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A Review of Coastal Zone Management Facing Climate Change and Natural Disasters in Mauritius

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Abstract

The National Climate Change Adaptation Policy (NCCAPF) enabling framework in Mauritius has been designed to address key barriers such as lack of financing options, lack of institutional framework and low levels of adaptation technology transfer and aims to integrate and mainstream climate change into core development policies, strategies and plans of Mauritius. The long term energy Strategy 2009-2025 now aims to meet 35% of the energy demand through renewable energy sources by the year 2025. The limits of the EEZ of Mauritius (1850 km², 20°S, 58°E, South Western Indian Ocean, 1.3 million inhabitants) have been defined by geographical coordinates through subsequent regulations under the Maritime Zones Act 1977 as the Maritime Zones (EEZ) Regulations 1984. Flash floods in Port-Louis have become increasingly frequent with floods of March 2013, dubbed as the 'Black Saturday' due a death toll of 11. Swells with wave heights of about 10 m occurred on the western coast in May 2007 whereas floods were recorded on the island in March 2008 as a consequence of climatic change. The Capability Approach would ensure that social arrangements target at increasing people's capabilities and would consider indicators that reflect the importance of assessing the quality of processes rather than simply outcomes of policies and the significance of measures to enhance the ownership and participation of local communities in the management of their natural resources under integrated coastal zone management ICZM. The overall objective should be to develop climate compatible projects for vulnerable coastal regions. The paper reviews measures to strengthen coastal zone management facing climate change and natural disasters and to further improve natural disaster risk management in Mauritius in line with climate compatible development schemes and effective integrated coastal zone management of small islands states under the DPSIR Framework.

Keywords: Floods; Cyclones; Coastal zone management; Eutrophication; Coastal vulnerability; Climate compatible development

Introduction

The Republic of Mauritius consists of a main island, Mauritius, which lies approximately 20.17°S and 57.33°E and a group of small islands in the Indian Ocean, namely, Rodrigues, the Cargados Caragos, Agalega, Tromelin and the Chagos Archipelago. The total land area is 2040 km² whilst the maritime exclusive economic zone covers an area of about 1.9 million km² extending from latitude 10°S to 20°S and from longitude 55°E to 75°E. The main island is volcanic in origin and consists of a central plateau whose mean elevation is between 300 to 400 metres and has a mountainous topography with the highest peak at 817 metres. Mauritius is situated on the south rim of the Mascarene Plateau with an area of 1865 km² and a length of coasts reaching 160 km surrounded completely by fringing coral reefs and enclosing a lagoon area of 243 km², Figure 1. The island has no continental shelf proper; the water reaches a depth of 3000 meters within 20 km of its coastline. The limits of the EEZ of Mauritius (1850 km², 20°S, 58°E, South Western Indian Ocean, 1.3 million inhabitants) have been defined by geographical coordinates through subsequent regulations under the Maritime Zones Act 1977 as the Maritime Zones (EEZ) Regulations 1984. Mauritius has proclaimed its Territorial sea (12 nm) through the Territorial Sea Act of 16 April 1970, its Exclusive Economic Zone (200 nm, about 1.9 million km², (Figure 2) and has also defined its continental shelf through the Maritime Zones Act 1977 and has joint jurisdiction with Seychelles of an extended continental shelf (ECS) of 396000 km² beyond 200 nm as recommended by UN Commission on the Limits of the Continental Shelf (UNCLCS) in 2011.

The author reviews coastal problems in Mauritius and discusses adaptive measures to strengthen coastal zone management facing climate change and natural disasters to further improve natural disaster risk management in Mauritius in line with climate compatible development schemes and effective integrated coastal zone management of small islands states under the DPSIR Framework.

Natural Hazards

It is reported that hydro-meteorological hazards and disasters account for 59% of the total of the various types of hazards and disasters affecting the African continent. These include: floods and flash floods (27%), droughts (21%), tropical cyclones (9%) and fire, heat waves and windstorms (2%). Geological hazards and disasters account for only 4% of the total. These include earthquakes (2%), volcanic eruptions and explosive crater lakes (1%), mass movements and tsunamis (1%). Biological hazards and disasters account for 36% of the total and these include insect infestations (e.g. locusts), diseases (malaria, cholera, avian flu, etc.), conflict-related hazards (e.g. land mines) whereas technological hazards and disasters (e.g. pollution, gas flaring, mining incidents, power failures, failures of infrastructure, and traffic accidents) account for only 1% of the total [1]. Global Change is not just climate change but also encompasses biodiversity loss, land use and cover change, atmospheric composition change, and demographic change such as urbanisation.

