - 1520.

Nicholls, R., & Cazenave, A. (2010). Sea level rise and its impact on coastal zones. *Science, 328*(5985), 1517 - 1520.

Ohl, C., & Tapsell, S. (2000). Flooding and human health: the dangers posed are not always obvious. *British Medical Journal, 321*(7270), 1167 - 1167.

Palha, A., Mendes, L., Fortes, C. J., Brito-Melo, A., & Sarmento, A. (2010). The impact of wave energy farms in the shoreline wave climate: Portuguese pilot zone case study using Pelamis energy wave devices. *Renewable energy, 35*(1), 62 - 77.

Paniconi, C., Khlaifi, I. L., Giacomelli, A., & Tarhouni, J. (2001). A modelling study of seawater intrusion in the Korba coastal plain, Tunisia. *Physics and Chemistry of the Earth, Part B: Hydrology, Oceans and Atmosphere, 26*(4), 345 - 351.

Passeri, D., Hagen, S., Medeiros, S., Bilskie, M., Alizad, K., & Wang, D. (2015). The dynamic effects of sea level rise on low-gradient coastal landscapes: A review. *Earth's Future, 3*(6), 159 - 181.

Pelling, M., & Uitto, J. I. (2001). Small island developing states: natural disaster vulnerability and global change. *Global Environmental Change Part B: Environmental Hazards, 3*(2), 49 - 62.

Prato, T. (2008). Conceptual framework for assessment and management of ecosystem impacts of climate change. *Ecological complexity, 5*(4), 329 - 338.

Ragoonaden, S. (1997). Impact of sea-level rise on Mauritius. *Journal of Coastal Research*, 205-223.

Ramsar Convention on Wetlands. (2016). *The Annotated Ramsar List: Mauritius*. Retrieved June 13, 2016, from http://ramsar.rgis.ch/cda/en/ramsar-pubs-notes-anno-mauritius/main/ramsar/1-30-168%5E16515_4000_0__

Rani, N. S., Satyanarayana, A. N., & Bhaskaran, P. K. (2015). Coastal vulnerability assessment studies over India: a review. *Natural Hazards, 77*(1), 405 - 428.

Reuveny, R. (2007). Climate change-induced migration and violent conflict. *Political Geography, 26*(6), 656 - 673.

Rignot, E., Bamber, J. L., Van den Broeke, M. R., Davis, C., Li, Y., Jan Van de Berg, W., & Meijgaard, E. V. (2008, January 13). Recent Antarctic ice mass loss from radar interferometry and regional climate modelling. *Nature Geoscience*, 106 - 110.

Robinson, G., Ahmed, A., & Hamill, G. A. (2016). Experimental saltwater intrusion in coastal aquifers using automated image analysis: Applications to homogeneous aquifers. *Journal of Hydrology, 538*, 304 - 313.

Romine, B., Fletcher, C., Frazer, L., & Anderson, T. (2016). each erosion under rising sea-level modulated by coastal geomorphology and sediment availability on carbonate reef-fringed island coasts. *Sedimentology*.

Ruggiero, P., Komar, P. D., McDougal, W. G., Marra, J. J., & Beach, R. A. (2001). Wave runup, extreme water levels and the erosion of properties backing beaches. *Journal of Coastal Research, 17*(2), 407 - 419.

Saaty, T. L. (2008). Decision making with the analytic hierarchy process. *International Journal of Services Sciences, 1*(1), 83 - 98.

San Pedro, L., Babonneau, N., Gutscher, M. A., & Cattaneo, A. (2016). Origin and chronology of the Augias deposit in the Ionian Sea (Central Mediterranean Sea), based on new regional sedimentological data. *Marine Geology*.

Schröter, D., Cramer, W., Leemans, R., Prentice, I. C., Araújo, M. B., Arnell, N. W., . . . Anne, C. (2005). Ecosystem service supply and vulnerability to global change in Europe. *Science, 310*(5752), 1333 - 1337.

Semedescu, D., & Fîntîneru, G. (2013). Tourism phenomenon in the post-crisis economy. *Management, Economic Engineering in Agriculture and Rural Development, 13*(2), 393 - 396.

Skagen, S. K., Burris, L. E., & Granfors, D. ,. (2016). Sediment Accumulation in Prairie Wetlands under a Changing Climate: the Relative Roles of Landscape and Precipitation. *Wetlands, 36*(2), 383 - 395.

Smith, A. J. (2004). Mixed convection and density-dependent seawater circulation in coastal aquifers. *Water resources research, 40*(8).

Snoussi, M., Ouchani, T., & Niazi, S. (2008). Vulnerability assessment of the impact of sea-level rise and flooding on the Moroccan coast: the case of the Mediterranean eastern zone. *Estuarine, Coastal and Shelf Science, 77*(2), 206 - 213.

Spencer, T., Schuerch, M., Nicholls, R. J., Hinkel, J., Lincke, D., Vafeidis, A. T., . . . Brown, S. (2016). Global coastal wetland change under sea-level rise and related stresses: The DIVA Wetland Change Model. *Global and Planetary Change, 139*, 15 - 30.

Statistics Mauritius. (2014). *Demography*. Retrieved Apr 10, 2017, from http://statsmauritius.govmu.org/English/Pages/demography.aspx

Statistics Mauritius. (2014). *Mauritius in figures.* Port Louis: Ministry of Finance and Economic Development.

Statistics Mauritius. (2015, May 19). *Statistics Mauritius.* Retrieved from International travel and tourism: http://statsmauritius.govmu.org/English/Publications/Pages/Tourism-Year-2014.aspx

Statistics Mauritius. (2016). *List of Licensed Hotels in operation as at 31st December 2015.* Port Louis: Statistics Mauritius .

