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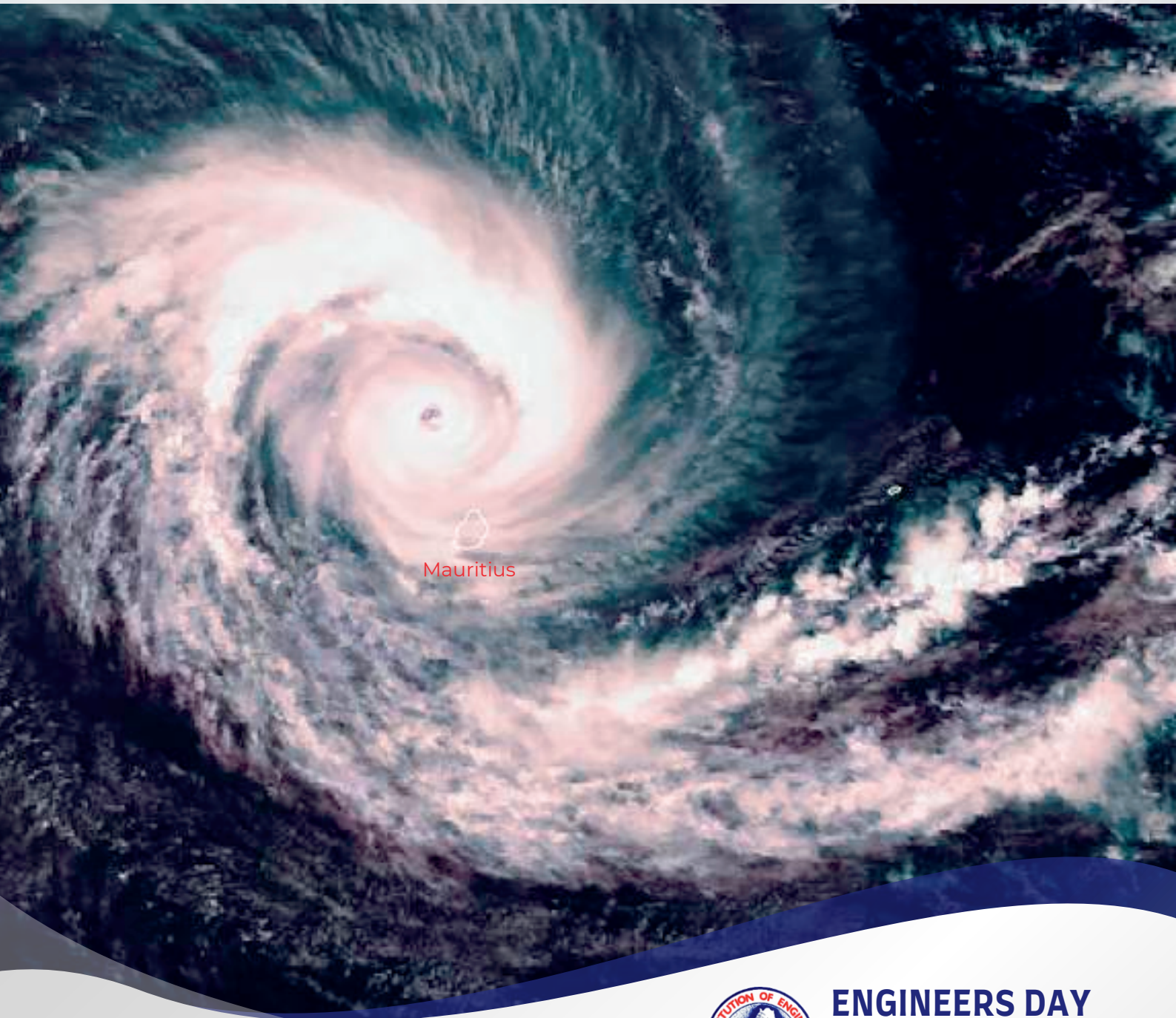
"ENGINEERING: THE PATHWAY TO BUILDING RESILIENCE TO CLIMATE CHANGE IN SIDS "



ENGINEERS DAY
13 September
Mauritius

Tuesday 13th September 2022

WFEO - SUSTAINABLE DEVELOPMENT GOALS


MAURITIUS

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INSTITUTION OF ENGINEERS MAURITIUS [IEM]

The Institution of Engineers Mauritius (IEM), was created on 26th February 1948, under the appellation Engineers Association of Mauritius, to represent the engineering profession and provide a forum for all engineers to come together for the advancement of the engineering profession irrespective of the engineering disciplines in which they specialised or practised, and had set itself the following objectives: to foster engineering science and its application in all engineering disciplines, ensure the highest standard of service in engineering, and improve the status and safeguard the interests of the engineering profession. Its name was changed to "The Professional Engineers Association of Mauritius" during a Special General Meeting held on 28th January 1965. Thirteen years later, on 1st Dec 1978, the association was restructured and adopted a new name "The Institution of Engineers Mauritius". The changes were approved by the Registrar of Associations on 19 January 1979.

The founder members desired to regulate the profession and the practice of engineering. The government of the day agreed on the regulation but by a different body. The engineers were nevertheless satisfied when a Council of Registered Professional Engineers Bill was pushed through the Legislative Assembly and was eventually approved. The Council of Registered Professional Engineers Ordinance was gazetted on 23 December 1965.

The IEM has remained an association of professional engineers, whereas the Council of Registered Professional Engineers (CRPE) is the body authorised to approve qualifications, leading to registration as Professional Engineers, and to register the holders of such qualification subject to their also meeting tie experience requirements. If at all the Institution has to intervene at the level of the Council, it does so through its two representatives on the council of the C.R.P.E.

In addition to serving on the council of the C.R.P.E. the Institution is active at the level of the Board of the Central Electricity Board and puts in its contribution at the Mauritius Standard Bureau, the University of Mauritius. The IEM has made requests to Government for the Institution to be represented on major Government committees and parastatal Boards concerned with the provision of services requiring heavy investment of engineering nature.

The IEM joined the World Federation of Engineering Organisations, (WFEO), as a Regional Member in 1981, and became a Full member of the Commonwealth Engineers Council (CEC) on 15 November 1985.

IEM's constitution was amended in October 2018 to create the Engineering Accreditation Board (EAB), in the context of the Washington Accord project. IEM's goal is to become full member by 2025. www.iemauritius.com

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This years' journal is entitled **The Pathway to Building Resilience to Climate Change in SIDS in view of the Environmental emergency status at Global level**. On 25th July, USA's President Joseph Biden was talking of declaring an environmental emergency because of the catastrophic high temperatures and wildfires across USA. The hour is grave and full of menace for the world when we see the wildfires and high temperature coupled with droughts across the planet from Australia, to California, across Europe in countries such as Spain, France, UK etc. However, the C/C impacts will be felt much, much more in the Small Islands Developing States because of their highly sensitive environment and of their low-lying coastal areas where 90 percent of the activities, both for habitation and associated activities are held.

The future does not look bright unless URGENT action is taken TODAY by the 20 % of the nations responsible for 80% of the emission. Fatil Birol of the International Energy Agency recently drew the attention of the Nations that the west is facing an energy emergency and they are reverting to carbon emission although they have put on hold construction of any further coal power plants.

The world needs leadership on energy policies and management.

However, there is a glimmer of hope when one sees that in 2019 there was 2% of electric vehicles in the world and three years later the number has gone up to 15%. China is today the powerhouse for developing solar and wind energy. This is followed by India. The power shedding issue of South Africa is being addressed through importing of hydro generated from Botswana and Zambia which is also supplying its excess Zimbabwe and DC Congo.

Most of the effort towards renewable sources of energy is from the countries deemed to be from the South. Unless the competition between economic growth and energy emergency is addressed, and a just compromise is reached, it will be business as usual with further endangering of the world's environment.
This has to be the time to walk the talk BUT we are handicapped by the quest for more energy, more economic growth for today and tomorrow will take care of itself. Where are the global leadership in energy?

The Engineers must step up in decision making regarding policy making at national level as much can be done for enhancing green energy from the sun and the wind. These sources of energy are available around us. Let us, Engineers take the lead to look for local solutions to some global problems. So much resilience and sustainability can be built through providing each building with a solar energy producing kit and water harvesting system.

We are already too late to meet the carbon emission target as set up at the COPs on Climate Change (CC) but we, Engineers at local level, should step up and influence the policies on CC adaptation and building reliance and sustainability for the future of mankind.

IEM stands ready to lead and we are asking the authorities to help us to help our nations.

Message from Past President WFEO

Dr Marlene Kanga AM FTSE HON. FIE Aust. Hon. FIChemE

President World Federation of Engineering Organisations 2017–2019
President, Engineers Australia 2013

I am honoured and delighted to present this Foreword to the Institution of Engineers Mauritius for this special journal that focuses on engineering and the pathway to building resilience to climate change in the Small Island Developing States. My congratulations to Past President of the Institution Mr Shyam Roy and to all the engineers from Mauritius and around the world who have contributed to this important publication.

Mauritius faces unique challenges, arising from its small geographical area and location in the southern Indian Ocean, from sea-level rise, altered rainfall patterns, storm-surges and extreme weather events such as cyclones. Extreme weather events can threaten low lying coastal development and infrastructure, the economy and livelihood of the population and have negative impacts on the economy, including key industries such as tourism. Importantly, they reduce progress towards the UN Sustainable Development Goals.

Engineers have a key role in addressing the impacts of climate change. Engineers can design more resilient infrastructure and buildings, especially in low-lying coastal areas. They can develop more resilient, climate independent sources of clean water, and harness the power of the wind and the sun, which are generally abundant in Mauritius, for renewable sources of energy which will also reduce dependence on imported fossil fuels. Engineers can develop sustainable programmes for improved food security. Such projects will also reduce greenhouse gas emissions, a global priority.

Capacity building for more engineers is therefore an important priority for Mauritius. I have observed, first hand, the importance that the government and the engineering community places on educating young Mauritians to the the highest standards, especially in engineering. The World Federation of Engineering Organisations is proud to be collaborating and supporting Mauritius in its goal for capacity building in this important area.

The release of this important special journal on Engineers Day in 2022 will assist in informing the community in Mauritius and internationally on the important role of engineers in designing, developing and implementing solutions to address climate change. I am sure that many young people will gain a better understanding of the contributions that engineers make for a better sustainable future for us all.

ASSESSING THE RESILIENCE OF INFRASTRUCTURES AND CITIES USING THE UNDRR BALANCE SCORE CARD METHOD

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1.0 Abstract

Cities support the economy of a country and play a key role is the socio-economic welfare of citizens. The need to keep a city healthy is often not fully appreciated. Development, easy access to jobs, and access to welfare facilities are increasingly putting pressure on cities. Impacts of climate change are enhancing this situation further. As the demands on cities increase at a fast rate, so does the vulnerability of cities and unless this vulnerability is brought to light, the need for a holistic approach to managing cities may go unnoticed. Already global trends indicated that more than 50% of the world population live in cities and three-quarter of the GDP is concentrated in cities. Cities are characterized by multiple uses, transportation, infrastructure, services, utilities and open spaces, all of which operate in harmony to providing a conductive working and living environment. However, these elements have a design capacity and a design life span and any additional pressure to this system, can threaten the socio economic situation. Cities are dynamic systems, and have to be reviewed regularly. The United Nations Office for Disaster Risk Reduction (UNDRR) Disaster Resilience Score Card for Cities has been developed to guide cities on how to develop resilience to the impacts of climate change. This working tool is based on the concept of ten essential elements that are key to building a resilient city and this tool has been applied in many countries with much success. The UNDRR tool is adaptive and allows for engaging the decision makers as well as technical staff to adopt a holistic approach. The UNDRR Disaster Resilience Score Card for Cities was tested through field surveys, focus group discussions and interviews. This research study noted that: (1) The concept of resilience to climate change is currently being addressed in the context of flood mostly and landslide to some extent, specially where landslide problems have been recorded; (2) Directly concerned authorities require additional training to support development for a resilient city to climate change; (3) There is a lack of technically supporting documents and maps in an integrated system to support decisions; (4) The actual and future potential impacts of climate change on cities are well appreciated, and some future scenario analysis exist, but the cascading effects of climate impacts are not well understood; (5) There is a lack of funding mechanism or budget lines that are dedicated to retrofitting cities to make them more climate resilient in sectors other than floods; (6) The community are not fully engaged in the process of adapting to climate change; (7) First responders have been proactive and have developed reliable response mechanism and (8) Learning from past experience to build back better is not structured. Overall, the main concern is that there is a lack of ownership at institutional level.

***Keywords**: Resilient Cities; UNDRR Disaster Resilience Score Card; Impacts of Climate Change; Community Engagement*

2.0 Introduction

A city is very complex, hosting residential, commercial, services, recreation facilities, and utilities. All these systems, though each one do not related to the other, are expected to operate in harmony for the socioeconomic welfare of a country and for the safety of communities. Over time, increase in population, improvement in living conditions, the development of new businesses and the movement to urban areas, have put much pressure on cities. Over the recent years, the growing harsh impact of climate change are adding to the pressure being faced by cities. Cities are the backbone of the economy of a country and in SIDS, investment is directly related to the investment in the economy of the country. Trends indicate that cities are expected to grow significantly over time (McCartney, 2022; Miller, 2012). This growing trend requires that due consideration be given for the cities to accommodate not only the growing population but all the infrastructure that comes with the services that a city provides to its inhabitants. In addition, it cannot be overlooked that impacts of climate related disasters result among others in major losses in infrastructure. The design of cities need to be reviewed if we are to allow for both development and to learn how to live with climate related disasters. Hence, the global emphasis nowadays is, on building climate resilient infrastructure.

Worldwide local government are being encouraged to participate in international climate resilience city initiative to develop climate resilient cities. Flood, heat waves, cyclones, typhons, flood type rainfall events and droughts, are climate related disasters which are expected to grow with time, and with that the negative impacts they can have on cities. The situation is expected to be of concern, to the extent that first responders will be overwhelmed. Much emphasis is on building climate resilient cities, for the citizens and with the citizens. The CRIC is an example of a unique corporation between city officials, non-governmental organisations and academia[1]. The AMS is another such initiative[2], where the focus in on cities being empowered and taking ownership to become climate resilient. Innovation will be a strong component in the development of climate resilience at city level, as was highlighted by Pichola et al, 2021[3]. Venema, 2017, had emphasised on the fact that In coming decades, building resilience will be essential urban policy

The world bank is also playing its part in encouraging local government to reinvent themselves and become more resilient to climate related disasters[1]. The City Resilience Program (CRP) is a partnership between the World Bank and the (Global Facility for Disaster Reduction and Recovery) GFDRR. Launched in June 2017 as a multi-donor initiative aimed at increasing financing for urban resilience, the Program is supported by the Swiss State Secretariat for Economic Affairs (SECO) and the Austrian Federal Ministry of Finance. This program has for objective to guide the local government into minimizing disaster risk reduction at residential level or at the level of an organisation.

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[1] CDRI, 2022. 'Climate Resilient and Inclusive Cities Programme'. Available at: [https://www.resilient-cities.com/en/]

[2] AMS, 2022. 'Climate Resilient Cities'. Available at: [https://www.ams-institute.org/urban-challenges/resilient-cities/]

[3] Pichola, I., Kelkar, M. & Bratek, M., 2021. 'Building climate-resilient cities; Exploring the five lenses of climate action', Available at: [https://www2.deloitte.com/us/en/insights/industry/public-sector/climate-resilient-cities.html] Venema, H., 2017. 'Eight Ways Cities Are Building Climate Resilience', Available at: [https://www.iisd.org/articles/building-a-climate-resilient-city]

[4] City resilient program' Available at:[https://www.worldbank.org/en/topic/disasterriskmanagement/brief/city-resilience-program]

A recent study carried out by Wong et al., 2022, carried out at a number of mega cities, to identify the factors that allow a cities to become resilient in the face of a disruption, noted that the main driving force is the ability of a city to bounce back to normal. Hence, this study, places much emphasis on building resilient infrastructure for cities. This very point was also raised by McCartney (2022), with the advocacy of the need to build 'Charter' cities.

Mortaheb & Janvowski (2022) went further and proposed cities revolving around the comfort and safety of human beings, 'human centered' supported by GeoAI, i.e, geospatial technology and artificial intelligence. Hence, the development of cities is undergoing major changes with development in technology, information systems and the need for new developmental models. The more complex the system goes, the more important is to factor in the impact of climate change on such multilayered and multicomplex systems. Any failure of such systems, will likely have major negative impacts in the future. Lately, much has been said about the need for climate resilient cities. The GPDRR has developed dense networks to support countries in creating awareness and in guiding local government to think in terms of climate resilient cities.

The Amsterdam Institute for Advanced Metropolitan Solutions (AMS), noted that heavier rainfall and storms, higher temperatures, rising sea levels, drought and other climate change consequences all present challenges to the quality of city life. Moreover, due to increasing urbanisation the number of people having to deal with these consequences is also growing. As a result, cities across the globe need to prepare for the impact of climate change on urban life. The country, Amsterdam is aware of this, and is committed to becoming as climate-proof as possible by 2050. AMS is helping cities to develop resilience to climate, by focusing on four main areas; Weather and Meteorology; Water and Hydrology; Scenario Planning and Urban Planning and Societal Factors. All these areas when considered together, define the way climate related disasters can affect the social welfare of communities.

A similar approach is being adopted by the Natural Resources Defense Council (NDRC), a group of volunteers, noted that many communities are ill-prepared for the impacts of climate change on their water, air, and health. The NDRC has as mission to advise officials on plans to protect residents against extreme heat, floods, and other climate-related hazards.

A more common and open source methodology was prepared by the UNDRR, the Disaster Resilience Scorecard for Cities. This is a 2 phased methodology and acts as a guide to inform authorities about the status of the cities and the way forward to build climate resilience within the city. For the propose of this study, the UNDRR Score Card was applied and discussed.

3.0 Methodology

The UNDRR Disaster Resilience Score Card for Cities has been developed to guide the local government towards building climate resilient cities. The score card methodology is holistic, taking into consideration, existing policies, regulations, strategic plans, action plans, physical measures, existing development and the planned development. The methodology is structured around the Sendai Framework for Disaster Risk Reduction: 2015-2030, and the UNISDR's Ten Essentials for Making Cities Resilient. Each of the ten essentials represent one of the main pillars that contribute to making a city climate resilient.