This priority area cuts across all of the other three areas and manifests a complex relationship between human activity and survival on the one hand, and the Earth system and its processes on the other hand. The

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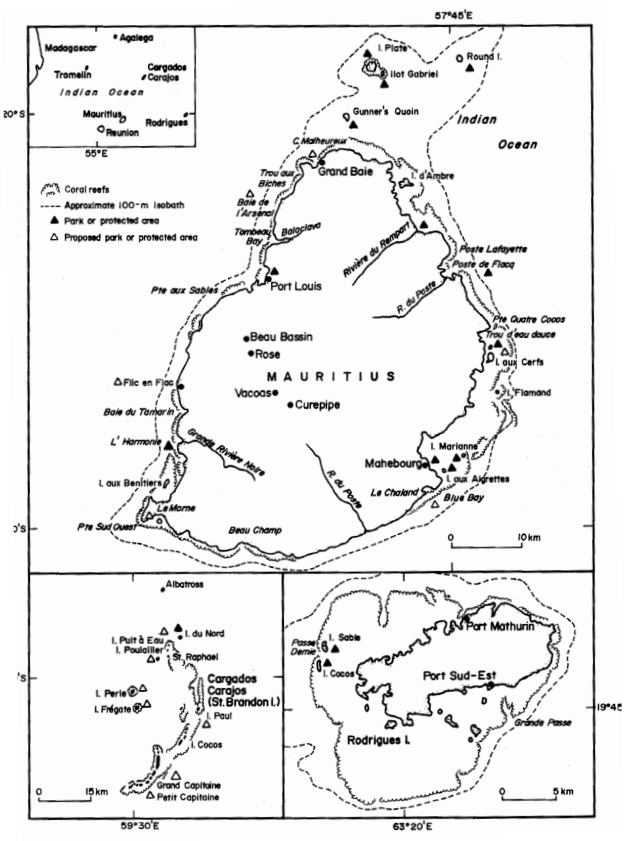

Figure 1: Shallow banks around Mauritius and Rodrigues.

areas of interest include eco-systems and biodiversity, desertification, water and air pollution, global warming and sea-level changes. Hence, our quest for a sound understanding of Global Change compels us to work on the complex interactions between the Earth's core-mesosphere-asthenosphere-lithosphere-biosphere-atmosphere [1].

Statement of the Problem

Countries in the South Western Indian Ocean are affected mostly by hydro-meteorological hazards and disasters, namely, floods, heat waves, wildfires, tropical cyclones, tsunamis, swells and dust storms [2,3]. Devastating catastrophes experienced on the African continent, also result from other natural and/or human-induced events which may be geological (e.g, earthquakes, volcanoes, tsunamis and collapse of constructions); biological (e.g, diseases, pest infestation and biological weapons); or technological (e.g, global warming, air and water pollution). Despite the regular occurrence of hazardous events, there is little understanding of their actual economic impact, especially when several devastating events occur together. Integrated modelling would enable precise evaluation of the vulnerability to compounded hazards and disasters (e.g droughts, tsunamis, swells, floods and cyclones). The ultimate objective is to minimise the damage costs, make accurate assessments of losses due to hazards and disasters including the minimisation of vulnerability associated with urbanisation, and prediction of the effect of climate change on hazards and disasters. Geographic Information System (GIS) softwares are nowadays used for Environmental Sensitivity Index (ESI) map compilation and production as generated by Reefbase, a global information system for coral reefs, Figures 3-4. ESI maps are finding ever widening use

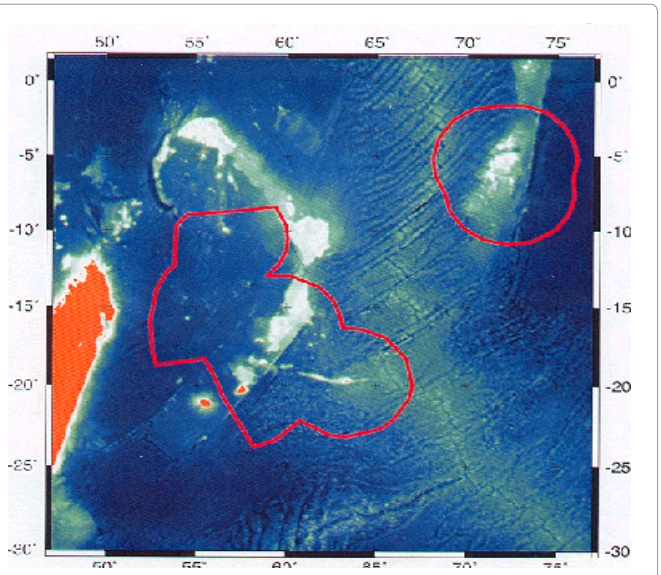

Figure 2: Exclusive Economic Zone around Mauritius, Rodrigues and Chagos Archipelago (Source Mauritius Oceanography Institute).