Sweet, W., Park, J., Marra, J., Zervas, C., & Gill, S. (2014). *Sea level rise and nuisance flood frequency changes around the United States.* Maryland: NOAA Technical Report.

Syvitski, J. P., Vörösmarty, C. J., Kettner, A. J., & Green, P. (2005). Impact of humans on the flux of terrestrial sediment to the global coastal ocean. *Science, 308*(5720), 376 - 380.

Temmerman, S., De Vries, M. B., & Bouma, T. J. (2012). Coastal marsh die-off and reduced attenuation of coastal floods:a model analysis. *Global Planet*, 267 - 274.

Temmerman, S., Govers, G., Wartel, S., & Meire, P. (2004). Modelling estuarine variations in tidal marsh sedimentation: response to changing sea level and suspended concentrations. *Marine Geology, 212*, 1 - 19.

The International Disaster Database. (2016). *Disaster List.* Belgium: Centre for Research on the Epidemiology of Disasters.

Tong, T. M., Shaw, R., & Takeuchi, Y. (2012). Climate disaster resilience of the education sector in Thua Thien Hue Province, Central Vietnam. *Natural Hazards, 63*(2), 685 - 709.

Turner, B. L., Kasperson, R. E., Matson, P. A., McCarthy, J. J., Corell, R. W., Christensen, L., . . . Schiller, A. (2003). A framework for vulnerability analysis in sustainability science. *Proc Natl Acad Sci USA*, 8074 - 8079.

Turvey, R. (2007). Vulnerability assessment of developing countries: the case of small-island developing states. *Development Policy Review, 25*(2), 243 - 264.

Uluocha, N. O., & Okeke, I. C. (2004). Implications of wetlands degradation for water resources management: lessons from Nigeria. *GeoJournal, 61*(2), 151 - 154.

UNDP. (2015). *UNDP supports the battle against Coastal Erosion in Mauritius*. Retrieved Aug 6, 2017, from http://www.mu.undp.org/content/mauritius_and_seychelles/en/home/ourwork/environmentandenergy/successstories/undp-supports-the-battle-against-coastal-erosion--storm-surges-a.html

UNESCO. (1994, January 21). IOC-UNEP-WMO-SAREC Planning workshop on an integrated approach to coastal erosion, sea level changes and thier impacts. *Intergovernmental Oceanographic Commission*, pp. 1 - 62.

UNFCCC. (2017). *Kyoto Protocol.* UNFCCC.

UN-OHRLLS. (2015). *Small Island Developing States in Numbers.* Office of the High Representative for the Least Developed Countries.

USGS. (2016). *USGS Flood Inundation Mapping Science*. Retrieved April 24, 2016, from http://water.usgs.gov/osw/flood_inundation/

Veisi, H., Liaghati, H., & Alipour, A. (2016). Developing an ethics-based approach to indicators of sustainable agriculture using analytic hierarchy process (AHP). *Ecological Indicators, 60*, 644 - 654.

Velicogna, I. (2009). Increasing rates of ice mass loss from the Greenland and Antarctic ice sheets revealed by GRACE. *Geophysical research letters, 36*, 1-4.

Vermeer, M., & Rahmstorf, S. (2009). Global sea level linked to global temperature. *Proceedings of the National Academy of Sciences, 106*(51), 21527 - 21532.

Wadey, M. P., Brown, J. M., Haigh, I. D., Dolphin, T., & Wisse, P. (2015). Assessment and comparison of extreme sea levels and waves during the 2013/14 storm season in two UK coastal regions. *Natural Hazards and Earth System Sciences, 15*(10), 2209.

Wassmann, R., Hien, N. X., Hoanh, C. T., & Tuong, T. P. (2004). Sea level rise affecting the Vietnamese Mekong Delta: water elevation in the flood season and implications for rice production. *Climatic change, 66*(1), 89 - 107.

Water Resources Unit. (2001). *Groundwater Resources.* Water Resources Unit.

Werner, A., Ward, J. D., Morgan, L. K., Simmons, C. T., Robinson, N. I., & Teubner, M. D. (2012). Vulnerability indicators of sea water intrusion. *Groundwater, 20*, 48 - 58.

WWF. (2017). *Marine problems: Tourism & coastal development*. Retrieved October 14, 2017, from http://wwf.panda.org/about_our_earth/blue_planet/problems/tourism/

Xue, C. (2005). Causes of land loss in Tuvalu, a small island nation in the Pacific. *Journal of Ocean University of China, 4*(2), 115.

Yao, J. Y., El-Masry, G., Khandelwal, P., & Sacerdoti, E. (2005). *Mauritius: challenges of sustained growth.* International Monetary Fund.

Yuan, R., Zhu, J., & Wang, B. (2013). Impact of sea-level rise on saltwater intrusion in the Pearl River Estuary. *Journal of Coastal Research, 31*(2), 477 - 487.

Zalidis, G., Stamatiadis, S., Takavakoglou, V., Eskridge, K., & Misopolinos, N. (2002). Impacts of agricultural practices on soil and water quality in the Mediterranean region and proposed assessment methodology. *Agriculture, Ecosystems & Environemnt, 88*(2), 137 - 146.

Zhou, X. (2016). Estimation of the position of the sharp interface in littoral aquifers with hydraulic head differences within the fresh-water zone. *Environmental Earth Sciences, 75*(2), 1 - 8.

Zuurbier, K., Raat, K., Paalman, M., Oosterhof, T., & Stuyfzand, P. (2016). How subsurface water technologies (SWT) can provide robust, effective, and cost-efficient solutions for freshwater Management in Coastal Zones. *Water Resources Management*, 1 - 17.