The UNDRR Disaster Resiliene Score Card for Cities works at 2 levels; The Preliminary Level and the Detailed Assessment level. The Preliminary level (Level 1) is an evaluation of the prevailing conditions as defined by the Sendai Framework targets and Indicators. It is best conducted through multistakeholders' participation. There are 47 questions indicators each rated from 0 to 3. The Level 2, the detailed assessment

level, is also a multi-stakeholders' participation exercise and here stakeholders' are expected to implement measures, monitor them and report back to the different stakeholders. This approach allows for the construction of knowledge. At this stage, the 117 indicator criteria rated from 0 to 5 are used for a more in depth analysis of the situation.

The analysis in this study was conducted first as a desk study, then as a focus group discussion and then as case studies at different local government. The desk study was based on published information and work through surveys. The focus group discussions with representatives from both Municipal Councils and District Councils took into consideration the experiences from the various instances on common matters. The case studies were more a reflection of what prevails in specific areas. The results were then compared to capture the strengths and gaps, prevailing situation at national level.

4.0 Results

4.1 Essential 1 – Organise For Resilience

In this first analysis, Essential 1, the objective is to identify policies and strategies around the concept of disaster risk reduction. In this section, there are 3 main issues that are addressed; is the local government concerned fully aware of the need to reduce risk to climate related disaster, where has this objective, if any, been translated in a strategic document or an action plan and is building climate resilience a concept reflected in the budget allocation. Thus, by having a vision to develop a climate resilient city, followed by an action plan and dedicated funds to gradually build, a local government can get started with building a climate resilient city

Through information discussions and focus group discussion, it was noted that a DRR Strategic Action Plan had been prepared at country level in collaboration with the NDRRMC but not specifically at Local Government Level. The discussions highlighted that there is a need to develop capacity and facilities related to disaster risk reduction at individual institution level and not rely solely on a national organisation. It could also be noted that disaster risk reduction so far focused at lot on mitigating impacts of flood, specially drain maintenance, and not enough on river management, as fluvial flooding is also an element of concern. Elements such as promoting use of solar energy within the area could also be addressed. The result for Essential 1 is as shown in Figure 1;

Essential 01: Organize for Resilience

P1.1	Does the City master plan (or relevant strategy/plan) adopt the Sendai Framework?	1
P1.2	Is there a multi-agency/sectoral mechanism with appropriate authority and resources to address disaster risk reduction?	1
P1.3	Is resilience properly integrated with other key city functions / portfolios?	3

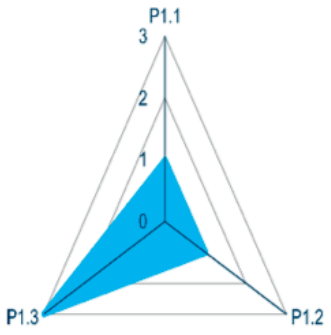


Figure 1: Results for Essential 1

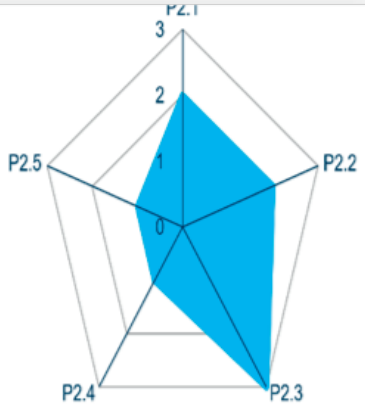
As shown, Figure 1, visually illustrates the strength of the organisation as far as the concept of organising for resilience is concerned.

4.2 Essential 2 – Identify, Understand And Use Current And Future Risk Scenarios

Essential 2 is about knowledge of different types of hazards that can affect the city concerned, and stakeholders' involvement in managing these risks. The aim is this essential is to highlight whether those involved in decision making about managing climate risk have the right documents and the right support to work toward reducing the impacts of these hazards.

The results of this particular analysis showed that in general information about climate related hazards are well documented and the local government is made aware of the relative vulnerability of specific zones to these hazards. The gaps lie in the future risk scenarios and the availability of supporting interactive maps which are important working tools for the authorities. Understanding the way climate hazards will affect an area is important, but at the same time necessary working tools are important for decision makers to avoid development in high risk areas and be able to sustain their decisions.

P2.1	Does the city have knowledge of the key hazards that the city faces, and their likelihood of occurrence?	2
P2.2	Is there a shared understanding of risks between the city and various utility providers and other regional and national agencies that have a role in managing infrastructure such as power, water, roads and trains, of the points of stress on the system and city scale risks?	2
P2.3	Are their agreed scenarios setting out city-wide exposure and vulnerability from each hazard, or groups of hazards (see above)?	3
P2.4	Is there a collective understanding of potentially cascading failures between different city and infrastructure systems, under different scenarios?	1
P2.5	Do clear hazard maps and data on risk exist? Are these regularly updated?	1

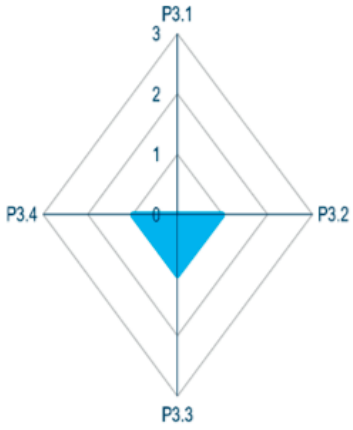


4.3 Essential 3 - Strengthen Financial Capacity For Resilience

Discussions around Essential 3, noted that so far technical people are not fully aware of the funds dedicated to consolidating risk reduction. While funds are kept for emergency situations, under Contingency funds, it would seem that there are no dedicated funds for DRR policies and practices, something considered a matter of concern. Similarly, it would seem that financial incentives such as insurance cover to support DRR initiatives are not well anchored in our culture.

Essential 03: Strengthen Financial Capacity for Resilience

P3.1	The city / lead agencies understand all sources of funding, and the "resilience dividends", are well connected, understand all available routes to attract external funding and are actively pursuing funds for major resilience investments.	0
P3.2	Does the city have in place a specific 'ring fenced' (protected) budget, the necessary resources and contingency fund arrangements for local disaster risk reduction (mitigation, prevention, response and recovery)?	1
P3.3	What level of insurance cover exists in the city, across all sectors – business and community?	1
P3.4	What incentives exist for different sectors and segments of business and society to support resilience building?	1



4.4 Essential 4 – Pursue Resilient Urban Development

Detailed outline schemes guide development to minimize disturbance and to ensure safety. However, when it comes to hazards to go beyond boundary, it was noted that there are need for more information specially when sites fall within two zones. Here lack of adequate support documents make it difficult to take decisions.

Essential 04: Pursue Resilient Urban Development

P4.1	Is the city appropriately zoned considering, for example, the impact from key risk scenarios on economic activity, agricultural production, and population centres?	2
P4.2	Are approaches promoted through the design and development of new urban development to promote resilience?	1
P4.3	Do building codes or standards exist, and do they address specific known hazards and risks for the city? Are these standards regularly updated?	0
P4.4	Are zoning rules, building codes and standards widely applied, properly enforced and verified?	2

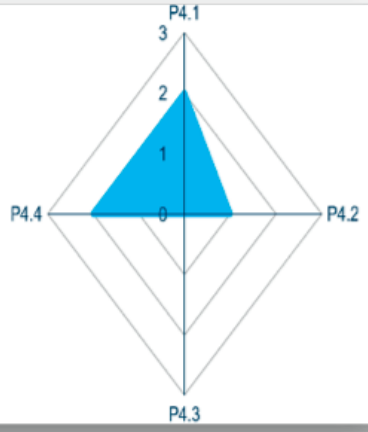


Figure 4: Esssential 4 – Pursue Resilient Urban Development

4.5 Essential 5 - Safeguard Natural Buffers To Enhance The Protective Functions Offered By Natural Ecosystems

Essential 5 is about building in harmony with nature, with focus on nature based solutions. Here discussions noted that locally there is much emphasis on provision of green space in developmental project. However nature based solutions is not yet a concept which is fully appreciated and implemented. The appreciation of natural capita and how they go beyond boundaries is not being given due consideration in development plans.

Essential 05: Safeguard Natural Buffers to Enhance the Protective Functions Offered by Natural Ecosystems

P5.1	Beyond just an awareness of the natural assets, does the city understand the functions (or services) that this natural capital provides for the city?	1
P5.2	Is green and blue infrastructure being promoted on major urban development and infrastructure projects through policy?	1
P5.3	Is the city aware of ecosystem services being provided to the city from natural capital beyond its administrative borders? Are agreements in place with neighbouring administrations to support the protection and management of these assets?	1

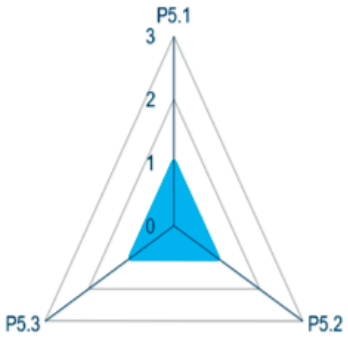


Figure 5 – Essential 5 – Nature based solutions, natural ecosytems

4.6 Essential 6: Strengthen Institutional Capacity For Resilience

With regards to the potential of strengthening institutional capacity for resilience, the discussions revealed that much is happening at country level as far as training and capacity building is concerned, but the information is not well disseminated. Collaboration among Municipal and District councils is weak, making learning from each other and from past experience something not being practice locally. Training in the field of climate resilience is not considered as a priority or a need.

Essential 06: Strengthen Institutional Capacity for Resilience

P6.1	Does the city have clear access to all the skills and experience it believes it would need to respond to reduce risks and respond to identified disaster scenarios?	1
P6.2	Does a co-ordinated public relations and education campaign exist, with structured messaging and channels to ensure hazard, risk and disaster information (that can be understood and used) are properly disseminated to the public?	1
P6.3	Extent to which data on the city's resilience context is shared with other organizations involved with the city's resilience.	0
P6.4	Are there training courses covering risk and resilience issues offered to all sectors of the city including government, business, NGOs and community?	1
P6.5	Are training materials available in the majority of languages in common use in the city?	1
P6.6	Is the city proactively seeking to exchange knowledge and learn from other cities facing similar challenges?	0

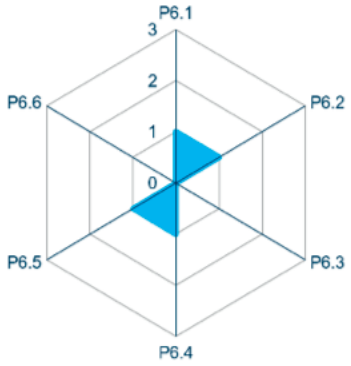


Figure 6 – Essential 6: Strengthening Capacity for Resilience

4.7: Essential 7: Understand And Strengthen Societal Capacity For Resilience

This essential has shed some light on the public engagement. The District and Municipal councils do have a system in place through which the general public is engaged in the process of disaster risk reduction. Talks and meetings are regularly conducted, as well drills are conducted with the general public. Business owners take the safety of their clients seriously and are well conversant with building resilience in their businesses. However, citizen engagement in the process remains more a top down approach.

Essential 07: Understand and Strengthen Societal Capacity for Resilience

P7.1	Are "grassroots" or community organizations participating in risk reduction and post-event response for each neighbourhood in the city?	1
P7.2	Are there regular training programmes provided to the most vulnerable populations in the city?	2
P7.3	What proportion of businesses have a documented business continuity plan that has been reviewed within the last 18 months?	2
P7.4	How effective is the city at citizen engagement and communications in relation to DRR?	1

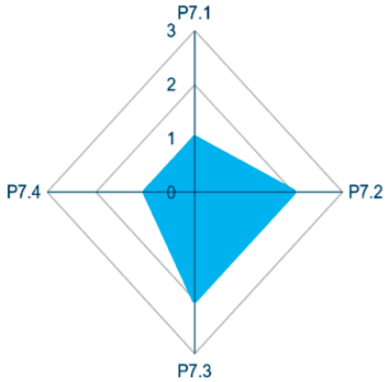


Figure 7: Essential 7: Understand and Strengthen Societal Capacity for Resilience

4.8: Essential 8: Increase Infrastructure Resilience

Restoration of critical infrastructure after a disaster is always given due consideration to restore the situation back to normal within the next day, but this is done by concerned authorities, such as utilities authorities, rather than by the Local Government. During disasters, shelters are opened to welcome those who need support. Utilities are given due recognition for life to go back to normal. Clearing of debris from roads is given due priority to restore activities to normal. Where utilities are buried, climate related disasters have minimum impacts on them, but for security reasons primary and secondary schools are closed until their security has been evaluated. One important point that stood out, is that presently the general public and other authorities rely a lot on first responders, but in the future first responders may not be able to cope with the growing hazards, so the concerned authorities and the general public will need to be more engaged in the process of disaster risk reduction.

Essential 08: Increase Infrastructure Resilience

P8.1	Is critical infrastructure resilience a city priority, does the city own and implement a critical infrastructure plan or strategy?	2
P8.2	Is existing protective infrastructure well-designed and well-built based on risk information?	1
P8.3	Would a significant loss of service for these two essential services be expected for a significant proportion of the city under the agreed disaster scenarios?	2
P8.4	Would a significant loss of service be expected for a significant proportion of the city in the 'worst case' scenario event? In the event of failure would energy infrastructure corridors remain safe (i.e. free from risk of leaks, electrocution hazards etc.)?	2
P8.5	Would a significant loss of service be expected for a significant proportion of the city in the 'worst case' scenario event? In the event of failure would transport infrastructure corridors remain safe (i.e. free from risk of flood, shocks etc) and passable?	1
P8.6	Would a significant loss of service be expected for a significant proportion of the city in the 'worst case' scenario event?	2
P8.7	Would there be sufficient acute healthcare capabilities to deal with expected major injuries in 'worst case' scenario?	2
P8.8	% of education structures at risk of damage from "most probable" and "most severe" scenarios	1
P8.9	Will there be sufficient first responder equipment, with military or civilian back up as required?	2

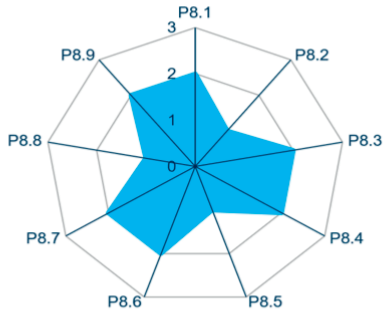


Figure 8 – Increase Infrastructure Resilience

4.9 Essential 9: Ensure Effective Disaster Response

A strong system exists that allows for a an effective response to disaster at the level of the community, but this is managed at national level, by the NDRRMC, and the Council has its own responsibility in this process. The structure of the system is very effective and allows for effective communication, hence this is a very strong point locally.

Essential 09: Ensure Effective Disaster Response

P9.1	Does the city have a plan or standard operating procedure to act on early warnings and forecasts? What proportion of the population is reachable by early warning system?	3
P9.2	Is there a disaster management / preparedness / emergency response plan outlining city mitigation, preparedness and response to local emergencies?	1
P9.3	Does the responsible disaster management authority have sufficient staffing capacity to support first responder duties in surge event scenario?	2
P9.4	Are equipment and supply needs, as well as the availability of equipment, clearly defined?	1
P9.5	Would the city be able to continue to feed and shelter its population post-event?	2
P9.6	Is there an emergency operations centre, with participation from all agencies, automating standard operating procedures specifically designed to deal with "most probable" and "most severe" scenarios?	3
P9.7	Do practices and drills involve both the public and professionals?	2

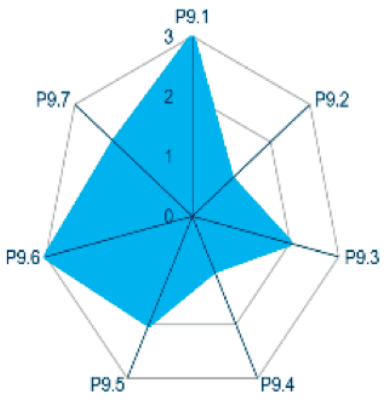
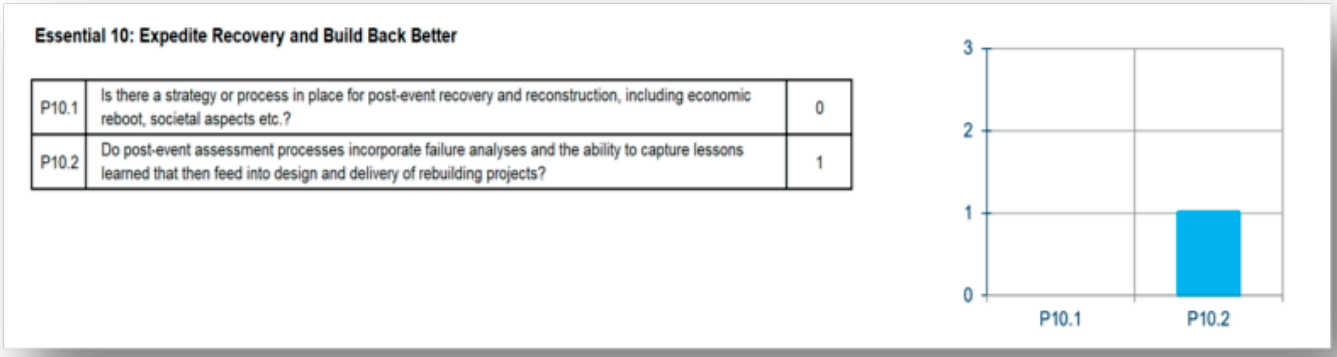


Figure 9: Ensure effective disaster response

4.10 Essential 10: Build Back Better

The concept of learning from our experience and building back better is regretfully not practiced locally. The valuable information remains with only those involved in the process and is not shared to a wider audience as indicated by Figure 10.