in such areas as coastal resource inventories and assessments, coastal planning, and recreational planning in Mauritius [4,5]. For instance, sensitive wetlands are a high priority for protection, but when oiled, cleanup should be restricted to prevent additional damage from human activities. ESI shoreline classifications now provide information necessary to aid in these decisions. Key links between large-scale and local scale climate change problems are biodiversity, food and water security. Sea-level rise and accelerated beach erosion, degradation of coral reefs (including bleaching), and the loss of cultural heritage on the coasts through inundation and flooding will most likely reduce the attractiveness of small island states to tourists. Increases in the frequency or intensity of hurricanes and cyclones will also strongly affect the tourism industry. Other projected impacts include: economic losses from reduced agricultural yields, for example from shortening of the growing season or drought; loss of mangrove forests due to sea-level rise, loss of coral reefs due to bleaching and acidification of the oceans and damage to terrestrial forests due to extreme events; reduction in the size of freshwater lenses and general water resource availability due to decreased rainfall and saltwater intrusion; inundation of settlements and arable land on the coast and reduction in tourism resulting from increases in extreme weather and environmental degradation. Water pollution is one of the major problems facing small islands; poor water quality affects human health and the incidence of water-borne diseases. Tourism and agriculture, in particular, will be negatively impacted by these changes. Likewise climate change, through these impacts, threatens the achievement of the sustainable development goals contained in the Mauritius Strategy. Responses to climate change and sea-level rise could be coordinated and integrated with existing policies of socio-economic development and environmental conservation to facilitate sustainable development. Degrading and over-exploitive uses of land, water, and other coastal resources and disruption of environmental processes through degradation of environmental quality and loss of critical terrestrial and aquatic habitats will lead to serious deleterious impacts on the health and productivity of coastal ecosystems [6]. Management strategies aimed at a sustainable development related to climate change have to be based on a fair knowledge of what is going on in the natural systems.

Climatic Conditions

Mauritius lies within the tropical belt, but near the southern limits. It enjoys a mild, maritime climate, which is sub-tropical. The climate is generally dominated by the South East Trade Winds and is practically free from continental influences. Average seasonal variation of temperature is very small, being of the order of 4°C, which is nonetheless sufficient to cause a well-marked difference in the season. Diurnal temperature variation over the centre is around 4°C. The range between day and night temperatures is of the order of 7°C in coastal areas. Temperatures are higher in the coastal areas and decrease towards the Central Plateau. The West and the North, which are on the leeward side of the South East Trade Winds, are warmer than the South and the East. The average mid-day temperature on the central plateau varies from 21°C in August to 27°C in February. Near the coastal regions, temperatures are about 4-5°C higher. Mauritius experiences two seasons. Summer occurs between the months of November to April, and winter between the months of May to October.

The long-term mean (1961-1990) rainfall is considered as the normal rainfall for the different parts of Mauritius. The mean annual rainfall is about 2100 mm, ranging from 1050 mm on the West to reach a peak of 3340 mm over the windward slopes of the Central Plateau. Mauritius receives a mean rainfall of 1410 mm during summer and about 700 mm during winter.

Flash Floods in Port Louis

Port-Louis is the most populated region in Mauritius, boasting a population of around 118,000 [7]. The figure easily doubles during normal workdays. Port-Louis is also an intensely industrialised region due to its proximity with the harbour. Economic activities in the region are varied, ranging from fishing and food processing to textile manufacturing and automobile repair. During the past few years, Mauritius and the region of Port-Louis in particular have witnessed unprecedented heavy rainfall. The extreme climatic conditions have been attributed to climate change, which is affecting islands such as Mauritius to a large extent. Flash floods in Port-Louis are becoming increasingly commonplace with floods of February 2013 and more recently that of 30 March 2013, dubbed as the 'Black Saturday' due to a death of 11 with 176 mm of rain falling for a period of only 3 hours generating flash floods which cost the lives of 11 people and complete damage of entire regions of Port-Louis, notably at Canal Dayot found along the Grand River North West, Figure 3.

Eutrophication of Lagoons

Sources of water pollution can be grouped under point source water pollution and non-point source water pollution. The former can be easily measured and controlled since it represents those activities where wastewater is routed directly into receiving water bodies by, for example, discharge pipes, while the latter emerges from a wide range of human activities for which the pollutants have no obvious point of entry into receiving watercourses. Their dispersed characteristic makes it harder to design a system of controls for pollutants. The effects of rising seawater temperatures, inflow of fresh water and turbidity on deterioration of coral reefs and an increase of algal mats are known to a certain extent, but the effects of eutrophication in particular have yet to be clearly established. According to previous studies of coral reef eutrophication, the indicators of eutrophication in coral reefs should be the threshold values of eutrophication, with the concentration of inorganic nitrogen around 1 µM and the concentration of inorganic phosphorus (PO4-P) around 0.2-0.3 µM [8].

Figure 3: Map of Mauritius with drainage and river systems (left) and Flash Floods along Canal Dayot in Port Louis in March 2013 (right) .

In Mauritius, land area devoted to agriculture is approximately 100000 ha, 90% of which is under sugarcane cultivation. A low dissolved [nitrate]: [phosphate] ratio of 7 was computed for the Flic en Flac lagoon situated in a rural area but which fell between 2 to 15 usually found for coastal waters globally suggesting denitrification and a high dissolved [nitrate]: [phosphate] ratio in the wells and seepage chambers indicated a high input of nitrate in the Flic en Flac coastal area which may be of agriculture origin and fertilizers [9-11].The steady rise in the number of vehicles using unleaded petrol since the 1980s and has also contributed to water pollution to some extent [12-17]. Lead content of freshwater systems near areas exposed to a high flow of motor vehicles was found to be higher than those less exposed to such conditions [18]. NO3-N in the lagoons is normally less than 0.1 mg/l. From 2001 to 2003, values higher than 0.1 mg/l (detection limit) were detected in Baie du Tombeau, Harbour and Poudre d'Or as shown in Figure 4. In Blue Bay, concentrations higher than 0.1 mg/l were detected in 2007. PO4-P in the lagoons is normally in the range of 0.01-0.1 mg/l [7].

In 2010, concentrations higher than 0.1mg/l were detected in Poudre d'Or, Albion, Bird Sanctuary and Riviere Noire. These facts suggest that water pollution caused by the pollution load of domestic wastewater has had an effect on the decline of corals and an increase of coastal algal mats. Meanwhile, heavily polluted water was found in the lagoon on the coast of Poudre d'Or in the early part of the first decade of this century and in the lagoons on the coasts of Poudre d'Or and Blue Bay from 2007, on the eastern coast of the island. The decline of corals is likely to be caused by pollution load from land, namely an increase of the nitrogen and phosphorus.

The coastal conditions in Mauritius of coastal waters have declined since 2000 as the Mauritian economy underwent major structural changes successfully with a rapid phase of industrialization in the 1980s. The threat of contamination of oligotrophic waters in Mauritius and deterioration in water quality by eutrophication and industrial wastes, in particular, metal pollution have caused a decline coverage of live corals to 10-30% in coastal lagoons around Mauritius in 2012 and exceeding the Redfield ratio for nutrients. Nutrients are now the largest pollution problem in coastal marine ecosystems globally. In the US, 60 percent of estuaries are moderately to severely degraded, primarily from nutrients like nitrates and phosphates [19-23]. Globally, human activity has roughly doubled the flux of nutrients and trace metals from land to the oceans, with much of this occurring over the past 40 years [24].

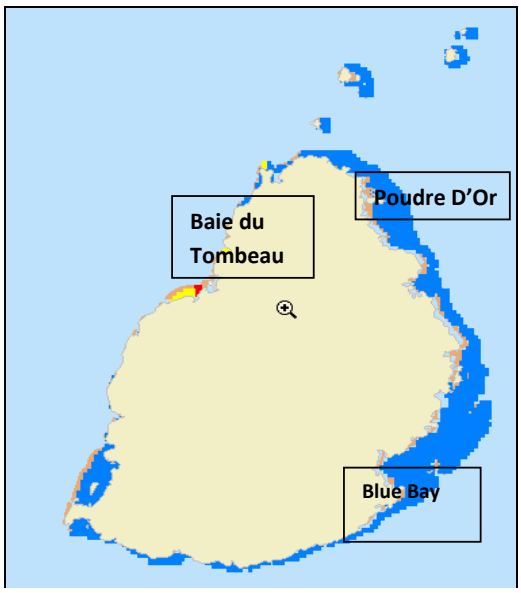

Figure 4: Marine Pollution (Code: Blue- Low Threat, Yellow-Medium Threat, Red-High threat) [19].