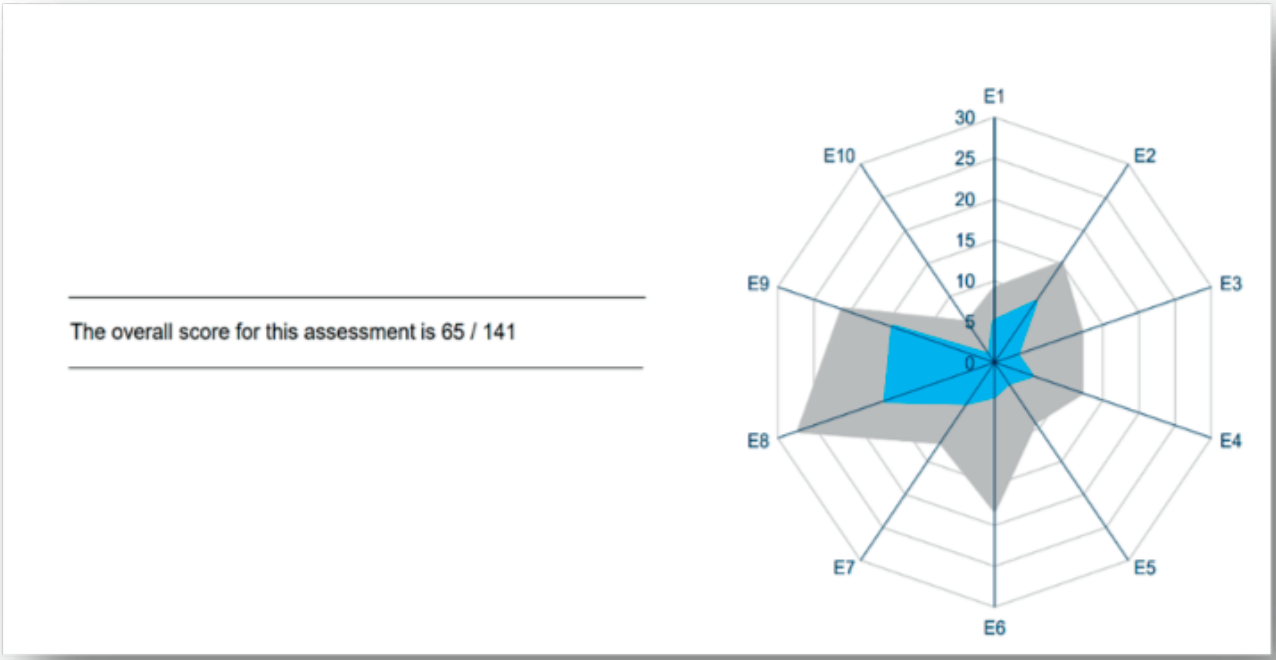
Essential 10: Expedite Recovery and Build Back Better

P10.1	Is there a strategy or process in place for post-event recovery and reconstruction, including economic reboot, societal aspects etc.?	0
P10.2	Do post-event assessment processes incorporate failure analyses and the ability to capture lessons learned that then feed into design and delivery of rebuilding projects?	1

Figure 10: Expediate recovery and build back better

5.0 Discussion & Conclusion

The application of the Phase I UNDRR score card highlighted the strengths and weaknesses of the prevailing system with regards to building climate resilience cities in Mauritius (Figure 11).



The overall score for this assessment is 65 / 141

Figure 11: Overall Results of the 10 Essentials (E1 to E10)

Figure 11 is a spider/radar diagram which gives an overall indication of the level of climate resilience of our cities in Mauritius. It can be observed that the level of climate resilience is still low, with a score of 65 out of 141. This situation is as expected for there is much dependency on top down approach.

At national level the NDRRMC has set up an elaborated structure which ensure communications and effectiveness of managing a disaster. This structure ensures communication with the community with respective officers at the level of local government. This structure also ensures community engagement in the process of disaster risk reduction through talks and drills.

The results of the analysis highlighted one very important component behind the successful development of climate resilient infrastructure, i.e, the need for a local government institution to adopt the concept of climate resilient city. The local government needs to be empowered with the right training programme, the right technical working documents and the right coordination with multistakeholders for them to work towards developing a climate resilient city for the safety and comfort of their inhabitants. Unless this initiative comes from the either the Municipal and District Council, the cities which are at the heart of the socio-economic development of a country, will be subject to major disturbance in the future. This situation needs to be planned now, if we are to adapt to the changing climate situation.

The UNDRR Score card method, Phase I and Phase II, are a very good starting point for the Local Government. Other initiatives such as CityRap, a UN-Habitat process, takes the process further and allow a local government to fully engage in the process of the developing a climate resilient city. This process involves many stakeholders and such a process has to driven in collaboration with key stakeholders such as experts in the field of disaster risk reduction and experts in the field of numerical modelling for simulation of future scenarios associated with prediction of climate impacts.

Building climate resilient cities is the best holistic approach to adapting to climate change, specially in densely populated area, where urbanization rate is increasing fast. The impacts of climate change are expected to worsen over time and SIDS and building climate resilient cities is a continuous improvement process which is driver by the locals. The earlier we start, the better.

6.0 Acknowledgements

The author wishes to acknowledge the contributions of Town and Country Planning undergraduate students during the discussions.

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THE CHALLENGE OF CLIMATE CHANGE WITH A NEW APPROACH OF PRODUCING CLEAN ENERGY THROUGH AGROVOLTAIC SYSTEMS.

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Abstract

In 2019, according to McKinsey's Global Energy Perspective 2019, fossil fuels were responsible for 83% of total CO2 emissions, and electricity generation alone from coal-fired power plants contributed 36%, although in 2020 - due to of the Covid-19 pandemic - emissions have dropped dramatically (source: World Energy Outlook 2020).

Island states have a greater dependence on oil, many SIDS depend on expensive fossil fuel imports for their energy supply, even agri-food systems as stated by Santos N. et.al. (2022), in the study conducted by FAO, generate some of the largest contributions to global greenhouse gas (GHG) emissions, mitigation and adaptation to climate change are two further pillars of food security and nutrition; but something is changing, today there are many technologies to overcome climate change, a substantial cultural change is needed, the way to go is clear, agri-food systems need to be redesigned to adapt to climate change, the solution is a gradual transition from the use of fuels one carbon neutral fossil based on renewable energy sources.

An important contribution is already the use of "Agrovoltaic" APV technology, where the land where the photovoltaic panels are positioned for the production of clean electricity, gives space for agricultural crops, which benefit the production and agricultural profitability and the production of renewable energy.

***Keywords**: agrovoltaic (APV), climate change, food, innovation, renewable energy.*

Acronyms and Abbreviations

APV	Agrovoltaic
CNR	National Research Council (Italy)
FAO	Food and Agriculture Organization of the United Nations
GHG	Greenhouses Gases
GSE	Energy Services Manager (Gestore di Servizi Energetici)
LR	Lazio Region
PAUR	Single Regional Authorization Provision
PNRR	Next Generation EU (Piano Nazionale di Ripresa e Resilienza)
SDG	Sustainability Development Goals
SIDS	Small Island Development State
UN	United Nations
UNESCO	United Nations Educations, Scientific and Cultural Organization
WFEO	World Federation Engineering Organization

1.Introduction

There is a worldwide growth in the use of renewable energy, focusing on global energy needs, as governments are gearing up to replace fossil fuels by encouraging energy policies for the use of renewable sources, such as reports. Pulkit J et.al. (2022), large areas of land have been a major obstacle to this global goal. Bearing in mind the concern of the growing population and the threats to food security, it is argued that Agrovoltaic (APV), which is a synergistic combination of photovoltaics and crop cultivation.

Applied research in the agricultural field is increasingly oriented towards experimenting with innovative and as sustainable solutions as possible, both for nature and for communities. APV's one of the most promising applications to accelerate the development of renewable energy. In fact, it exploits agricultural land to produce solar energy, but without competing with food production and without consuming land. The APV represents an integrated solar and agricultural energy production system that allows you to maximize the production of electricity from solar sources. At the same times it increases the agricultural yield through the shading generated by the photovoltaic modules. In this way, the thermal stress on the crops is also reduced. It is therefore a system focused on the qualitative yield of the products of the earth.

In 2020, in Italy, photovoltaic self-consumption amounted to 4,735 GWh, a value equal to 19.0% of the total production of photovoltaic systems and 46.0% of the production of self-consuming systems alone. In absolute terms, the highest level of self-consumption is recorded in July; in percentage terms, the highest self-consumption rates are instead recorded in the winter months.

Table 1 - Regional distribution of photovoltaic systems attributable to the agricultural sector in 2020, with indication of self-consumption and the relative% of production, calculated both considering the production of all systems and the production of self-consumption systems only
Referenze: GSE

Power (kW)	*N° Plant*	*Installed Power (MW)*	*Gross Power (GWh)*	*Self consumption (GWh)*
Until to 3 kW	1.180	3	4	2
Between3 kW to 20 kW	19.676	264	289	108
Between 20 kW to 200 kW	6.834	505	526	213
Between 200 kW e 1MW	367	191	200	84
Between 1 MW e 5 MW	17	41	47	17
Total	**28.074**	**1.004**	**1.065**	**423**

With regard to the electricity consumption of farms, they appear to be limited, globally equal to approximately 2.4 TWh corresponding to 0.186 MWh / ha6. By making a breakdown of electricity consumption in relation to the number and extension of farms, an average annual consumption of 16.6 MWh is found for the cluster of larger companies (over 50 ha).

Table 2 - Distribution of photovoltaic systems in self-consumption attributable to the agricultural sector by power class - year 2020 (GSE estimate)

Agricultural Area Class	N. of Agricultural Holding	Utilized Agricultural (hectares)	Average electricity consumption per company (MWh)	Electricity consumption (MWh) per company range by surface class	Total Electricity consumption (MWh)	Electricity consumption by surface class %	Number of farms by surface class %
Until to 5 hectares	717.287	1.458.501	0,4	less to 0,93	271.281	12	60
to 5 until 10 hectares	187.184	1.269.806	1,3	to 0,93 until1,86	236.184	10	16
to 10 until 20 hectares	136.187	1.666.079	2,3	to 1,86 until 3,72	309.891	13	11
to20 until 50 hectares	104.138	2.773.974	5,0	to 3,72 until 9,3	515.959	22	9
Over to 50 hectares	60.338	5.375.304	16,6	higher to 9,3	999.807	43	5
Total	1.205.134	12.543.664	1,9		2.333.122	100	100

Table 3 - Regional distribution of photovoltaic systems attributable to the agricultural sector in 2020, with indication of self-consumption and the relative% of production, calculated both considering the production of all systems and the production of only self-consumption systems

	All Plant					Only plants in self-consumption				
Region	N° Plant	Installed Power (MW)	Gross Power (GWh)	Self onsumptio (GWh)	self-consumption on production %	N° Plant	Installed Power (MW)	G. Power (GWh)	self onsumptio (GWh)	self-consumption on production %
Abruzzo	680	42	53	7	13%	470	19	22	7	32%
Basilicata	553	50	67	4	6%	364	10	11	4	36%
Calabria	1.012	62	79	10	13%	708	21	24	10	42%
Campania	1.370	53	57	14	25%	1.208	30	34	14	41%
Emilia Romagna	4.986	360	421	51	12%	2.986	113	117	51	44%
Friuli Venezia Giulia	1.452	62	64	16	25%	1.184	40	41	16	39%
Lazio	1.282	82	95	16	17%	1.081	37	39	16	41%
Liguria	326	18	20	2	10%	256	6	6	2	33%
Lombardia	4.115	352	354	57	16%	2.910	146	138	57	41%
Marche	1.448	142	180	9	5%	856	27	30	9	30%
Molise	249	12	14	3	21%	201	6	7	3	43%
Piemonte	4.082	239	261	40	15%	3.024	101	102	40	39%
Puglia	1.832	112	139	24	17%	1.449	51	59	24	41%
Sardegna	1.193	164	209	21	10%	1.054	49	58	21	36%
Sicilia	2.185	158	208	27	13%	1.742	57	71	27	38%
Toscana	2.733	125	150	21	14%	2.312	48	52	21	40%
P.A* Bolzano	2.077	75	83	20	24%	1.223	46	51	20	39%

P.A* Trento	533	23	24	10	42%	443	17	18	10	56%
Umbria	1.172	65	73	9	12%	927	28	30	9	30%
Valle D'Aosta	179	3	4	1	25%	159	2	3	1	33%
Veneto	4.656	297	318	62	19%	3.517	151	153	62	41%
Italia	**38.115**	**2.497**	**2.870**	**423**	**15%**	**28.074**	**1.004**	**1.065**	**423**	**40%**

** Autonomous Province with special status*

A significant value of these self-consumption data on all regions of Italy is that the self-consumption of farms is tested on average at 40%, this would mean that we are beginning to think in terms of self-consumption and not just energy production. electricity or cultivation, the Italian state is introducing a series of initiatives such as the PNRR (Next Generation EU) to intensify not only the production of electricity from renewable sources but also APV as the winning combination of agriculture 4.0, climate change, quality of food and renewable energy.

2.Objective of Study

In this introduction to the topic, the contribution analyses the following:

- The broad definition of the APV system
- The advantages of installing an APV system from the point of view of the production of clean energy for the agricultural sector
- The impact of this new system in the 2030 Agenda, the links between SdG and technical skills.
- Some Italian Best Practices for the installation of the "Agrovolatic" system.
- Advantages of installing Agrovoltaic in SIDS.

3.Research Methodology

In the process of energy transition, a leading role are industrial-scale photovoltaic systems and large areas on the ground that can host a significant share of the new installations necessary to achieve the decarbonisation goals by 2030.

The development of APV would allow the recovery of uncultivated areas and would facilitate the innovation of agricultural processes on the land in use. It would also contribute to the need to reverse the current trend, which sees the loss of more than 100,000 hectares of agricultural land per year due to increasing desertification.

Through targeted literature searches and other studies, we aim to bring out how crucial the development of APV has become in terms of clean energy, climate change and agriculture, focusing on the diverse technical skills of many sectors, creating new jobs that I can help not. only the environment also the quality of life in terms of food.

4.Analysis

The objectives of the paper have been analysed in this section as below

4.1 The broad definition of the APV system

In the literature there are several definitions regarding the "agrovoltaic" system (APV), we made a trade union between the technical definition presented by the Italian government on the guidelines on agricultural plants and the REM Tec.

The APV that adopts solutions aimed at preserving the continuity of agricultural and pastoral cultivation activities on the installation site through a mono or biaxial solar tracking system, which maximizes the production of electricity from solar source while keeping the land available for agriculture and other purposes, with APV, the land occupied by photovoltaic installations ceases to be an item of cost, purchase and maintenance. It is a model in which electricity production and soil maintenance are integrated and concurrent to the achievement of the production, economic and environmental objectives of the land. In addition, the installation of APV is flexible enough to allow adaptability to the production needs of the company according to its profile.

Fig-1 APV Example
Reference: 1.architetturaecosostenibile.it, 2.edilizia balia

4.2 The advantages of installing an APV system from the point of view of the production of clean energy for the agricultural sector

From the point of view of opportunity, the development of Agrovoltaic would allow the recovery of uncultivated land and would facilitate innovation in agricultural processes on the land in use, also increases the need to reverse the current trend, which sees the loss of many hectares of agricultural area per year due to increasing desertification, an advantage in the creation of new agro-energy companies by developing photovoltaic systems in harmony in the agricultural context, this would allow the development of agriculture 4.0 making agricultural processes more eco-sustainable and more competitive with a reduction of evaporation of soils and recovery of rainwater, protecting crops from extreme climatic events by offering shade and protection from bad weather.

From an economic managerial point of view, it would allow the creation of an agro-energy community to distribute economic benefits to citizens and agro-energy companies in the area and, last but not least, the creation of new jobs, combining the production of renewable energy with agriculture and pastoralism with a recovery of part of abandoned agricultural land allowing the achievement of the objectives of the 2030 Agenda.

The key point is the search for a balance between the profitability of the photovoltaic installation and agricultural production.

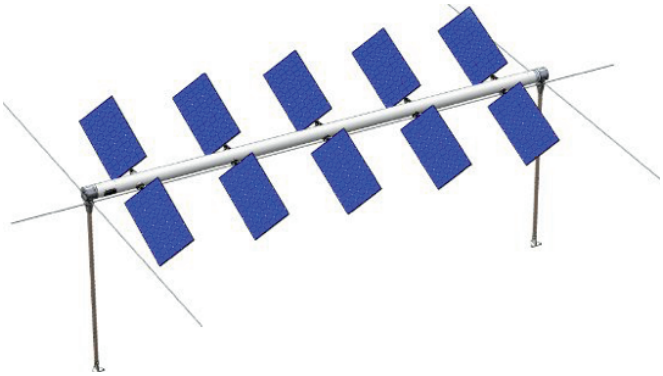
4.3 The impact of this new system in the 2030 Agenda, the links between SdG and technical skills.

The design of an APV requires transversal skills that from engineering reach agronomy, passing through specific skills such as geology, archaeology, even managerial and legal skills, it is a complex system of

stakeholders, especially if the discipline is regulated by the point from a legislative point of view as happens in Italy, that for some types of Plants the competences are attributed to the Italian Regions as public bodies, through the issuance of an authorization process called PAUR (Single Regional Authorization Provision), which has the task of simplifying express a binding opinion in relation to the opinions expressed by the Regional Competence Areas divided by Thematic Areas such as: Agriculture, Urban Planning and Landscaping, Hydrogeological, Mobility, Constraints on Owned Land, Environment, and others, through Specialized Agencies, and others Constraints such as those related to the historical, archaeological and artists heritage co, the competent Ministries by Thematic Area are also informed, the Municipal Bodies where the Plants are positioned are also involved, the procedure concludes with the provincial bodies where the Plants are located that have the duty to control the execution of the works relating to the Plants, is a very complex system but it guarantees that the authorized plants are not in contrast with the environment, but rather a resource for the territory.

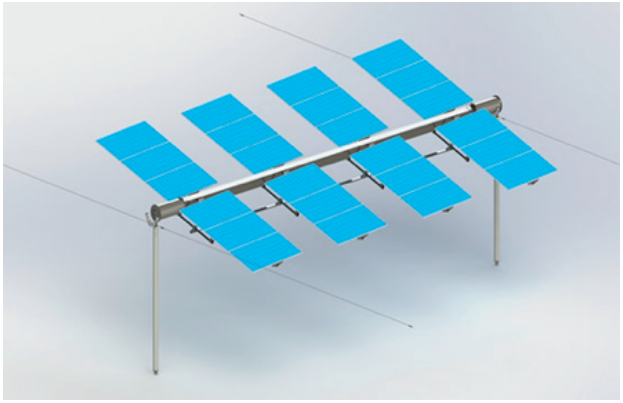
The design of an APV takes into consideration the following technical parameters: type of structure, height and characteristics; distance between modules; percentage of expected shading; tilt modules, fixed or variable system; type of modules. Secondly, it is necessary to study the degree of shading in the various months of the year.