Studies have showed that estuaries are particularly vulnerable to nutrient over-enrichment and trace metal contamination hence highlighting the need to monitor these aspects of pollution in estuarine regions [25-27]. The major source of dissolved phosphate in lagoons may come from runoff of phosphate fertilizers that leach from sugarcane plantations into groundwater, which feeds the wetlands and the lagoons. Heavily polluted water was found in the lagoons on the coasts of Bain des Dames, Baie du Tombeau, Harbour and Pointe aux Sables in the early part of the first decade of this century (from 2001 to 2003) and on the coasts of Pointe aux Sables, Albion, Bird Sanctuary and Riviere Noire from 2007, on the western coast of the island of Mauritius [7]. The potential source of dissolved nutrients may probably due to the lagoon water being mixed with the submarine groundwater discharge containing nutrients of agricultural and domestic origin in the lagoon. The geology of Mauritius consists basically of basalt rocks only. The complex nature of its formation has given rise to basalt of various densities: impermeable compact basalt to highly porous basalt. The latter acts a water collector; thus aquifers of Mauritius have a high permeability in excess of 10^{-5} m/s. The texture and type of formation from the different volcanic activities would thus determine the natural infiltration rates, the contribution of rainfall recharge to aquifers and also the amount of runoff.

Recent eutrophication in several Mauritius lagoons has highlighted the need for a greater understanding of nutrient sources to lagoon waters. Submarine groundwater discharge (SGD) into the marine environment is one possible transport mechanism for excess terrestrial nutrients to reach the sea. However the direct discharge of groundwater into the sea has been difficult to measure, since fluxes may be episodic and patchy in distribution. The coastal environment of Mauritius receives significant SGD, the seepage of fluids through coastal marine sediments from the underlying aquifer into the overlying coastal ocean. SGD using radium tracers have been investigated in 2005 during the UNESCO-IAEA expedition in Mauritius to investigate seepage in the Flic en Flac lagoon, including seawater cycling within submarine sediments and groundwater discharge from the Curepipe aquifer which can significantly contribute to coral reef degradation in the lagoon and as a pathway for nutrients [9,11,23]. Given the potential for groundwater transport of nutrients far from their sources and the sensitivity of the marine environment to excess nutrients, there is a clear need for greater understanding of SGD nutrient sources to Mauritian lagoons and its implications for ICZM.

Reef Vulnerability and Bleaching

The unprecedented bleaching event of 1998 affected up to 90% of many shallow living corals throughout the Indian Ocean region, massive mortality occurred in the Seychelles, Chagos Archipelago and St Brandon and along the East African coast as and many of these reefs have now eroded to rubble [28-29]. Mauritius also experienced raised sea surface temperatures of 1 to 1.25°C during February 1998 but mass bleaching of corals did not occur due to high cloud cover, high rainfall and low sunshine during the passage of cyclone Anacelle [30-31]. Severe coral bleaching and mass mortality that would have occurred due to the synergistic effects were mitigated by the cyclone and recent coral bleaching events also occurred in January and March 2009 on the east coast.

The most likely impacts of reef degradation due to coral bleaching in Mauritius will be on the two common socio-economic reef based activities, namely fisheries and tourism: (1) artisanal catch rates may decrease and the catch composition may shift towards the herbivorous species. (2) the target species of the offshore FADs are the large predatory pelagics that forage near the reefs on reef fish, so these devices may also offer lower catch rates (3) major shifts in the ecology of these small scale fisheries may occur due to over-exploitation pressure, (4) the fishermen may no longer disperse their effort over larger areas to decrease fishing effort locally, and (5) being a beach, dive and snorkel destination. More recently, swells with wave heights of about 10 m occurred on the western coast in May 2007 whereas floods were recorded on the island in March 2008 with more than 100 mm rainfall in 24h and inadequate drainage systems.

In 2013 the tourism industry attracted more than 950 000 tourists annually and the capacity of the new airport which opens in October 2013 will handle about 3 million passengers annually. Tourism, particularly coastal and marine based, is among the most important sectors of the Mauritian economy as a source of foreign income. The widely practised types of tourism include beaching, swimming, snorkelling and diving, boating, skiing, parasailing and game fishing. The coastal sites chosen for tourism are largely exploited for their beauty and exoticism, aesthetic value and natural habitats with remarkable biodiversity (e.g. coral reefs, sand beaches and dunes, warm, clear and attractive lagoon water). The rapid expansion of the hotel industry has brought economic benefits both to the public and private sectors. There is at present a need to manage the 49 inshore islets around Mauritius. Many of the islets are under-utilized and many of them through a proper land use zoning can be used for conservation, education, recreation and eco-tourism projects. The main piece of legislation for providing protection and management of offshore islets in Mauritius are: Forests and Reserves Act 1983, Wildlife and National Parks Act 1993, Pas Geometrique Act 1895 and the State Lands Act 1874. The 49 islets have been grouped into 3 categories- Strict nature reserve with restricted access, open nature reserve with controlled access and tourist and recreational with free access. Many of the offshore islets are biologically important and have conservation potential due to their unique native and endemic flora and fauna.

Urbanized Estuaries

Industrial and urban development coupled with a rise in the tourism industry have led to major concerns in pollution problems, especially in estuaries with fishermen communities giving rise to conflicts amongst the various coastal stakeholders. Important increases in the level of copper and lead in sediments due to traffic have been reported in the north-west [18]. Concerning agriculture and its impact on trace metal levels in natural freshwater, it was noted that high levels of lead were present in water samples near agricultural fields, probably as a result of inorganic insecticides [31]. Other studies have also related abnormally high concentrations for zinc, copper and other trace metals to anthropogenic point sources or to discharges from urban areas and correlations between lead and zinc indicated a traffic related source [15].

At present, compared to contaminant levels found in the US and Europe, Mauritius still looks relatively uncontaminated but there is growing concern about trace metal contamination. The decontamination of contaminated sites of the estuary in urban areas will become necessary to prevent harm to the environment in the long term. Any engineering solution for this problem in order to be implemented has to take into account the distribution of the amounts of copper and lead from urban runoff in the Grand River estuary. Furthermore, the evaluation of sediment remedial alternatives should consider their feasibility, contaminant losses, overall environmental impacts and total project costs. There will also be a need for long-term perspectives in estuarine management to involve integrated strategies in which water-sediment interactions need to be considered and international standards for sediment quality developed. Such studies undertaken in the future would then further the understanding of the biogeochemical processes of estuarine system which could be used in environmental development schemes and effective integrated coastal zone management of small island states.

Discussion of Capability Approach for Coastal Zone Management

The use of capability approach, recognising that poverty is multidimensional, also shows that non-point water pollution leads to poor health, but poor health does not only imply suffering from any form of diseases. The main notion of the Capability Approach is that social arrangements should target at increasing people's capabilities-their freedom to upgrade or accomplish what they value doing and being as described for the GRNW area in Mauritius in how water pollution affects the capacity of people to convert resources into well-being [17]. Two important elements of the approach are: functionings and capabilities. The former refers to being and doing activities that people value and have reason to value, while the latter denote the freedom to enjoy valuable functionings and thus convey some kind of opportunity freedom.

Poor health is much beyond that if we make use of health capabilities and deprivations dimensions in terms of achieved valued functionings, for those living in contexts of poverty in Mauritius. Being deprived in health capabilities lead to productivity loss, reduction in income, loss of employment, deprivation in education thereby pushing individuals and households further down the poverty ladder. Given the feedback effect from health deprivations into deprivations in other dimensions, the poverty cycle is further reinforced. Alongside deprivations in health may be irreversible compared to deprivations in other dimensions such as education which can be offset at later stages of life through for example adult literacy programmes. Consequently this signals to the need to give health its due importance in development policy. Galvanized by the United Nations Conference on Environment and Development meeting of 1992, Planet Under Pressure Conference in 2012 and Rio+10, there has been a search to improve capacity of coastal nations and communities to manage their coastal and estuarine resources in a sustainable manner. Following the Recomap-EU Regional ICZM Workshop in 2008 in Mauritius, the need for ICZM has become critical because of limited land resources and disproportional domination of coastal areas. During the 1980s, the Mauritian economy underwent major structural changes successfully with a rapid phase of industrialization and urbanization with the threat of contamination of surface waters in Mauritius and deterioration in water quality by industrial wastes, in particular, metal pollution, being only relatively recent as compared to industrialized countries. The coastal zone of Mauritius was redefined in 1997 in the Environment Protection Act of to include all islets within the EEZ. Mauritius has also ratified and adhered to international law or legal instruments.