Regarding the type of structure, the fixed, tracking or vertical installations are applied in the cultivation of fields, viticulture, arboriculture, livestock, beekeeping, horticulture, grazing, gardening while the photovoltaic on greenhouses is intended for arboriculture, horticulture and gardening. Finally, photovoltaic on buildings is ideal for breeding, fish farming and machinery shelter. On the technological front, solutions are being developed for the new frontiers of photovoltaics in agriculture, with double-sided modules, vertical structures for mounting panels and single-axis trackers.



power: to 2.5 until 4.35 kwp for every tracker
10 panels installed for tracker
tracker length 12 m
ground height 4-5 m

Fig. 2: REM Tec Technology TRACKER 1.0



power: until 16,8 kwp for every tracker
78 cells installed in each tracker (single or bi-facial)
tracker length 14 m
ground height 4-5 m

Fig. 3: REM Tec Tecnology TRACKER 2.1

4.4 Some Italian Best Practices for the installation of the "Agrovolatic" system.

One of the most important objectives in Italy in recent years is to spread APV plants to have sustainable agriculture and energy production from renewable sources, the goal is to reduce the energy supply costs of the sector which today exceed the 20 percent of business costs and improve climate and environmental performance, with a potential decrease of 0.8 million tonnes of CO2, the agricultural sector is responsible for 10 percent of greenhouse gas emissions in Europe. The investment aims to improve the climatic-environmental performance and, at the same time, to make agriculture more competitive, reducing the costs of energy supply (today estimated at over 20 per cent of the variable costs of companies, with peaks even higher for some herbivorous and granivorous sectors) through the spread of medium and large-sized APV plants.

The measures envisaged concern, first of all, the implementation of hybrid agriculture-energy production systems that do not compromise the use of land dedicated to agriculture, but contribute to the environmental and economic sustainability of the companies involved, potentially also enhancing the water basins through solutions floats. An accurate monitoring of the achievements and their effectiveness, with the collection of data both on photovoltaic systems and on production and underlying agricultural activity, will allow to evaluate the microclimate, water saving, recovery of soil fertility, resilience to climate change and agricultural productivity for the different types of crops, reaching, when fully operational, a production capacity from agro-voltaic plants of 1.04 GW, would produce about 1,300 GWh per year, with a reduction in greenhouse gas emissions estimated at about 0, 8 million tons of CO2., These are some of the proposals within the Mission 2 "Ecological Transition and Green Revolution" of the European Next Generation EU Program.

More than 10 years ago, the first agro-planning plant in the world was inaugurated in Italy, with a registered technology, it is now fully functional in the province of Mantua in Virgilio, in the Lombardia Region. The plant is capable of integrating agricultural activity with the production of clean energy, made with mobile structures, suspended and maintained at about 5 meters in height by a tensile structure designed to allow the free passage of agricultural machinery and the cultivation of the soil below.

Company	**Rem Tec**
Location	Virgilio, Mantova (Italy)
Installed Power	2, 15 MWp
Type of panel	280 Wp Poly
N. of panels installed	7680
Plant Area Surface	15,080 ha
Expected Production	3,32 GWh/year
Total area of Panel	11,40 ha

Fig. 4: APV Mantova (Italy)

There are APV plants in the large islands of Italy, in this case in Sardinia, in the Province of Sassari, the land occupied by the plant is classified E which means agricultural, according to the classifications established by Italian law. Photovoltaic greenhouses were installed where cardoncelli and pleorotus mushrooms, berries, ginger, various vegetables are cultivated.

Company	**Algowatt**
Location	Cheremule,Sassari Sardinia Island (Italy)
Installed Power	2,80 MWp
Type of panel	Shanghai Solar Energy
N. of panels installed	15102
Plant Area Surface	12,70 ha
Expected Production	3,6 GWh/year
Total area of Panel	19,64 ha

Fig. 5: APV Sardinia Island (Italy)

4.5 Advantages of installing Agrovoltaic in SIDS

The climate transition that we need to stop the growth of the planet's temperature can link together the objectives of a 100% clean energy model, because it focuses on renewable sources, with that of a virtuous management of the water cycle and renewable material. The smaller islands are isolated systems that can become the ideal laboratory to face the most urgent and important environmental challenges that the world must face, where to apply innovative models in the field of energy.

The Italian, Mediterranean and in general contexts are also extremely fragile contexts subject to strong anthropogenic pressures for which the research and experimentation of innovative solutions becomes even more important and urgent to reduce damage to biodiversity.

The more we go down to the situation of the islands, the better we understand how we can completely change the scenario by focusing on the contribution of only wind and other renewables - to be enhanced according to the competitions through an innovative management of storage networks and efficient technologies that deepen the storage of the islands of also respond to the demand for mobility, moreover agriculture, a sector in which future challenges are more than ever intertwined in the attention to water and waste management, offers us an incredible opportunity.

A virtuous example is the island of Reunion in the Indian Ocean, 30% of electricity needs come from renewable sources, an ambitious goal is to become an island with zero energy balance by 2025, Réunion is an island extremely exposed to hurricanes, its agricultural production is inconsistent, but through the construction of greenhouses capable of resisting cyclones it has been possible to achieve the goal of producing different crops even continuously throughout the year. The idea was to develop a model in which the energy operator could exploit the surface of the greenhouse and this was able to withstand the cycles and ensure continuous production throughout the year.

Fig. 6: Agrinergie[2] V Reunion Island (France)

The Agrinergie V solar park is the third second generation Agrinergie® solar park to be installed in Réunion. It consists of 12 cyclone-proof photovoltaic greenhouses, with a total area of 2.82 hectares, uses this land for the ecological production of fruit and vegetables for the local market.

5.Result

Today we have environmental, climate and energy priorities, as already illustrated in the latest UNESCO Report (206EX / 36),promoting the importance of engineering innovation and international cooperation in research and development of new advanced technologies in wide and interdisciplinary areas to drive action for climate change and sustainable development, including low-carbon energy, integrated water management, artificial intelligence, big data and analytics, information and communication technologies, and environmental technologies. Discoveries in these areas will have a significant impact in addressing the 2030 Agenda for Sustainable Development; clear objectives are needed as already defined in the FAO Report (2019), many of the Sustainable Development Goals concern climate change, agricultural production, natural resources and ecosystems, income and / or food security. Climate smart agriculture is at the heart of these development imperatives, given its goals of simultaneously achieving productivity and increasing income, building resilience and reducing and removing greenhouse gas emissions where possible can overlap, one is the need to produce clean energy from renewable sources, the other is an environmentally friendly agricultural production.

There are technical solutions and I can many solutions for these goals as required by the FAO Report (2021), a distinctive systemic approach to support the transformation of agri-food systems and the four accelerators to accelerate progress towards achieving the 2030 Agenda.

The combination of photovoltaics with agriculture will be a future segment in the photovoltaic market, agricultural projects dare to add value to agricultural entrepreneurs, with the aim of making the agricultural enterprise more productive with less land consumption and higher quality of production.

A paradigm could be the destination of a part of agricultural land to photovoltaic systems for the production of electricity, one could think that the land to be cultivated can disappear and the production of biodiversity cannot be preserved, for example for island states where the land consumption is a problem, it would be appropriate to understand how this agricultural land could be used, how it would be possible to integrate agricultural activity with the production of clean electricity.

The challenge is to combine energy production, technological innovation and agriculture through landscape conservation, respecting local communities and their activities, through a large-scale WIN-WIN project for all stakeholders involved.

6.Conclusion

The application of APV in low ground level areas such as islands would allow for a reduction in soil evaporation where rainwater can be recovered, protects crops from extreme climatic events by offering shade and weather protection, non-consumption of soil and using it in two different ways, one to produce clean energy from renewable sources, the other related to agri-food production, an economic business model focused on agriculture is created with the creation of agro-energy communities for the distribution of economic benefits to citizens and to businesses, it creates new jobs by combining the production of electricity from renewable sources and agro-agriculture and pastoralism, the recovery of abandoned agricultural land allowing the achievement of the objectives of the Agenda 2030 SdG2 (Zero Hunger), SdG 7 (Energy clean), SdG 11 (Sustainable cities and communities).

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- *The Agrinergie solar park are different on Reunion Islands and located in other regions of the world, the design was developed and patented by the French group AKUO, more info: https://www.akuoenergy.com/en/solar*
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CIVIL ENGINEERING FRAMEWORK FOR ADDRESSING VULNERABILITY OF SEAPORT INFRASTRUCTURE TO CLIMATE CHANGE AND EXTREME WEATHER EVENTS IN SIDS

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1.0 Introduction

According to the United Nation Intergovernmental Panel on Climate Change (IPCC) latest report climate change is hitting our planet much faster than scientists predicted less than a decade ago. The IPCC has holistically identified the following indicators of climate change: warming of the world's oceans, rising mean global sea level, changing salinity of the oceans, increases in ocean acidification, decreases in snow cover, degrading of the permafrost, changes in large scale precipitation, shrinking Arctic sea ice, widespread retreat of glaciers, changes in ice sheets, rises of average global temperature, and increases in the Earth's surface humidity. The associated outcomes of the afore-mentioned changes are resulting in hydro-meteorological hazards such as torrential rain, storm surges, floods namely flash floods, drought, heat waves and cold spells. Major impacts are unavoidable and will affect the world's most vulnerable populations hardest. The IPCC also confirms that any more delay in climate action is going to close off opportunities to avert more dreadful impacts of climate change. The Global Natural Disaster Assessment Report 2020 indicated the following percentages for economic damages caused by natural disasters on a global scale: storm 47.53%, flood 29.52%, wildfire 21.28%, earthquake 1.4%, landslide 0.16%, and drought 0.11%.

2.0 Inherent Acute Vulnerability of SIDS to Disaster Risks

The 52 Small Island Developing States (SIDS) are grouped into 3 geographic clusters, each represented by a regional cooperation entity. The Africa, Indian Ocean, Mediterranean and South China Sea (AIMS) region, facilitated by the Indian Ocean Commission group 9 states. The Caribbean region, represented by the Caribbean Community, includes 23 states. The Pacific region, coordinated by the Pacific Islands Forum, consists of 20 states. While small compared to international figures, the impacts of disasters are disproportionately large in SIDS. More than 33,518 major natural disasters have occurred in SIDS since the year 2000, resulting in an estimated USD 22.7 billion in direct damages. The latter island states account for two-thirds of the countries in the world that suffer the highest relative losses due to natural disasters on an annual basis amounting to between 1 to 9% of their GDP annually. For SIDS, the disaster risk landscape is shaped by several features such as small size and correspondingly limited resources, and elevated disaster frequency and severity based on geography (located in regions with a high occurrence of tropical cyclones), geophysics (proximity to tectonic plate boundaries), and topography (low elevation). The phenomena of natural disaster vulnerability, climate change, and rising ocean levels act synergistically to create disproportionate risks for island states. Spatially isolated and separated from all other populations by expanses of ocean on all sides, these states have no choice but to be self-sustaining during the immediate aftermath of a disaster.

3.0 Vulnerability of seaports in SIDS relative to Climate Change

Ports are transportation lifelines for SIDS as the latter nations are sea-locked and everything they need; trade, tourism, energy and food, depends mostly on their respective sole seaport. Shipping transportation systems consist of ocean-going cargo and cruise vessels and ferry traffic on the coastal waterways. These systems rely on ports equipped with waterfront structures such as wharves, piers, and seawalls, port control centers, cranes and bulk cargo handling equipment, facilities for ocean-going fishing vessels, fuel facilities, shipping container storage areas and warehouses. Seaports are located in one of the most vulnerable areas to climate change impacts that can cause heavy structural damage, collapse of costly and crucial equipment and infrastructural breakdown. Port disruptions not only affect ports but also impact the hinterland, global supply chains as well as urban areas or economic centres that are hundreds of kilometres away from the ports. Observations from long-term tide gauges and global satellite altimetry confirms that sea level is rising. This is due to the thermal expansion of seawater, melting of glaciers, and loss of ice from the Greenland and Antarctica ice sheets which accelerate with increasing temperature relative to Global Warming. Climate model simulations with analyses of tide gauge records indicate a global mean sea level rise (SLR) between 1.6 and 1.8 mm/yr over the 20th century. High-precision satellite altimetry suggests a recent acceleration with rates as high as 3.4 mm/yr between 1993 and 2009. The IPCC Fifth Assessment Report projects a global mean SLR between 52 and 98 cm by the year 2100 under the highest emissions scenario, and 28–61 cm under the lowest emissions scenario. The impacts to seaports attributed solely to SLR include submergence, flooding, saltwater intrusion and erosion. Over and above SLR, other hazardous impacts of climate change with magnifying severity includes tropical cyclones of greater intensity, stronger wind speeds and higher rainfall and storm surges with gigantic destructive waves. The latter hydro-meteorological events can cause significant damage to port infrastructure including important economic loss.

4.0 Civil Engineering elements vulnerable to the effects of climate change at Seaports

Port infrastructure and operations are vulnerable to future changes to water, oceanic, and atmospheric conditions exacerbated by climate change. Previous research has highlighted the most known and obvious direct impacts to port infrastructural components and assets as follows:

• *Berthing structures*: The purpose of a berthing structure is mainly to provide a vertical front where ships can berth safely, for mooring of ships, loading and unloading goods. These include piers, wharves, jetties, bulkheads and docks. Infrastructure damage and deterioration resulting from heavy storm activity, inundation of infrastructure and shifting tidal and splash zone levels are identified as the most visible impact on berthing structures.

• *Protection barriers*: Breakwaters are barriers constructed in the sea to provide protection for shipping by dissipating energy generated by waves and storms. Seawalls are a common form of foreshore protection and are used in estuaries and on open ocean shores to protect against erosion or as retaining walls for reclaimed land. Revetments are sloping structures used to armour shorelines against erosion. Visible impacts on protection barriers include an increase in wave overtopping, barrier material displacement, fracture or overturning, and erosion of barriers.

• *Port superstructures*: Port superstructure includes administration buildings, offices, warehouses, storage sheds and other terminal facilities. These have mainly experienced failure of foundations, degradation of superstructure materials and failure of roofs and cladding through increased ground movement and changes in groundwater.

- *Channels and harbour basins*: The harbour basin is the protected water area which should provide safe and suitable accommodation for ships. Visible impacts include change in water flow, altered sediment loads for channels affecting navigability due to change in channel depth and dredging regimes, and change in timing of seasonal high and low water.

• *Land transport infrastructure*: The road/rail network within a port precinct are important physical assets, which may include bridges, that service ports and port infrastructure by connecting the latter to the hinterland. Roads have experienced embrittlement and cracking of bitumen, loss of water seal causing potholing, low-lying roads may be submerged and road foundations damaged. Rail lines have experienced buckling of tracks, submerging of low-lying rail tracks, signal and other electrical damage and damage to rail foundations.

• *Deterioration of structural materials*: The impacts of climate change on temperature, salinity and humidity variance in port areas lead to a more aggressive and corrosive environment. The ingress of chlorides is the principal mechanism responsible for corrosion-related damage of concrete infrastructure thus resulting in added vulnerability of the service life of port structures. Within the long list of impacts upon structures caused by climate change, corrosion has been identified as a priority theme, as it has been estimated that the increased maintenance and repair costs worldwide resulting from the acceleration of the corrosion process due to climate change might be of hundreds of billions of dollars annually.

5.0 Engineering design of seaport infrastructure and relevance of codes and standards

The design of port infrastructure requires an in-depth knowledge of structural engineering including structural materials behaviour, structural dynamics, wind engineering, advanced concrete technology, finite element methods, and software tools. The design process includes mastering nonlinear dynamic behaviour of structures and foundation systems including construction of mathematical models capable of reliable prediction of such behaviour with understanding and skills in the assessment of element strength, deformation, and deterioration.

The scope and coverage of the British Standard for the design of maritime structures, BS 6349 consist of adequate guidance and technical calculation details for the design of safe port infrastructure and port operations with the document systematically referring to the basic knowledge mix relative to structural functions. It is a multi-part document divided into eight parts with the general criteria in Part 1 is subdivided into four sub-parts. Part 1-1 deals with the code of practice for planning and design for operations. Part 1-2 is about the code of practice for assessment of actions. Part 1-3 gives the code of practice for geotechnical design and Part 1-4 concerns the code of practice for materials. Part 2 highlights the design of quay walls, jetties and dolphins. Part 3 explains the design of dry docks, locks, slipways and shipbuilding berths, ship lifts and dock and lock gates. Part 4 includes the design of fendering and mooring systems. Part 5 is the code of practice for dredging and land reclamation. Part 6 concerns the design of inshore moorings and floating structures. Part 7 is the guide to the design and construction of breakwaters. The last part; part 8 governs the code of practice for the design of Ro-Ro ramps, linkspans and walkways.

The recommended design life in BS 6349 is 50 years taking into account the safety of the structure relative to fatigue loading, corrosion, marine swell, the reduction of the soil bearing capacity while considering future developments. Probabilistic reasoning is applied for the determination of boundary conditions for the estimation of the return period of extreme weather events. Self-weight, imposed load, horizontal loads together with environmental load combinations with respective safety factors are considered with reference to normal situation, extreme situations, and temporary loading conditions. BS 6349 provide complete

equation and formula for calculation of structural components and guidelines for monitoring and inspections of constructed facilities.

The American Society of Civil Engineers (ASCE) port design standard, the German Standards (EAU 2004), and the Standards Design Criteria for Port and Harbour in Japan (OCDI, 2009) are other practical international port design standards for the structural design of marine facilities.

Engineering design codes and standards evolve over the years to incorporate lessons learned from past disasters or failures and as well as from research performed in the laboratory. Basically, structural design codes and standards have been set with primary regard to life safety issues. Restorability for continued use of the facility after a destructive event by restoration using technologies available within reasonable ranges of cost and time. For example, buildings codes can assure that buildings are designed so that occupants can evacuate safely from a building during a natural disaster, but they do not guarantee that the building itself will be inhabitable after the latter event. Thus, existing design codes and standards alone may not fully guarantee resilience from unprecedented events in relation to climate change. The second generation of Eurocodes is planned by 2023 and is planned to incorporate the adaptation of structural design to climate change.

6.0 Performance Based Design for Enhancing Resilience of Port Infrastructure

Traditional design approaches in civil engineering mainly focus on codes and standards based on prescriptive specifications with standardized methods of design calculations which applies many factors of safety to account for unknowns in both the loading and resistance of structures. Although design specifications strive to achieve some level of performance, they do not establish specific performance levels. The development and recent advancements in the Performance-based Design approach (PBD) enables a progression to more explicit evaluation of the safety and reliability of structures for various hazards and progressive collapse scenarios. PBD is founded on the premise that structural systems must meet specific performance objectives. Specific performance expectations are set for the completed design. The engineer then engages creativity and innovation employing science and principles of structural and material mechanics to identify optimal solutions and the design is completed by demonstrating complying performance through analysis, simulation, testing, or a combination thereof. The profession needs to describe for the public the damage levels or service states that are attainable for a variety of hazards acting at specific intensities on structures serving certain purposes and occupancies.

Performance-based design offers several advantages over prescriptive design. First, properly executed performance-based approaches enable desired performance to be attained with greater confidence and expectations of reliability mainly because of the focus on the damage states of the facility. Second, since the performance objectives for the design are explicitly defined, the stakeholders can select the expected performance levels that are appropriate and satisfy their own needs. Third, since performance is evaluated directly as part of the engineering process, engineers need not be limited by requirements to conform to prescriptive solutions, thereby allowing for innovation and creativity using new materials and systems, and using existing materials and systems in new ways.

7.0 Improving Maintenance and Rehabilitation Techniques

The life of harbour facility is rather long and designed today must be expected to meet demands during its design working life that cannot be foreseen. Strategic and comprehensive maintenance is crucial after the start of service for avoiding heavy deterioration and loss of structural performance during the design

working life of the infrastructure. To ensure the reliability during the long working life of the facility, the levels of initial design and maintenance should be linked. Port infrastructures are facilities with certain particularities in terms of highly aggressive environments, the presence of salt water, and the impact of coastal dynamics. Maintenance activities for this type of infrastructure are highly affected by the difficulty of access, the lack of as built documents. For the maintenance of port infrastructure, the accurate inspection of deformations, deteriorations and damage is crucial. Faced with the difficulties and problems presented by port infrastructures, new methodologies and technologies need to be adopted. Technologies such as unmanned aerial vehicles (UAVs) allows for the surveying of environments, reaching areas with difficult access, and their 3D digital reconstruction by photogrammetry. From the photographs captured with UAVs and the processing of images in software based on structure from motion and multiview stereo (MVS) techniques, it is possible to reconstruct real scenarios and three-dimensional models for increasing efficiency of inspection exercises allowing timely and precise decision taking.

8.0 Adaptation Strategy for Addressing Climate Risks for Seaports in SIDS

Vulnerability is the degree to which a system is susceptible to, and unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability 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. Vulnerability of seaport infrastructure can be addressed in many different ways; it is important to anticipate and as far as possible respond to the conditions and risks that may be faced during the asset's lifetime. There is increasing evidence to demonstrate that proactively incorporating climate-related design considerations from the start of the process can be significantly less costly and less complex than having to modify designs, reactively, at a later date.

SLR coupled with extreme weather events have the potential to significantly damage maritime infrastructure and cause port closures, delays and disruption which can be highly detrimental for SIDS. Hence, the design and provision of new, as well as retrofitting of existing; breakwaters, quay walls, terminals, storage facilities, drainage systems and other navigation infrastructure should be envisaged. Local hydro-meteorological data can help to understand local trends for informing location-specific adaptive decisions and allowing optimal selection of design criteria. For major, long-term investments, special attention should be paid to how the 'worst case' climate change scenario has been defined. Joint occurrences such as a storm surge during torrential rain at a high tide, superimposed upon an increased sea level must be considered.

In the navigation infrastructure context, an adaptation pathway might support the implementation of interim or temporary measures in the first instance, allowing additional data to be collected and uncertainty reduced during a period of acceptable risk; or it may recommend a staged investment or construction process, incumbent on certain thresholds being met. For example, action may be triggered when measured mean sea level reaches a certain point, or when a pre-determined frequency of maximum wind speed or significant wave height is exceeded. Adaptation pathways should allow climate change risks to be dealt with in a flexible way where future options are kept open so that the risk of maladaptation can be minimised.Adaptation pathways can be used to set out sequences of actions that can be implemented progressively, depending on future dynamics. Rather than locking in to a single climate change scenario and investing in a structure of a certain height, consideration should be given to whether the asset can be designed to be raised and strengthened in future years as conditions demand. Similar, adaptability principles can be applied to many other types of physical port infrastructure. The foundations for a breakwater, for example, might be constructed so as to withstand the load of subsequent raising if wave conditions exceed current projections.

In the context of climate change, it is vital to acknowledge and plan for the consequences of failure if an event exceeds design standards or a high-impact event occurs. To some extent this can be addressed by designing-in redundancy; designing specifically to enable rapid replacement or repair; or using temporary infrastructure. Structures and operations that are prone to failure should also be designed to fail 'gracefully' rather than 'catastrophically' and/or measures should be implemented to manage the consequences of failure. Designing a structure to fail in a controlled manner may involve deliberately weakening specific elements to retain a degree of control, or sacrificing components that are vulnerable to extreme climate loading in order to improve the structure's overall resilience.

9.0 Conclusion

Ports sit on the frontlines of global climate change and SIDS experience the most severe consequences of escalating global anthropogenic risks. Engineers play a pivotal role in improving the resilience of ports, as they are responsible for design and maintenance of port infrastructure that will be adequately prepared for future sea level change and escalating extreme weather events. The main challenge of standardising "lowcost and no-regret adaptation measures" in the context of structural codes is posed by the uncertainty related to climate change, which mainly depends on the trajectory of greenhouse-gas emissions. Nevertheless, the SuRe Standard for Sustainable and Resilient Infrastructure can be used for the integration of key criteria of sustainability and resilience into infrastructure development and upgrade. Along the same line, BS 8631 and ISO 14090 describes principles, requirements and guidelines for adaptation to climate change. The standard helps organizations to identify and understand impacts and uncertainties and how these can be used to inform decisions. Also relevant is the ISO 31000 which helps organizations develop a risk management strategy to effectively identify and mitigate risks, thereby enhancing the likelihood of achieving their objectives and increasing the protection of their assets.

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UNLEASHING THE CREATIVITY OF EDUCATION TO COMBAT CLIMATE CHANGE: AN OPPORTUNITY FOR GLOBAL LEADERSHIP

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Abstract

The challenges of lack of climate change awareness and education include, fragmentation of climate change education themes in the various subjects, inadequate instructional materials, inadequate training of teachers to handle climate change education related topics in their subject areas and over-reliance on the lecture method of teaching among others. Climate change threatens the lives and livelihoods of billions of people, making it one of the most urgent problems of our time. Natural disasters, environmental deterioration, and unusual weather can lead to disease outbreaks and disruption of crops, fisheries, and livelihoods. In general, people who receive education are more likely to adopt new attitudes and behaviours, and make more informed decisions on climate change issues. Students can learn about the effects of global warming and how to adapt to climate change in the classroom. All individuals are empowered by education, but young people are especially inspired to take action. The researchers claim that one of the study's most unexpected findings is that raising educational attainment frequently causes a negligible increase in the emissions that cause climate change. Lower emissions are a result of slower population growth, according to numerous other research. In this paper, creative and efficient environmental and climate change education will be highlighted, teaches people and communities to understand the climate change, environment and the challenges that it faces, to become aware of the answers to those climate change problems, to inspire people to find solutions, and to take the necessary steps to protect the environment from future difficulties.

1. Introduction

Promoting climate action requires creative education. It assists individuals in comprehending and addressing the effects of the climate crisis by equipping them with the information, know-how, values, and attitudes necessary to engage as change agents. The challenges of lack of climate change awareness and education include, fragmentation of climate change education themes in the various subjects, inadequate instructional materials, inadequate training of teachers to handle climate change education related topics in their subject areas and over-reliance on the lecture method of teaching among others.

People who receive education tend to adopt new attitudes and behaviours, as well as make more informed decisions especially on climate change issues. Students can learn about the effects of global warming and how to adapt to climate change in the classroom. All individuals are empowered by education, but young

people are especially inspired to take action. Knowing the truth helps dispel apprehension surrounding a topic that is typically portrayed in the media as being doom and gloom. In order to convey what it means to be a child growing up in the age of fast climate change, UNICEF has put a lot of efforts to cultivate minds and imaginations of kids on climate change all over the world.

The importance of education and training in addressing climate change is emphasized on a global scale. Governments are urged by the UN Framework Convention on Climate Change (UNFCCC), the Paris Agreement, and the related Action for Climate Empowerment (ACE) agenda to inform, empower, and involve all stakeholders and key groups in climate change-related policies and actions. The significance and effects of climate change education on engineering and social change will be discussed in this paper.

2. Climate Change as a Major Threat Worldwide

Three major concerns of environmental education is awareness and sensitivity to the environment and environmental challenges. Knowledge and understanding of the environment and environmental challenges. Attitudes of concern for the environment and motivation to improve or maintain environmental quality.

From a 2018 Pew Research Center survey [1] on how people assess climate change risks, as well as other surveys performed by the Center, the following Figure 1 on perception regarding how people perceive climate change around the world is presented. The majority of the nations questioned believe that the threat posed by global climate change to their country is serious. In fact, more than any other issue, it is regarded as the greatest threat in 13 of the 26 countries surveyed.

Greece's citizens are extremely concerned, with 90% citing climate change as a serious threat (similar to the 88 percent there who cite the condition of the global economy). Strong worries are also voiced by people in Mexico, France, Spain, South Korea, and France. At least 80% of people in each of these nations believe that climate change is a serious issue.

With 59 percent of Americans believing it to be a severe issue, Americans are less likely to be concerned about climate change. ISIS (62%) and North Korea's nuclear programme are mentioned by about as many Americans as climate change (58 percent).The least number of people, 43% in Russia, 41% in Nigeria, and 38% in Israel, believe that climate change poses a serious threat to their country.

Not everyone in the surveyed nations views climate change as a serious concern. Global warming is viewed as a threat by 20% of people on average throughout these nations, whereas only 9% believe it to be non-existent. In Israel and Russia, the majority, if not more than that, believe that there is little to no concern from global warming (58 percent and 51 percent , respectively). Nearly a quarter (23%) of Americans consider climate change to be a small threat, while 16% think it poses no threat at all.

People who receive education tend to adopt new attitudes and behaviours, as well as make more informed decisions especially on climate change issues. Students can learn about the effects of global warming and how to adapt to climate change in the classroom. All individuals are empowered by education, but young people are especially inspired to take action. Knowing the truth helps dispel apprehension surrounding a topic that is typically portrayed in the media as being doom and gloom. In order to convey what it means to be a child growing up in the age of fast climate change, UNICEF has put a lot of efforts to cultivate minds and imaginations of kids on climate change all over the world.

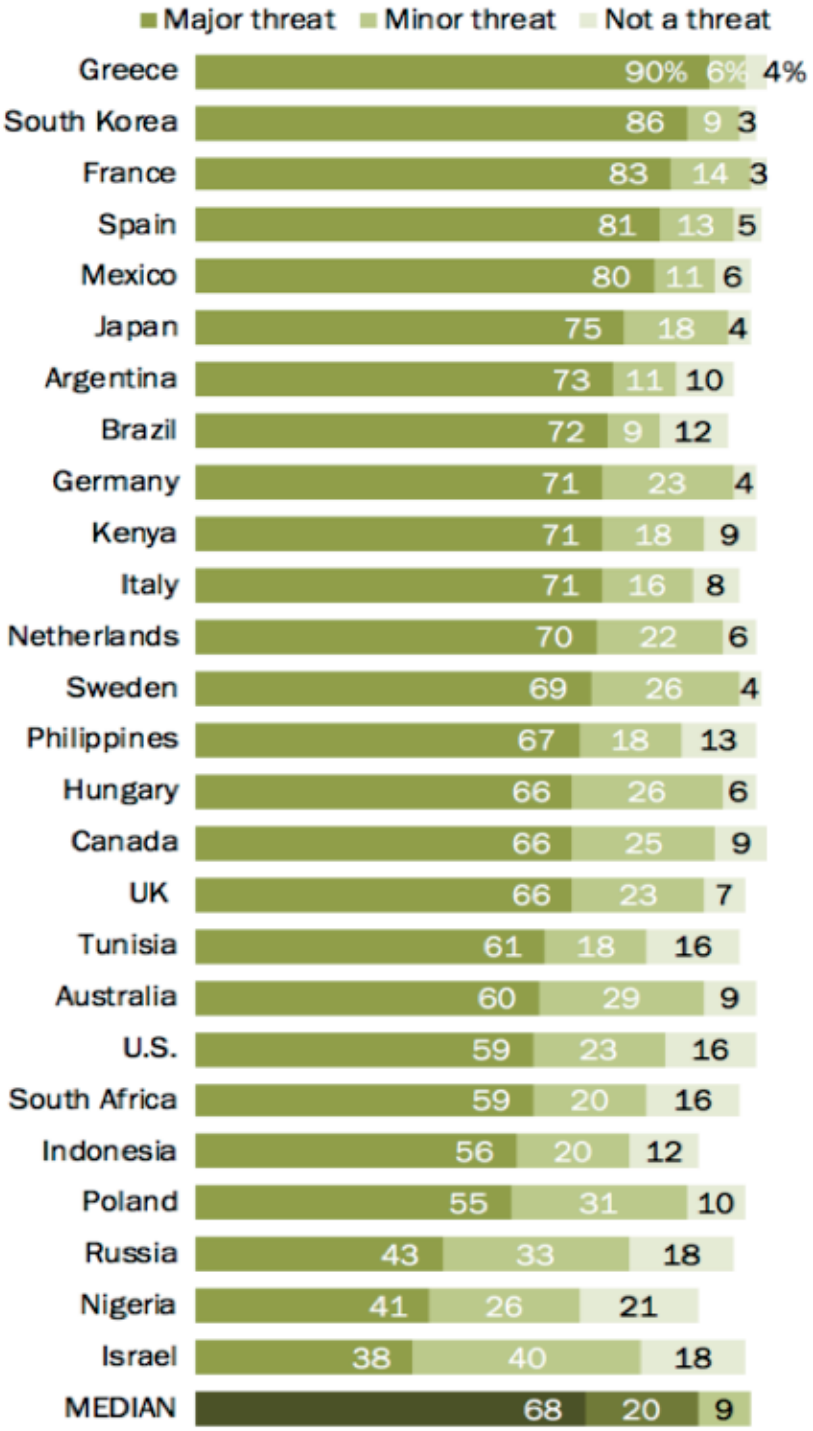

Figure 1: Spring 2018 global attitudes survey on climate change [1]

3. Climate Change Education for Social Transformation

What is the challenge for environmental education in 21st century? The challenge, then, is to express the complexity of modern environmental issues in ways that are understandable and inviting, and at the same time to ensure that science continues to play an important role in explaining and evaluating environmental issues and in forging solutions to environmental problems.

A global crisis that needs an immediate solution has been caused by pollution, biodiversity loss, and climate change. As we try to reform our society to follow the 1.5-degree path advised by the Paris Agreement, UN Secretary-General António Guterres refers to the climate problem as "a battle for our lives". There is a growing need for education to enable people to acquire the knowledge, skills, values, and attitudes that lead to the green transition of our societies, as indicated in SDG Target 4.7, and, in fact, in the entire 2030 Agenda, so that they can act as an agenda of change in a world that is becoming more complex and interconnected and facing a real, existential threat like climate change.

Referring to Paris Agreement, Article 12, that parties shall cooperate in taking measures, as appropriate, to enhance climate change education, training, public awareness, public participation and public access to information, recognizing the importance of these steps with respect to enhancing actions under this Agreement [2]. Education and communication can promote the social and political will for addressing climate change, overcome climate denial and inaction, facilitate adaptation to a rapidly changing climate, and, in general, enhance the much-needed level of climate literacy and action globally, as in Figure 2.

UNESCO and UNFCCC are starting a series of monthly conversations on climate change education for social transformation in response to young people's urgent calls for action to ensure that everyone is prepared to combat climate change and to promote sustainable development, as indicated in the Sustainable Development Goal Target 4.7. The 'On the way to Berlin' series of seven online seminars held between 2020 and 2021, which brought together more than 15,000 stakeholders to address cutting-edge ESD challenges, serves as the foundation for this series.

On the way to COP27, which will be held in Sharm El-Sheikh, Egypt from November 7 to 18, 2022, the UNESCO-UNFCCC Webinar Series will consist of 8 webinars for this season, one on the last Tuesday of every month from April to November.

The series is put together as a component of the Action for Climate Empowerment (ACE) Hub, a project that the UNFCCC and the North Rhine-Westphalia regional government of Germany launched in 2022 to promote training, public access to information, education, and participation in climate change action.

Referring to the first season, the whole initiative is focused on transforming all educational policies and curricula to be climate-ready. For COP27, each episode will examine the crucial role that education plays in addressing climate change and how to tap into its revolutionary potential.

Figure 2: Climate change education and Communication by UNFCCC [2]

4. Climate Change Education for Youth

The first peer-reviewed national survey of Science Teachers [3], which examined how the controversy surrounding anthropogenic climate change affects curricula, was published in the journal Science in 2016. It was found that throughout the course of a full academic year, the majority of middle- and high-school teachers only include one or two hours of instruction regarding climate change. Less than an hour was dedicated by 30% of the teachers.

Seriously, most teachers lack the knowledge necessary to impart climate science to students effectively. According to the Yale Program on Climate Change, 55% of high school science instructors and 70% of middle school science teachers do not agree with the scientific consensus on climate change [4]. Furthermore, the National Center for Science Education reports that 40% of teachers who include climate change in their science curriculum do it in a misleading way [5].

It is evident that the existing educational curriculum covering climate change is failing our kids because less than a third of middle school instructors and less than half of high school teachers educate their students on the human causes of climate change.

Nationally standardised and testable curricula for schools must be legislated, along with clear instructions and materials for teachers to effectively teach climate science. Teachers also require ongoing training on climate change through conferences and seminars, as well as current materials and studies that are simple to access.

Some initiatives have already begun to take effect in some countries. Climate science is included in the K–12 curriculum according to the Next Generation Science Standards [6], which were created by state governments in collaboration with the National Research Council, the National Science Teachers Association, and the American Association for the Advancement of Science. The standards have been adopted by 20 US states. The Creating Climate Champions pilot programme [7] was created by the Center for Research on Educational Equity, Assessment & Teaching Excellence at UC San Diego. It is a collaborative initiative between partners from the university and the local community to create lesson plans, in-class activities, and projects to support San Diego county K–12 teachers. Indigenous knowledge and climate science are ingrained in the curriculum to encourage students to take action.