The complexity of biotic systems and the interrelationship of their components require that each coastal water system be managed as a separate system. The coastal areas and waters are the ultimate

recipients for environmental degradation and pollution released to the atmosphere, land and water. Mauritius is classed as having a high level of reef-based tourism because over 70% of the total tourists take part in reef-based activities. The number of tourists visiting Mauritius annually has exceeded 950,000 in 2013. Coastal developments have occurred in three major touristic zones in the north, west and east of the island. Popular touristic areas are situated in the north (Grand Baie); the Port Louis waterfront in the capital offers shopping facilities and leisure activities. Hotel properties occupy around 44.5km (14%) of the coastline and bungalows have been built along 323 km occupying 16% of the entire coastline. Public beaches represent approximately 28.3 km (9%) of the coastline and most of the beaches are devoid of proper amenities coupled with a serious lack of inland recreational/leisure amenities as compared to those offered by the hotels. The concentration of the population in the narrow coastal strip has created several user conflicts.

Perpetual conflicts have been generated by: (i) access of the public to beaches; (ii) access of fishermen to their boats; (iii) dredging of the lagoon for coastal expansion. Disposal of dredged material, sand mining, jetty constructions, filling of wetlands, mangrove destruction and high-speed water sports are present-day problems. Conflicts have recently arisen between the fishing and the hotel industry in the south east and east of the island due to hotel expansion projects along the coastline and islets at Ile aux Cerfs and Iles aux Deux Cocos. A conflict between the fishermen in the northwest of the island and a construction company was also recorded in 1998 following offshore extraction of sand at Albion for commercial purposes and between residents and the coal power plant proposal in Albion in 2012. There is at present a need to manage the 49 inshore islets (area ranging 253 m^2-253 ha).

Strategies and Requirements for ICZM

Baseline investigations carried out on the west coast of Mauritius have highlighted the susceptibility of oligotrophic water bodies to nutrient inputs and the threats posed by rapidly increasing residential and industrial development [11]. Protecting estuarine resources and coastal ecosystems from continued nutrient inputs and trace metal contamination particularly requires the ability to predict responses to potential increases in nutrient loading resulting from changing land-use patterns. Pollution of oligotrophic systems in Mauritius is a real problem and in-depth monitoring of this issue is of vital importance. As insufficient suitable baseline data on the marine and coastal environment are available in Mauritius projects, lagoonal health characteristics and coastal pollution monitoring have been implemented since 1991 to provide baseline data in the field of marine ecology, marine pollution and coastal physical oceanography. It is also recognized that there is a general lack of scientific data on trace contaminants and their dispersal mechanisms, SGD and on marine pollution indicators. Studies are now aimed towards strategies to better protect, manage and conserve marine ecosystems. The requirements of an Environmental Impact Assessment (EIA) are mandatory for any coastal development project as scheduled under the EPA Act and new coastal water quality standards for recreational activities and mariculture are under preparation. Waste treatment plants by polluting industries and major hotel complexes have also become mandatory, and assistance is being sought for the implementation of the provisions of MARPOL in Mauritius. Necessary equipment has been procured recently to implement an oil contingency plan for the harbour in case of oil spill. Studies for recommending measures for coastal protection and rehabilitation of beaches around the island and mitigate landslide disasters are carried out since 2012 under the "Environment and Climate Change Adaptation Program", in which the Disaster Risk Reduction, water resources management and sanitation are the main covered areas under Japan International Corporation Agency (JICA).

Application of a Geographical Information System (GIS) for coastal and marine resources is now underway, and collaborative research exists with various institutions on a bilateral basis for capacity building and for improving quality of resource assessment. The use of GIS has gained more importance in planning processes for coral reef management and has provided information for sensible policy-making for the south east coast. GIS is facilitating the inventory of present and planned land-use and assessment of impact of proposed development and land-use changes. Mauritius has included plans for promoting sustainable tourism as well as protection of the coastal belt in its National Physical Development Plan in 1993. A considerable amount of improvement has been noted over the recent decade following the enactment of the Environmental Protection Act (EPA) in 1991. In Mauritius, there are indirect incentives in the form of tax credits for importation of pollution abatement facilities to encourage industry to invest in new production equipment and clean technology. The reef monitoring network is a sub-regional node of the Global Coral Reef Monitoring Network and supported under a GEF mid-size project. The European Commission considered the ICZM programme as a pilot one among the many programmes it supported with African/Caribbean/Pacific (ACP) countries and island states whereas Southern African Regional Universities Association (SARUA) has established a five year programme for climate Change Capacity Development [1,32-34].