However, notwithstanding how promising these attempts are, given the size of the challenge, they are obviously insufficient. The national level of these activities needs to be increased. As a shining example, consider Italy. An programme spearheaded by Italy's Education Minister Lorenzo Fioramonti requires teachers in every grade to teach a minimum of 33 hours on climate change and environmental sustainability starting in September 2020.

No climate change agenda was overlooked by the ministry. The curriculum was evaluated by Kate Raworth of the Environmental Change Institute at Oxford University and Jeffrey D. Sachs, head of the Center for Sustainable Development at Columbia University.

Political leaders in the United States must follow suit and mandate climate science education for students across the country, just as Finland and Mexico have done or are attempting to do.

According to a report by the Yale Program on Climate Change Communication in 2021 [8], 78 percent of voters who are registered support educating kids about the causes, effects, and potential solutions to global warming. It's time to demand action from the federal government now that popular support for climate education is growing. Climate science education must be appropriately provided for both students and teachers.

Let's educate our young with the exact information they need to comprehend climate change and, when it's their turn, to take the necessary steps to secure a livable future for everybody, rather than deciding the future status of the planet for them.

5. Environmental Education Help to Combat Climate Change

What are the problems of environmental education? Lack of Environmental Training Modules: The status of Environmental Training programs and its contents is not satisfactory. Lack of Preparedness of teachers: Another barrier to environmental education activities is the reluctance of support and lack of preparedness on part of the teachers.

A key component of the increasingly urgent worldwide fight against climate change is education. Understanding this phenomenon enables young people to confront the effects of global warming, motivates them to alter their behaviour, and aids in their ability to adapt to what is already a serious problem on a worldwide crisis.

UNESCO supports knowledge in regards to environmental issues, and more specifically in everything relating to climate change. According to UNESCO, education is a crucial component in slowing climate change, especially when it focuses on children and young people. Education, specifically, encourages changes in young people's views and behaviour and helps them to adapt to trends related to climate change.

6. The Importance of Environmental Literacy

Why is it difficult to solve environmental problems? Environmental problems can be complex and hard to resolve. The complexity arises because the components of the environment are linked, and their interactions may be separated by both time and distance.

Several projects have been started in the last several years to attempt and stop climate change. The 17 Sustainable Development Goals (SDGs) that the UN has been promoting since 2012 stand out among them. Number 13 of them is entitled "Climate Action."

The development of a climate-friendly culture and environmental literacy campaigns among populations that are frequently unfamiliar with these significant political agreements are key factors in determining the success of these kinds of initiatives. What do we mean by environmental literacy, though? educating the public, especially kids, and increasing understanding of the causes and effects of climate change.

According to the UN, who is committed to educating people about climate change, it is just as important to make progress in areas like reducing greenhouse gas emissions and formulating effective government policies as it is to provide education and training to raise awareness in as wide an audience as possible.

Experts emphasise the significance of beginning to use notions that previously thought to be the domain of scientists as part of this change in strategy. Global warming, greenhouse gases, renewable energy, carbon

footprint, deforestation, recycling, green jobs, green taxation, water footprint, sustainable food, . are some of the topics that we're discussing [11].

7. Developing A Culture of Caring For The Environment

Along with learning and applying the vocabulary. The significance of educating youngsters about environmental issues and creating a climate-friendly culture is being emphasised by experts. For instance, a recent study by the University of Stanford examined how this subject had helped students from nursery school through graduation from secondary school and came to the conclusion that 83% of students had changed their environmental behaviour.

There are several climate change-related activities that can be carried out in schools in addition to making it a required subject, with Italy being the only European nation to have done. For instance, environmental-related outdoor activities like cleanup projects, field trips to farms and nurseries to observe how to care for plants and animals, recycling classes and workshops.

The Educaclima portal, for example, provides instructors with free instructional materials about environmental issues including climate change, responsible consumption, energy use, and mobility that they may use with students in the classroom.

8. International Engineering Alliance in Environmental Issue

The International Engineering Alliance (IEA) [9] is a non-profit organisation with members from 29 countries and 41 jurisdictions. It is a signatory to seven international accords. The recognition of engineering educational credentials and professional competence is governed by these international agreements.

Members of the International Engineering Alliance develop and uphold internationally benchmarked standards for engineering education and the required competence for engineering practise through the Educational Accords and Competence Agreements, namely Washington Accord, Sydney Accord and Dublin Accord.

The Washington Accord is an international agreement between bodies responsible for accrediting engineering degree programmes. International engineering alliance graduate attributes & professional competencies, JUN 2021 version [10], the Washington Accord evaluation criteria include showing that in the educational process, the science-based engineering program achieves the following knowledge profile and graduate attribute profile.

No.	Attribute	Engineer Graduate
WA3	**Design/development of solutions**: Breadth and uniqueness of engineering problems i.e., the extent to which problems are original and to which solutions have not previously been identified or codified	**WA3:** Design creative solutions for complex engineering problems and design systems, components or processes to meet identified needs with appropriate consideration for public health and safety, whole-life cost, net zero carbon as well as resource, cultural, societal, and environmental considerations as required **(WK5)**
WA6	**The Engineer and the World**: Level of knowledge and responsibility for sustainable development	**WA6:** When solving complex engineering problems, analyze and evaluate sustainable development impacts to: society, the economy, sustainability, health and safety, legal frameworks, and the environment **(WK5, WK7)**

Table 1 : The Washington Accord Graduate Attribute Profile on environmental elements,WA3 and WA6 [10].

No	Knowledge Profile
WK5	Knowledge, including efficient resource use, environmental impacts, whole-life cost, re-use of resources, net zero carbon, and similar concepts, that supports engineering design and operations in a practice area
WK7	Knowledge of the role of engineering in society and identified issues in engineering practice in the discipline, such as the professional responsibility of an engineer to public safety and sustainable development. (Represented by the 17 UN Sustainable Development Goals (UN-SDG))

Table 2: The Washington Accord Knowledge Profile on environment element, WK5 and WK7 [10].

In Table 1, on Graduate Attribute Profile, WA3 and WA6, graduates of an engineering programme are expected to attain the environment and sustainability attribute in the practice oriented learning environment. Table 2 shows the knowledge profile and complex engineering graduates need to attain on the consequences to society and environment, WK5 and WK7.

Based on Sydney Accord and Dublin Accord [10], students of an engineering technology and engineering technician Diploma programme are expected to attain the following Graduate Attribute Profiles (Table 3) and Knowledge and Attitude Profile (Table 4) in the practice oriented learning environment:

Attribute	Engineering Technologist Graduate	Engineering Technician Graduate
Design/development of solutions: Breadth and uniqueness of engineering problems i.e., the extent to which problems are original and to which solutions have not previously been identified or codified	**SA3**: Design solutions for broadly defined engineering technology problems and contribute to the design of systems, components or processes to meet identified needs with appropriate consideration for public health and safety, whole-life cost, net zero carbon as well as resource, cultural, societal, and environmental considerations as required **(SK5) .**	**DA3**: Design solutions for well-defined technical problems and assist with the design of systems, components or processes to meet specified needs with appropriate consideration for public health and safety as well as cultural, societal, and environmental considerations as required **(DK5).**
The Engineer and the World: Level of knowledge and responsibility for sustainable development	**SA6**: When solving broadly-defined engineering problems, analyze and evaluate sustainable development impacts* to: society, the economy, sustainability, health and safety, legal frameworks, and the environment **(SK5, SK7).**	**DA6**: When solving well-defined engineering problems, evaluate sustainable development impacts* to: society, the economy, sustainability, health and safety, legal frameworks, and the environment **(DK5, DK7).**

Table 3: Graduate Attribute Profiles for Sydney Accord (SA3, SA6) and Dublin Accord (DA3, DA6) on environment elements [10].

A Sydney Accord program provides:	A Dublin Accord program provides:
SK5: Knowledge, including efficient resource use, environmental impacts, whole-life cost, re-use of resources, net zero carbon, and similar concepts, that supports engineering design and operations using the technologies of a practice area	**DK5:** Knowledge that supports engineering design and operations based on the techniques and procedures of a practice area
SK7: Knowledge of the role of technology in society and identified issues in applying engineering technology, such as public safety and sustainable development (Represented by the 17 UN Sustainable Development Goals (UN-SDG))	**DK7:** Knowledge of issues and approaches in engineering technician practice, such as public safety and sustainable development (Represented by the 17 UN Sustainable Development Goals (UN-SDG))

Table 4: Knowledge Profile of Sydney Accord (SK5, SK7) and Dublin Accord (DK5, DK7) on environment elements. [10]

The professional competence profiles on environmental elements for Washington Accord, Sydney Accord and Dublin Accord are stated generically and are applicable to all engineering, technology and technician disciplines. The application of a environmental competence profile may require amplification in different regulatory, disciplinary, occupational or environmental contexts.

The environmental attributes of Accord programs as knowledge profile, indicated volume of environmental learning and the attributes against which graduates must be able to perform. The requirements are stated without reference to the design of programs that would achieve the requirements. Providers therefore are free to design environmental based programs with different detailed structures, learning pathways and modes of delivery. Evaluation of individual programs is the concern of national accreditation systems.

Hence, graduates should understand the impact of engineering technology solutions of broadly-defined engineering problems in societal and environmental context and demonstrate knowledge of and need for sustainable development. The competent graduate has the attributes necessary to perform the environmental based activities within the profession or occupation to the standards expected in independent employment or practice. The professional competence profiles for each professional category record the environmental elements of competence necessary for performance that the professional is expected to be able to demonstrate in a holistic way at the stage of graduation.

9. Conclusions

Climate change, one of the most urgent problems of our day, puts billions of people's lives and means of subsistence under danger. Natural disasters, environmental damage, and extreme weather patterns cause harvests to be disrupted, fisheries to be depleted, livelihoods to be destroyed, and infectious illnesses to spread.

Based on analyses, not everyone in the surveyed nations views climate change as a serious concern. Global warming is viewed as a threat by 20% of people on average throughout these nations, whereas only 9% believe it to be non-existent. The challenges of lack of climate change awareness and education include, fragmentation of climate change education themes in the various subjects, inadequate instructional materials, inadequate training of teachers to handle climate change education related topics in their subject areas and over-reliance on the lecture method of teaching among others. Importantly, Environmental and climate change education teaches people and communities to understand the environment and the challenges that it faces, to become aware of the answers to these problems, to inspire people to find solutions, and to take the necessary steps to protect the environment from future difficulties.

We will all be impacted by climate change, not just the forest, the coral reefs, or even the people in other nations. People all throughout the world will experience the effects of it, from more harsh weather to rising food prices to recreation and fewer opportunities to appreciate the natural world.

By making simple dietary changes, you can combat climate change. By consuming less meat, shopping locally whenever feasible, and purchasing food with fewer packaging, you may drastically reduce your greenhouse gas emissions. Find out more about reducing your consumption of animal products here.

Through the process of environmental and climate change education, people can learn about environmental problems, solve them, and take steps to protect the environment. People have a deeper grasp of environmental issues as a result, and they are more equipped to make wise choices.

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SUSTAINABLE COMMUNITIES - CASE STUDY OF CENTRAL FLACQ

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1. Introduction

Urban areas have a great contribution towards the economic resilience in a country but they also have negative impacts on the ecology and the environment. As such, towns and villages around the world are trying to become more sustainable by implementing different policies and strategies and by adopting the Sustainable Development Goals. SDG 11 'Sustainable Cities and Communities' vision is to make cities and human settlements inclusive, safe, resilient and sustainable.

A sustainable city is defined as a city which has been designed with environmental concerns (McMahon, 2022). The city that balances and improves social, economic, and environmental aspects is thought to be the sustainable city. The New Urban Agenda emphasises various characteristics and objectives of urban sustainability, including "just, safe, healthy, accessible, affordable, resilient and sustainable cities." Cities, for instance, ought to balance economic soundness with social responsiveness and environmental responsibility (Geneva, 2020). A city's ecological impact cannot be limited to the urban metabolism inside the town limits because the effects on the environment of consumption occurring in a town are dispersed across the world. In order to appreciate the idea of urban sustainability, it is necessary to adopt a global viewpoint whereby a sustainable evaluations and urban planning decisions are taken while taking into consideration the wider effects of local behaviour or reaction (Mattias Höjer, 2015).

Sustainable cities have a tremendous potential for resolving climate concerns, as well as contributing to human benefit, because a city can apply locally feasible results. A city/town has its own unique setting like the local infrastructure, culture, institutions, and knowledge and can make room for the incubation of new green technologies as sociotechnical experiments for clean energy innovation, infrastructure, and institutions. Furthermore, it effectively combats climate change by exchanging knowledge and encouraging engagement in climate action through city networks. Local and national governments, are less encumbered by military, economic, diplomatic, and historical concerns, making it less difficult to form international urban connections for collective climate policies. The city network can be more proactive in responding to global warming by promoting local authorities to publish optimistic but feasible carbon reduction targets that are connected with their national government's Intended Nationally Determined Contributions to the UN foundation agreement regarding global warming (Monga, 2006).

Analysing the different towns and cities in the Mauritian context, it can be observed that urbanised regions such as Port Louis, Beau Bassin, Curepipe, Quatre Bornes, Vacoas, Central Flacq, Goodlands and Triolet

are not considered to be sustainable. In certain towns, unlawful developments are being carried out which will lead to environmental issues and sanitation problems. In this context, a study was carried out regarding how to convert existing towns to more sustainable one and a case study focussing on the region of Central Flacq has been analysed. The study will be based on different concepts that will convert Central Flacq into a sustainable village. The issues to be considered are the implementation of renewable energies, the transportation system, the creation of green spaces and the development of the concept of recycling in the region.

The aim of this study is to introduce and implement different concepts of sustainability in the region of Central Flacq. One of the main objectives is to assess the actual land use planning in Central Flacq in order to come up with recommendations to make the village more sustainable and resilient.

2. Benefits of Sustainable Cities

Sustainable cities bring many benefits namely:

- **Liveability**

Sustainability in a city is a key factor for the wellbeing of the inhabitants and is classified as a long-term vision. The improvement in sustainability will prove a confident consequence on the wellbeing of the inhabitants. In addition, sustainability in a city is to design an affordable lifestyle for the inhabitants in the future (Valcárcel-Aguiar, 2018).

- **Health issues**

Due to overpopulation, sustainability has become a key factor to consider. Overpopulation has contributed to various health issues which comprises of the imminent and reappearing of epidemics, no hygiene, food poisoning, water contamination, environmental problems and flood. The number of people in the city is growing by 1.2%, every year. According to economists forecast, the population will double to 13 billion in the next 58 years leading an increase in the number of pollution and diseases in the country (Hum Ecol Interdiscip, 2007). In addition, overpopulation often shows a connection between economic expansion and air pollution. Between 2000 and 2010, increased urbanization was linked to an increase in nitrogen dioxide in the country. Furthermore, since the cost of producing water treatment plants to the inhabitants is high, it has been observed that overpopulation has a great contribution in water pollution (Camaren, 2012).

- **Lack of facilities to dispose waste**

Moreover, the collection of solid waste has been very limited in several towns (Sweden, 1998). Study shows that the amount of solid waste in the world is increasing everyday by 11.2 billion tonnes (Camaren, 2012). Very often the inhabitants living in peri-urban areas complain that there is no provision of dustbins and wastes are not collected frequently. Researches prove that due to limited funding and an increase in population, it is difficult for the authority to give frequent services to the inhabitants. Furthermore, political influence also causes a lack in the solid waste management in the community. Politicians give preference to their respective regions and neglects the peri-urban areas. Moreover, technical issues from respective authorities regarding waste collection has also been observed. This occurs because all the advanced apparatus obtained are not operated and maintained appropriately by workers (Sweden, 1998).

- **Conservation of the environment**

The conservation of natural resources is an important factor to promote sustainability (Murtagh, 2020). While analysing different issues encountered, like extinction of different plants, animals, fungi and microorganisms, observation conclude that as the number of populations is increasing, the number of trees that are fell down to build new cities are increasing drastically. This action causes a negative impact in the environment, the landscape heritage and the green spaces. This action has created many floods prone areas in the community resulting to a nightmare to the inhabitants during heavy rainfall (Mbodi, 2015).

Moreover, climate change contributes in the degradation of our natural resources like the eco-system, freshwater, coastlines and wetlands (Wentz, 2016).

- **Transportation**

In the modern era study proves that man is highly dependent on their transport making the city unsustainable. Research shows that there is a huge amount of pollution of about 150-250% emitted from ships in the year 2007. The amount of energy used for the transportation system has increased to 37% from the year 1990 to 2005 and the amount of carbon dioxide emitted in the environment, is expected to increase up to 57% from the year 2005 to 2030. The amount of energy used in motorway has increased up to 41% from the year 1990 to 2005 (StatsMauritius, 2020). It can therefore be concluded that energy consumption for the transportation system rises faster in different countries. This is because there is a high demand in the number of vehicles per family. This action can contribute significantly to cities' carbon footprints, petrol consumption, smog, traffic jam, and excessive noise and increase in the number of health problems (Camaren, 2012).

3. Methodology

The village of Central Flacq was selected to carry out this study. The village which is situated in the district of Flacq, has been classified as one of the most developed districts in Mauritius. This particular region has recorded different types of development works, namely residential, commercial and industrial buildings since the year 2006.Moreover, to maintain sustainability in the district, the latter is supervised by the District Council of Flacq which is situated in the centre of the district.

A thorough literature review was carried out and different parts of the Outline Planning Scheme and the National Development Strategy Plans for the District of Flacq were investigated. Questionnaires were disseminated to the staff of the District Council in order to understand the challenges of converting Central Flacq into a sustainable village.

The survey consisted of four main themes namely Recycling, Renewable Energies, Green Spaces and Transportation system. Based on main the findings of the literature review, recycling is very important as it reduces the amount of pollution caused in the environment, reduces the amount of energy which therefore reduces the risk of global warming. Renewable Energy is an important factor as it does not produce harmful gasses in the atmosphere. The risk of air pollution is very low compared to that of fossil fuel. Furthermore, green spaces have proved to be very important as it increases biodiversity, lower noise levels, and reduces air pollution. Open spaces offer pleasant and shady regions and help to regulate temperatures in summer. Moreover, transportation system is very important as it reduces traffic jams, address urban pollution, and address climate change in significant global communities.

These four main themes have been analysed in the survey. Based on the findings, recommendations were made, mostly focusing on concrete steps that may be implemented to solve some of the challenges.