Institutional Framework

The National Climate Change Adaptation Policy (NCCAPF) enabling framework has been designed to address key barriers such as lack of financing options, lack of institutional framework, and low levels of adaptation technology transfer and aims to integrate and mainstream climate change into core development policies, strategies and plans of Mauritius. The long term energy Strategy 2009-2025 aims to meet 35% of the energy demand through renewable energy sources by the year 2025 in Mauritius. The lack of adequate institutional capacity is one of the major constraints in achieving biodiversity conservation in the Western Indian Ocean. Many targeted marine protected areas have not advanced beyond proposals and there is a need for institutional capacity building and strengthening for effective control of activities outside marine protected areas. Consultative committees have been set up to provide necessary stakeholders inputs into coastal and marine management decisions. Mauritius has ratified and adhered to international law or legal instruments such as the 1982 United Nations Convention on the Laws of the Sea (UNCLOS), Convention for International Trade of Endangered Species (CITES), the IMO Convention of 1973 for the prevention of pollution from ships, as modified by the Marine Pollution (MARPOL) protocols of 1978, the Code of Practice for Responsible Fishing and Agenda 21 of UNCED for sustainable development of marine living resources, protection of the marine environment and preservation of biodiversity (including the 1992 Convention on Biological Diversity). Enactment of national laws include the basic principles enunciated in International Conventions such as the Continental Shelf Act of 1970, the Territorial Sea Act of 1970, the Port Act of 1976, the Maritime Zones Act 1977, the Fisheries and Marine Resources Act 2001 and the Environment Protection Act of 1991.

From a technical perspective, existing coastal inventorying enabling coastal zone management of small island regions can benefit from advancement in GIS application and environmental networking. There

is, however, a need to synthesize and organize existing reports and data into a common DPSIR (Driving forces, Pressures, State, Impacts, Responses) framework as shown in Figure 5 that assists:

- Harmonizing the descriptions of the current status of the country's diverse coastal and ocean stakeholders and social players,
- Filling existing gaps in knowledge with data collection and scientific inquiries, identifying social and economic drivers of demographic changes and household attributes by ethnicity and geographic location, and relating socio-economic change to expected demands for environmental resources (land use, water resources, marine resources). Future data collection should therefore help extending the database and to include fishery areas, navigational routes, new recreation points, SGD and waste disposal sites. Remotely sensed data of the region have to be transferred to the GIS database to visualize and map pressure, state impact relation features. In a Mauritian example the use of GIS has gained more importance in the planning process and has provided information for sensible policy-making for the south east coastal region. GIS is facilitating the improvement of the inventory of present planned land-use and the related impact assessment of proposed developments and risk assessment allowing to develop and visualize scenarios of different use options.

Based on this kind of information Integrated Coastal Zone Management is an adaptive process of resource management for environmentally sustainable development. Once implemented an ICZM plan is not expected to be static but forms an iterative mechanism continuously evolving and which has to evaluate and eventually redefine its internal milestones regularly. This will ensure to meet the dynamic goals deriving from temporal and spatial changes that have to be made to the management objectives subject to changing demand or legislation.

Conclusions

For a future global change research focus on island dominated regions it is suggested to compare three larger integrated pilot projects in the Atlantic Pacific-Indian Ocean and for example the Wider Caribbean for CZM facing climate change. They should be aimed to investigate in higher detail the current status and observed and expected changes of material fluxes from drainage basins/islands including trans boundary impact assessment considering the ocean and atmospheric inputs. The overall objective should be to develop climate compatible projects for vulnerable coastal regions of small islands.

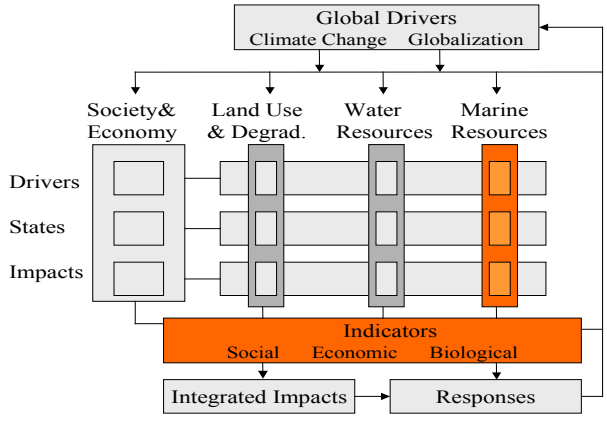

Figure 5: DPSIR framework in Mauritius [4].

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