4. Findings

The survey brought up many issues which were very pertinent to the local context.

- **Renewable energy**

The section on Renewable Energy brought up the following information:

- After reviewing the various proposals implemented in the survey, 62.9 % of the employees have chosen to implement solar energy for residential and commercial purposes. 50.5 % of the staff have chosen the solar electric pole project over the standard poles which are currently in use. In terms of the application of solar billboards and solar bus shelters in the community, the graph above shows that 62.9 % of participants prefer to use solar billboards and bus shelters operating with solar energy.
- The plan to install wind turbines in Central de Flacq has been quite successful, with 32% of the respondents are strongly agreed to do so in order to make the community more sustainable.
- The use of natural light was an essential topic to address with the local government's employees. According to the results, 61.9 % of the employees think that future buildings should consider the orientation idea and make greater use of natural light than artificial light throughout the day.
- Based on the findings, it is clear that the majority of the participants are in favour of the plan which is a positive aspect to switch to renewable energy.

• Green Space

Regarding Green Space, the following observations were made:

- 66 % of the participants are aware of the importance of recycling
- In addition, 22.7 % of the participants revealed that there is a shortage of green spaces for the inhabitants of Central Flacq. Furthermore, it was observed that 25.8 % of the participants complained about a lack of care for the green spaces in Central Flacq.
- However, 55.7 % of the employees and the inhabitants of Central Flacq believe the local government should spend more in green areas by transforming more state property into open spaces. Finally, 39.2 % of people support the plan to set aside at least 3% of each plot for green spaces or vegetable cultivation.
- After the data analysis, it is clear that the participants recognise the value of providing green spaces in the community which is good for health and for the environment.

• Transportation System

The different proposals regarding the transit system are analysed in this section.

- 29.9 % of the employees oppose the usage of gasoline-powered vehicles in the area.
- 46.4 % of the participants are agreeable to switch from gasoline cars to electric and hybrid cars to conduct home deliveries by firms such as Pizza Hut and Pizza and to travel throughout the neighbourhood.
- In addition, 26.8 % of the participants in Central Flacq are willing to implement the metro express project which is a mean of mass transport.
- Data analysis of the survey shows that 28.9 % of the participants are willing to develop and implement a walkable city idea in Central Flacq in order to minimise traffic congestion in the area and also reduce the risk of accidents.
- However, it has been highlighted that 23.7 % of the participants are opposed to the proposal of using cycles near the Flacq market, particularly on Wednesdays and Sundays.

5. Recommendations

Based on the findings of the literature review and survey carried out, the following recommendations must be adopted in order to fulfil the objective of making Central Flacq a more sustainable town in the future.

5.1 Recycling

Plastic bins placed at every bus stop, open area, and public beach for the collection of plastic bottles for recycling purpose is highly recommended. This concept has been conducted in various communities (for example, Curitiba in Brazil) which has been a success.

In addition, the concept of home composting should be encouraged by providing the inhabitants with compost bins to produce compost. This proposal has been very beneficial and it is advocate to propose same in the community. Furthermore, frequent E-trash collection campaigns at the home level and the exportation of same to other countries are recommended in Central Flacq.

5.2 Renewable Energy

Some countries like China, U.S, Japan and Vietnam have implemented the concept of solar energy in residential and commercial buildings, and same has proved to be very beneficial. It is suggested to apply the same concept in region. Moreover, the implementation of solar electric poles of led bulbs bearing a capacity of 40 Watts should be recommended in Central Flacq

Moreover, bus shelters and billboards which operate with solar energy are suggested to implement in Central Flacq. In addition, various communities have come up with the concept of wind energy to produce electricity for the country and this has been successul. It is therefore recommended to implement the same proposal in the locality.

5.3 Green space

It is highly recommended to convert different state lands in Central Flacq into green spaces and to have proper maintenance of same and for the existing one situated in Central Flacq. In addition, the concept of home gardening and urban gardening should be recommended to the inhabitants of Central Flacq.

5.4 Transportation system

It is highly recommended to encourage people and companies to use hybrid/electric type of vehicle in the community. The government of Mauritius is already providing schemes to encourage the use of these types of vehicles.

It is also recommended that pedestrian paths as well as cycle lanes be created in the centre of the village on encourage the concept of walkable village.

6. Conclusion

The research intends to highlight the various concerns presented in the introduction section of the research with relation to the notion of sustainability, such as environmental issues, unsustainable transportation, housing, energy, and land use management. In general, numerous issues have been taken into account in the recommendation section in order to achieve sustainability in Central Flacq.

The concept of recycling has also been taken into consideration. Different proposals like installing plastic dumpsters at every bus stop, open space and public beach, the implementation of suitable harvesting system in terms of freshwater conservation by the local authority. In addition, compost bins have been discussed in the recycling process. In addition, various types of renewable energy are used in residential and commercial structures as an environmentally friendly energy source that generates no pollution when compared to fossil fuels. For example, the use of solar electric poles, use of billboards generating with solar energy and the use of wind turbines in the coastal region.

This study introduces more green areas making the particular region more viable in the future. Aside from public green areas, the interior spaces of our homes, as well as community rooftops and vertical gardens, might all be repurposed to create a more sustainable town. The research also focuses on different opportunities that the government is offering to encourage people to use electric and hybrid cars. Similarly, efforts are being emphasised in the implementation of metro express in several locations of the Mauritius. In order to reduce traffic congestion and pollution in Central Flacq, the concept of a walking city was introduced near corporate buildings

The recommendations to transform the region of Central Flacq into a more sustainable village would be useful and provide a good change to the residents and for future generations. These recommendations can be extrapolated to other regions on the island to convert them into sustainable communities.

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INNOVATIVE AND DISRUPTIVE SOLUTIONS TO ADDRESS CLIMATE CHANGE ADAPTATION: TAKEAWAYS AND RECOMMENDATIONS FOR MAURITIUS HYDROMETEOROLOGICAL AND CLIMATES SERVICES

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Abstract

New ideas and tools have been recently developed encompassing social and political science and technological trade-offs. To boost advancing implementation and keep the 1.5°C limit alive, governments need to set-up disruptive decisions and listen to stakeholders in an innovative way, putting aside their preconcept and conservative ideas. As the latest IPCC report says, we are at a crossroads and decisions we make in 2022 may provide a framework for a livable future. We have the tools and know-how required to limit warming but may not be enabled to implement these: policies, regulations and market instruments have proved to be effective and if these are scaled up and applied more widely and equitably, they could support deep emissions reductions and stimulate innovation.

The Republic of Mauritius has a strong legal and institutional framework for disaster preparedness and response at national and local level, as it well known for its community preparedness, especially with respect to cyclones. Funding mechanisms for preparedness and response efforts are in place. There is a functioning Early Warning System (EWS) for hazards such as cyclones, tsunamis, and epidemics and, to a lesser extent, floods and landslides. To further strengthen the preparedness and response system, a significant effort is required to improve risk identification and information management system, and in particular flood early warning. Several guidelines and arrangements need to be further enhanced ranging from the design of simulation exercises to the pre-positioning of emergency stocks. Finally, existing capacities are tailored to manage average magnitude of disasters and the country must review its system to manage more complex emergencies such as industrial accident or whole-of-island pandemic.

In our paper, we shall introduce Strengths, Weaknesses, Opportunities and Threats, considering not only governance and socioeconomic effects of climate change, but also providing technical light on the EWS to be implemented for an optimized set of climate change adaptation tools. Inputs shall be analyzed and presented taken from various diagnosis reports available since past few years for Mauritius, that helped understand how to strengthen capacities to pursue integrated and coherent solutions to reduce disaster and climate risks across the Sustainable Development Goals (SDGs). Takeaways and recommendations will be provided considering the key questions for the Governance and Institutional elements of the EWS.

***Key words**: Climate change, meteorological services, Hydromet, Early Warning Systems, governance, SWOT analysis*

Introduction

The Republic of Mauritius has a strong legal and institutional framework for disaster preparedness and response at national and local level, and the Disaster Risk Management (DRM) structure is decentralized.

Mauritius is well known for its community preparedness, especially with respect to cyclones. Funding mechanisms for preparedness and response efforts are in place. There is a functioning Early Warning System (EWS) for hazards such as cyclones, tsunamis, and epidemics and, to a lesser extent, floods and landslides. To further strengthen the prepared ness and response system, a significant effort is required to improve risk identification and information management system, and in particular flood early warning. Several guidelines and arrangements need to be further enhanced ranging from the design of simulation exercises to the pre-positioning of emergency stocks. Finally, existing capacities are tailored to manage average magnitude of disasters and the country must review its system to manage more complex emergencies such as industrial accident or whole-of-island pandemic.

The enhancement of the National Meteorological and Hydrological Services (NMHS) capacities requires key actions including strengthening its governance, ensuring strategic and legal frameworks and standard operating procedures, both for long term development and more optimal contribution to Early Warning Systems (EWS). This will help more effective collaboration with EWS stakeholders with a clearer understanding of user requirements (civil protection, food security, water and sanitation authorities, municipalities, etc.).

This first Part provides a PESTEL analysis recalling high-level value-chain and linking it to the EWS stakeholders. It provides a comprehensive institutional analysis, together with a summary of the emerging issues from the Disaster Preparedness and Response perspective of the activities and strategies at national level.

Disaster Risk Management (DRM) and other related Strategies

Political (P):

The overall agreement of the Indian Ocean Commission (IOC) Member States sets-up a Regional Climate Centre (RCC or RCC-Network), a Regional Instrument Centre (RIC) and a Regional WIGOS Centre (RWC), in line with World Meteorological Organization (WMO) Regional Association I (Africa) recommendations, and in compliance with technical criteria. The Republic of Mauritius has developed a National Disaster Risk Reduction and Management Policy and a National Disaster Risk Reduction and Management Strategic Framework under the National Disaster Risk Reduction and Management Act 2016. The National Disaster Risk Reduction and Management Action Plan 2020-2030 identifies specific actions and related details to implement the National Policy and National Strategic Framework through 2030, this target date corresponding to the implementation period for the Sendai Framework for Disaster Risk Reduction 2015-2030.

The National Action Plan is organized into four strategic objectives as set out in the National Strategic Framework:

- Disaster Risk Governance: Ensure risk governance systems are enabled to face current and future disaster risks.
- Disaster Risk Reduction: Reduce disaster risk during the decade to 2030.
- Warning and Alert: Have in operation a multi-hazard, impact-based warning system and effective means of alert by 2030.

- Preparedness, Response and Recovery: Reduce the overall impact of disasters through better preparation and more efficient and rapid response and recovery.

However, capacities of all organizations involved in the EWS are only assessed superficially and training programmes need developing and more resources allocated.

Climate change activities in the Republic of Mauritius have been consistent towards sustainable development goals. The concept of a sustainable island was clearly defined in the "Maurice Ile Durable" programme presented in Parliament in June 2008. Since then both public and private sectors are making efforts to integrate climate change in new developments strategies.

Public and private sectors of the economy and the population of the Republic of Mauritius in general, are gradually becoming aware of the threat posed by climate change and climate variability. Some concrete efforts have already been made to mitigate GHG by integrating climate change issues into new development strategies. There is strong political will to further enhance the existing policies as to develop resilience to the adverse impacts of climate change and to ensure the achievement of sustainable developments goals.

Important factors that may positively affect the activities and strategies at national level from the Disaster preparedness and response perspectives include operations the status of the Regional Integrated Multi-Hazard Early Warning System for Africa and Asia (RIMES regional MHEWS) project and the potential to act as the 24/7 information provider hub as part of the MHEWS.

Economical and financial resources (E):

Governments of the Indian Ocean Commission (IOC) countries, including Mauritius, are still encouraged to allocate additional resources to reduce existing risk and prevent new ones. Mauritius may start to explore risk-financing mechanisms. Although the Meteorology Act 2019 is a major opportunity, there remains uncertainty about the administrative process, especially for timely and effective budget control and spending.

GDP per capita in Mauritius is projected to be approx. 9'800 USD by end of 2022: the tourism and hospitality industries which traditionally contribute around 24% of GDP and account for 22% of employment with significant spillover effected the whole economy (transport, agriculture, wholesale and retail trade, and administrative and support services), incurring an estimated 75% loss in value added, mainly because of drastic and fast action by the government to lock down and isolate the island during the pandemic in 2020. At the same time exports of seafood, textiles and apparel, and sugar were hurt by disruptions in global demand. Only the information and telecommunication sector grew, supported by heavy use of technological and teleworking services during the lockdown.

The Republic of Mauritius is highly vulnerable to the impacts of climate change and climate variability which are seriously impacting on the sustainable development of the country and has, therefore, developed comprehensive action plans to adapt to these. However, the costs of such adaptation measures are so exorbitant that Mauritius can only achieve its targets if financial support in terms of grant and technical support from partners is made available to enable it to implement the plans to protect life and property and mitigate any propensity of migration of its population. (Source INDC: 28 September 2015). The fundamental principles of sustainability and climate resilience are consistent with Agenda 2030 and the Paris Agreement on Climate Change the Republic of Mauritius signed in 2015.

The Adaptation measures adopted in the intended NDC includes for example a Disaster Risk Reduction Strategy Objective that is to understand disaster risk, implement disaster risk strategy, strengthen management of related governance, and invest in resilience. In addition, the Government of the Republic of Mauritius commits to adopt a responsible and environmentally sustainable policy regarding energy production, waste management and physical infrastructural development, in addition to mainstreaming climate change education for sustainable development. However, Mauritius has limited resources and is challenged by many pressing priorities such as free education, health care and eradication of poverty. A Marshall Plan on poverty alleviation is presently under preparation.

Social (S):

Global phenomena such as climate change are immediately translated into impacts on livelihoods and ecosystem health. There are many challenges and obstacles facing small island states in reconciling economic and social development and building their resilience in a sustainable manner. Climate change and other closely linked factors, such as water scarcity, pollution, food security and depleted fishing stocks pose serious risks which need to be accounted for. In the face of looming global challenges such as the triple economic, food and energy crises, care should be taken to ensure that the sustainable development concept is well understood to address not only the negative effects of climate change, but also to include social, equity and developmental dimensions, particularly when it comes to the provision of finance and technology.

With its population of approximately 1.3 million and 70% of which living in metropolitan areas or urban areas and 25% in rural areas, the republic of Mauritius needs to be proactive and agile when planning and always include the considerations of sustainability and resilience, including gender balance issues.

The WMO Climate Risk and EWS programme national outputs include gender-sensitive aspects, especially on the training and capacity building issues where the WMO can bring support (identification of gender-disaggregated user requirements, development of guidance for products and warnings responding to specific requirements of vulnerable groups, etc.) that ensures that the project is implemented with a gender-sensitive approach.

Science, Technology (T)

and innovative ways of solving challenges have been mainstreamed into daily life, acting as a catalyst for development. The Mauritius Meteorological Services is the sole authority mandated to provide weather and climate services for the general welfare of the citizens of the Republic of Mauritius, especially through the provision of early warning for natural hazards to reduce the loss of life and damage to property. With climate change and global warming, the frequency of extreme weather and climate events are increasing, resulting in increased vulnerability of the Islands of the Republic of Mauritius.

With the aim of mitigating the risks of disasters caused by tropical cyclone, heavy rainfall/torrential rains and floods/flash flood the network of observations on ground was improved and the exploitation of the Radar is being improved. Capacity building of the staff was given due consideration and main achievements in 2021-2022 include the upgrade of the Observation Network and the acquisition of Automatic Weather Stations:

- Doppler Weather Radar: The Doppler Weather Radar, a solid-state S-Band radar, capable of tracking tropical storm/cyclone up to a maximum range of 450 km radius. The Doppler Weather Radar became fully operational in March 2019. It has been further finetuned using rainfall and related echoes

available since 2019. Currently the on ground observed rainfall is better represented by the Radar echoes. Further calibration of the Radar is ongoing;

- Automatic Weather Station: 2 new AWS have been installed notably at Quatres Sœurs and Rivieres des Anguilles. A third one is planned at Baie du Cap by end of May. Three automatic rain gauge Stations were installed at Wooton, Providence and Bambous Virieux . 3 AWS made available by the SADC under the SDAC SARCIS Project were installed at Bagatelle, Plaisance and Midland Dam;
- Acquisition of new Automatic Message Switching System: with the current AMSS showing ad hoc failures the effective and timely service from the MMS became under threat. AMSS is a key communication equipment to reach the population with timely dissemination of warning bulletins and other daily weather and climate information and to maintain a high standard in providing quality service to the population.

On the climate mitigation side of the project, special attention is to be paid to specific local low Internet bandwidth and the need for customizable solutions. Social media awareness and potential for new services improving reach and engagement are opportunities offered by technology, even though problems with equipment exist and need to be solved.

Environmental (E):

The degradation of biodiversity of all ecosystems of the island (forests and other flora, rivers, streams, lagoons, seas, wetlands, coasts and reefs, etc.) is worrying. The threats to biodiversity are well-known: loss/destruction/degradation of the habitat, pollution in various forms, invasion of exotic species, over-exploitation. The endemic forest, for example, only represents 2 % of the territory's surface. In many cases, these are not threats any longer as the consequences are being already felt and are further worsened by climate change: recurring floods, coastal erosion (where it is predicted that 25% of beaches will disappear by 2050).

The impacts of climate variability and extreme weather events are becoming a concern to the Republic of Mauritius, including Rodrigues, St Brandon and Agalega. The climate of the Southwest Indian Ocean (SWIO) small island states is influenced by large ocean-atmosphere interactions such as trade winds. They are often affected by tropical cyclones and other extreme weather. Some of them like the Saint Brandon or the Cargados Carajos Shoals and Agalega Islands are threatened by sea-level rise as well.

Climate change and sea level rise monitoring has been enhanced in the following ways:

- Network of an increased number of automatic weather stations
- Installation of a new tide gauge at Agalega and another one at Blue Bay to monitor sea level
- Sea surface temperature is being monitored at Blue Bay as well as from ship reports in the Indian Ocean

To meet the Mauritius objectives under the UNFCCC, the following reports have been published:

United States Country Studies Programme (USCSP) on Inventory of GHG and Vulnerability and Adaptation
Climate Change Action Plan
Initial National Communication
Vulnerability and Adaptation of the sugar cane crop
Economics of GHG limitations
Vulnerability of coastal zone
Technology Needs Assessment
National Capacity Needs Self-Assessment
Stocktaking and Stakeholder consultation
The Second National Communication.

Legal (L):

National legislation provides an institutional and legal basis for implementing EWS, and further regulation is being prepared to better set out the roles of the various stakeholders in the country. In a country like Mauritius, vulnerable to severe weather events and disasters, having a strong legal framework to govern disaster risk management is critical.

In 2016, the Government of Mauritius Red Cross and IFRC Disaster Law drafted a disaster risk management bill that was passed into law, becoming the strong legal base that is the National Disaster Risk Reduction and Management Act 2016. In the aftermath of flash floods and other disasters in 2013, the Government of Mauritius decided to establish the National Disaster Risk Reduction and Management Center (NDRRMC) to improve overall coordination and to better define roles and responsibilities in the event of a disaster. A taskforce, including Government departments, ministries, and the Mauritius Red Cross Society, was created to develop a national legal framework for disaster risk management through the drafting of a bill. The bill was officially adopted into law in 2016 as the National Disaster Risk Reduction and Management Act 2016, which promotes a proactive all-hazard, multi-agency approach to disaster risk management that emphasizes building capacity at all levels from the individual to the institutional.

The Mauritius Meteorological Services Act 2019 resumes the main goals, functions, and powers of the Mauritius Meteorological Services (MMS) while describing the requirements for the Director and officers' positions, as well as the main regulations. It states that the MMS shall be the official authority responsible for:

- monitoring the evolution of weather and climate, including extreme weather, throughout the Republic of Mauritius;
- monitoring the progress of tsunami waves caused mainly by seismic activity;
- providing weather forecasts, advisories and warnings for the welfare and safety of the general public;
- providing climate services for the sustainable socio-economic development of the Republic of Mauritius;
- fulfilling the international obligations of the Republic of Mauritius under the conventions of the World Meteorological Organisation (WMO);
- fulfilling the international obligations of the Republic of Mauritius under the Convention on International Civil Aviation on Meteorological Service for International Air Navigation; and
- fulfilling such other weather or climate-related regional and international obligations as may be necessary.

It is also to be noted the Environment Protection Act 2002, amended in 2008[1], which provides protection and management of the environmental assets of Mauritius so that their capacity to sustain the society and its development remains unimpaired and to foster harmony between quality of life, environmental protection and sustainable development for the present and future generations; more specifically to provide for the legal framework and the mechanism to protect the natural environment, to plan for environmental management and to coordinate the inter-relations of environmental issues, and to ensure the proper implementation of governmental policies and enforcement provisions necessary for the protection of human health and the environment of Mauritius.

EWS stakeholders

Below we provide a non-exhaustive list of stakeholders, with a brief explanation of their roles in the EWS value chain, namely at:

- The global and regional levels the World Meteorological Organization (WMO) who implements for example projects funded through the CREWS Trust Fund. The WMO Regional Association RA1 is responsible for the coordination of meteorological, hydrological and related activities within Africa and in alignment with the AMCOMET strategy;
- The UNDRR (formerly UNISDR) which is the United Nations focal point for disaster risk reduction and oversees the implementation of the Sendai Framework for Disaster Risk Reduction 2015-2030, supporting countries in its implementation, monitoring and sharing what works in reducing existing risk and preventing the creation of new risk;
- Other international partners including research institutions, entities and industrial groups, companies, from the public and the private sector, science-policy interfaces who can help formulate EWS policies, and other financial partners with direct or indirect interests in the EWS;
- At global but also local level, the Civil Society representatives, mainly through the actions of the Non-Governments Organizations (NGO), are key partners in the EWS arena;
- Other stakeholders include at national level the media (TV, papers, radios, social media) who is an important stakeholder to pass on the information not only to the public, but also to the key users and beneficiaries of the EWS value chain;
- Municipalities and other types of local governmental authorities who are key instruments to convey information among local stakeholders and beneficiaries;
- Very importantly to be noted these governmental entities who not only design the rules and policies to be applied in Mauritius but also implement their mandate on a day-to-day basis:
    - the **Mauritius Meteorological Services (MMS)** which operates under the aegis of the Ministry of Local Government and Disaster Risk Management as an essential service, with 150 personnel working on shift. MMS is governed by the Mauritius Meteorological Services Act 2019 and is recognized in the Convention of the WMO as fundamental parts of national infrastructure, playing an important role in improving our understanding of the weather, climate, and the hydrological cycle over both land and sea, among other activities (WMO Role and operation of NMHS, 2015). Its mission is "to provide accurate and timely weather and climate services and early warnings for natural hazards for enhanced socio-economic development of the Republic of Mauritius";
    - the **National Disaster Risk Reduction and Management Centre (NDRRMC)**, under the umbrella of the Ministry of Local Government and Disaster Risk Management, with the mission to "to increase the country's resilience to disasters, reducing loss of life and negative impacts on economic, social, physical and environmental assets caused by natural and human-induced disasters through strategic commitment and engagement of all levels of society in understanding and managing identified threats. The NDRRMC has been administratively set up since 23 October 2013 after the deadly 2013 flash floods that affected Port Louis. It operates under the Ministry of Local Government, Disaster and Risk Management. It acts as the institution for the planning, organizing, coordinating, and monitoring of disaster risk reduction and management activities at all levels and is responsible to develop the national DRR Framework and Action Plan. In addition to the coordination role, NDRRMC plays an advisory role in the review of large development projects, and in some cases of building & land use permits (BLUP). It has a regular annual budget allocation for running costs.
    - Other important governmental entities include the **Ministry of Environment, Solid Waste Management and Climate Change (MoESC**, former Ministry of Social Security, National Solidarity, and Environment and Sustainable Development), with its Climate Change division and the division for Integrated Coastal Zone Management (ICZM). Other committees of relevance for DRR, especially in the tourism sector within MoESC are the Environmental Impact Assessment (EIA) Committee, the EIA/Preliminary Environmental Report (PER) Monitoring Committee and the Beach Authority responsible for the management and control of all public beaches in Mauritius and Rodrigues.

SWOT Analysis and Emerging Issues

The Table 1 proposes a synthesis of the SWOT analysis, presenting Strengths, Weaknesses, Opportunities and Threats with a "7S" perspective of the MMS.

The 7S model considers seven elements of organisations and institutions, three 'hard' (Strategy, Structure and Systems) and four 'soft' (Shared values, Skills, Staff, and Style), all of which are interrelated.

Table 1 - SWOT Analysis

Strengths	Weaknesses
• Existence of the Mauritius Meteorological Services act of Law (published October 2019) • Website providing the necessary elements on meteorology [22] • The MMS is an ISO-certified institution is the official authority in the Republic of Mauritius in all matters of weather and climate. • It has a well-qualified staff to deliver a 24 by 7 service to the public.	• Its contribution to the socio- economic development of the country is not perceptible even though very important: lack of visibility at national level. • Shortage in human resources in the different grades due to retirement of staffs. Young recruits tend to move away to greener avenue. • Limited budget allocation and thus scarce financial resources to modernise the MMS.
Opportunities	**Threats**
• Climate change is a real opportunity to modernize the service through advance technology and to focus on scientific research in parallel with the provision of services Potential for customisation and site-specific forecasts • New sources of funding, commercial services, and direct project funding. • Authoritative voice	• One of the major threats is insufficient investment in the field of meteorology. • The global village concept in the field of meteorology can represent a threat.

As a summary of the SWOT, we may conclude on the Capacity Development Strategy and Human Resources planning & Management needs, including Education and Training at the MMS. These do align with the strategic pillars defined by MMS for the coming years, and the enablers as follows (*indicates these integrate institutional components):

Key Recommendations and Conclusions

The Table 2 proposes a series of recommendations issued from part of the analysis above.

Table 2 - Recommendations

Strategic Direction	Enablers/recommendations
➢ *Improve accuracy weather forecast and advisories and warning for hydro-meteorological hazards and tsunami to build a more disaster resilient and climate smart nation*	1. Improve the competency of the human resources and continuous capacity building; 2. Improved network of Automatic Weather Stations; 3. Upgrade the existing storm surge model 4. Operationalized a High-Resolution Limited Area Model; 5. Maintain the monitoring of meteorological variables both at surface and in the different layer of the atmosphere; 6. Ascertain access to and use of integrated and interoperable earth and space-based observation system; 7. Optimise the use of the Doppler Radar System; 8. Work closely with Tsunami Service Providers of Australia, India and Indonesia; 9. Promote scientific research to increase understanding of extreme weather phenomena
➢ *Improve existing climate services for Agriculture, Water and Disaster Risk Reduction and initiate collaboration with the Renewable Energy and Health sectors to achieve the SDGs*	1. Setting up of the National Framework for Climate Services, as per guidance from the WMO; 2. Compilation of baseline information to monitor the impact of Global Warming on climate; 3. Co-production of tailored products and services; 4. Establishing a working arrangement with experts from the different concerned institution
➢ *Pursue the modernization of MMS*	1. AWS based on latest technology for the measurement of the different meteorological variables; 2. Improvement in the office space and work environment
➢ *Establishment of a Research and Development Section.*	1. Specialised training, notably in GIS and Data Analysis including programming, for existing human resource through scholarships and short courses; 2. Recruitment of additional human resource; 3. Acquisition of appropriate hardware and software; 4. Upgrade the existing Climate Database Management System; 5. MoU with local/international Academic Institutions and Research Centres in the field of Meteorology and Climate.

Other inputs were analysed and included in the recommendations below, taken from the CADRI partnership diagnosis report established in 2019 for Mauritius, that helped understand how to strengthen capacities to pursue integrated and coherent solutions to reduce disaster and climate risks across the Sustainable Development Goals (SDGs).

As demonstrated through this paper, we have the tools and know-how required to limit warming but may not be enabled to implement these: policies, regulations and market instruments have proved to be effective and if these are scaled up and applied more widely and equitably, they could support deep emissions reductions and stimulate innovation.

The Republic of Mauritius has a strong legal and institutional framework for disaster preparedness and response at national and local level, as it well known for its community preparedness, especially with respect to cyclones. It yet needs to be improved and offer modernized services and products to be ready and adapt to the climate change challenge of the XXIst century.

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- *Extract from the MMS Annual Report Financial Performance - period: July 2018 to June 2019 and its 3 Year Strategic Plan - 2022-2025*
- *The McKinsey 7 S model is a very good way of examining an organization and identifying elements that may not be contributing effectively to success. It is therefore a useful tool for using in a SWOT (Strengths, Weaknesses, Opportunities, Threats) analysis, to identify the strengths and weaknesses. It is presented here in details https://www.skillsyouneed.com/lead/mckinsey-7-s.html*
- *http://metservice.intnet.mu/index.php*

THE "BLUE ROOF" CONCEPT: STORMWATER ATTENUATION AT ROOF LEVEL

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WHY THE NEED FOR STORMWATER ATTENUATION?

Today, there is sufficient scientific proof which supports the fact that there is a change in the global climate, including change in rainfall profiles. One of the main reasons is the effect of global warming which is closely related to the depletion of the ozone layer due to human activities.

Due to the on-going changes in weather profiles, it is becoming increasingly important to consider the impact of climate change when undertaking master-planning and design of buildings. This will ensure that there are adequate strategies in place to eliminate or to minimise, as far as possible, the negative impact of climate change on a wider scale, including; sewer surcharging, overloading of existing drainage infrastructure, flooding of natural water courses, which may subsequently affect the surrounding environment.

For some new developments, during the planning stage, there is a requirement to submit a drainage strategy along with planning application, and sometimes this includes a Flood Risk Assessment, which assesses the risk of flooding in the area and provides necessary recommendations for stormwater management.

STATUTORY REQUIREMENT FOR STORMWATER MANAGEMENT IN THE UK

The need to demonstrate the impact of new developments on surface water run-off and subsequently the implementation of stormwater management systems has been enforced within the European Union through the European Water Framework Directive (the "WFD"). The WDF requires all member states of the EU to make the necessary provision for stormwater management through governmental bodies. In the UK the main organisations responsible for the implementation of the WFD include the Environment Agency (the "EA"), Department for Communities of Local Government (the "DCLG") and also for London, the Greater London Authority (the "GLA").

PROJECT BACKGROUND – ZENITH HOUSE

Zenith House is a residential development consisting of 309 residential apartments, including private and affordable houses. The scheme comprises the construction of a number of buildings ranging from 2 to 16 storeys with a landscaped courtyard and provision of 218 car parking spaces and 349 cycle spaces. The total site area extends over approximately 1.1 hectare of land.

Figure 1 - 3-D Architects' Model of Zenith House

A Flood Risk Assessment was required to support the planning application for the development, based on the National Planning Policy Framework.

PROBLEM STATEMENT

The challenge on this project was to investigate an alternative method for stormwater attenuation. This was required as part of the planning conditions to limit the discharge of surface water run-off routed to an external local water authority infrastructure to a maximum of 9 l/s.

The primary concern of the local authority in imposing such a restriction was to minimise the risk of surcharging the existing sewage system.

To control the rainwater run-off, prior to discharging to the main sewer, an attenuation tank and a flow control device are required.

Conventionally, a below ground attenuation tank with flow restrictors would have been the method to be adopted. However, due to site constraints and cost issues, a below ground attenuation tank could not be incorporated into the new development.

As such, part of the project sought ways to find an innovative and alternative method to attenuate rainwater run-off for the development whilst preserving the local authority's main objectives.

DESIGN CONSIDERATION

The volume of stormwater to be attenuated was calculated using drainage simulation software WinDES, modelling a specific storm duration and return period, and also limiting the maximum permissible discharge to the main sewer, in line with planning requirements. The total calculated volume to be attenuated was found to be 600 m3.

It was proposed to store 450 m3 of the stormwater in a concrete waterproof tank at basement level and the remaining 150 m3 at roof level, using an innovative method to control the discharge at roof level.

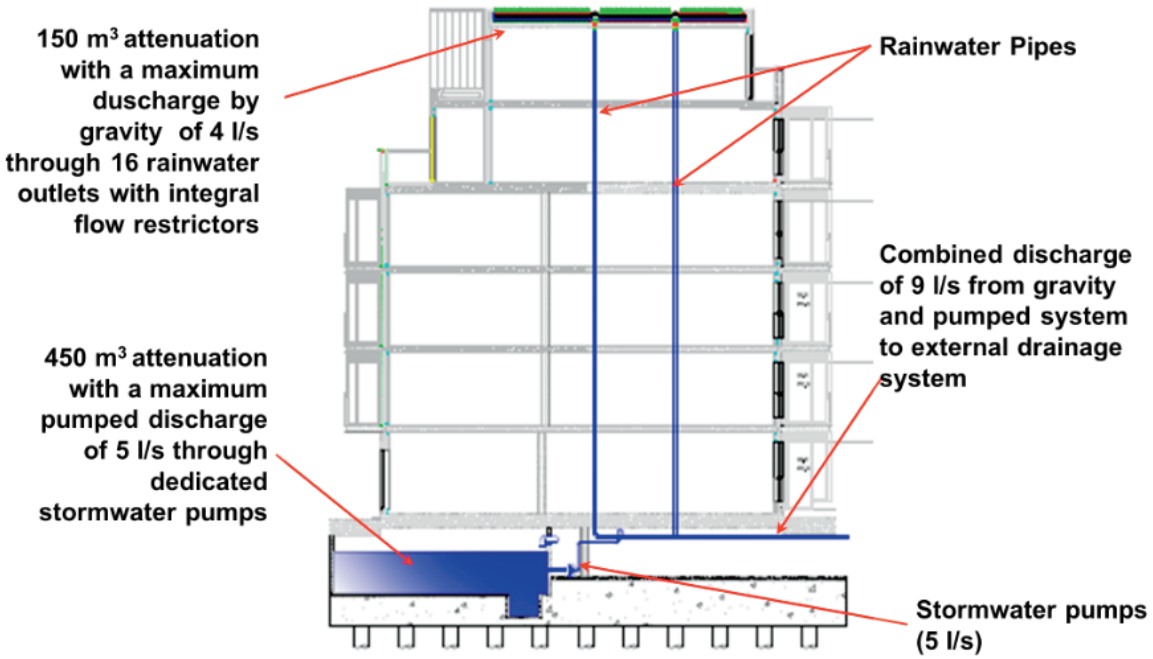

Figure 2 - Stormwater Strategy for Zenith House

THE "BLUE ROOF" CONCEPT

The management and control of stormwater at roof level is generally known as "Blue Roof" although there is no industry agreed definition or guidance in the UK relating to the particular concept. For the purposes of this dissertation and for ease of reference, the investigation and findings has been referred to in the context of the "Blue Roof Concept".

THE AUTHOR'S DEFINITION OF A "BLUE ROOF"

"A roof designed to allow the build-up of water above the roof waterproofing membrane (within various elements), not exceeding the designed hydraulic head, for a defined period of time, to enable attenuation of stormwater at roof level, and which also controls the discharge of rainwater run-off at a designed flow rate to meet the design requirements."

The roof was designed to enable the retention of stormwater for a defined period with flow discharge limitations, controlled through a new type of flow restrictor. The structural limitations with regards to loading were considered prior to start the design of the Blue Roof system to ensure that the maximum structural load would not be exceeded. A maximum water build-up of 150mm was agreed with the Structural Engineer. Thus, a maximum dead load of 1.5kN/m2 is available for temporary stormwater attenuation.

The rainfall profile used for the sizing of the attenuation volume required was based on a 1 in 100 years storm of 60 minutes duration, including 30 % for Climate Change, as stated in the Flood Risk Assessment.

The instantaneous rainwater run-off for specific storm duration can be determined from a hydrograph which shows instantaneous rainfall intensities against time. The outflow from the roof is controlled through an integral flow restrictor, which would significantly reduce the discharge through the rainwater outlet. The different values of the instantaneous rainwater run-off and stage discharge through the orifice were plotted and a typical representation is shown in Figure 5.

This difference in inflow and outflow results in rainwater backing up at a controlled rate at roof level. This allows temporary stormwater storage for a particular storm duration and return period, based on run-off constraints set by the Local Authority and Planning Conditions.

KEY COMPONENTS OF THE BLUE ROOF SYSTEM

Figure 3 shows a typical "Blue Roof" system integrated to a green roof build-up.
The key components of the Blue Roof system are as follows:

1. Integral Flow restrictor
2. Rainwater Outlet
3. Waterproofing membrane
4. Crate system (with a void ratio of approximately 90%)
5. Rainwater pipe
6. Filter Sheet
7. Structural Element
8. Roof Insulation
9. Timber Frame
10. Access & Inspection Chamber.

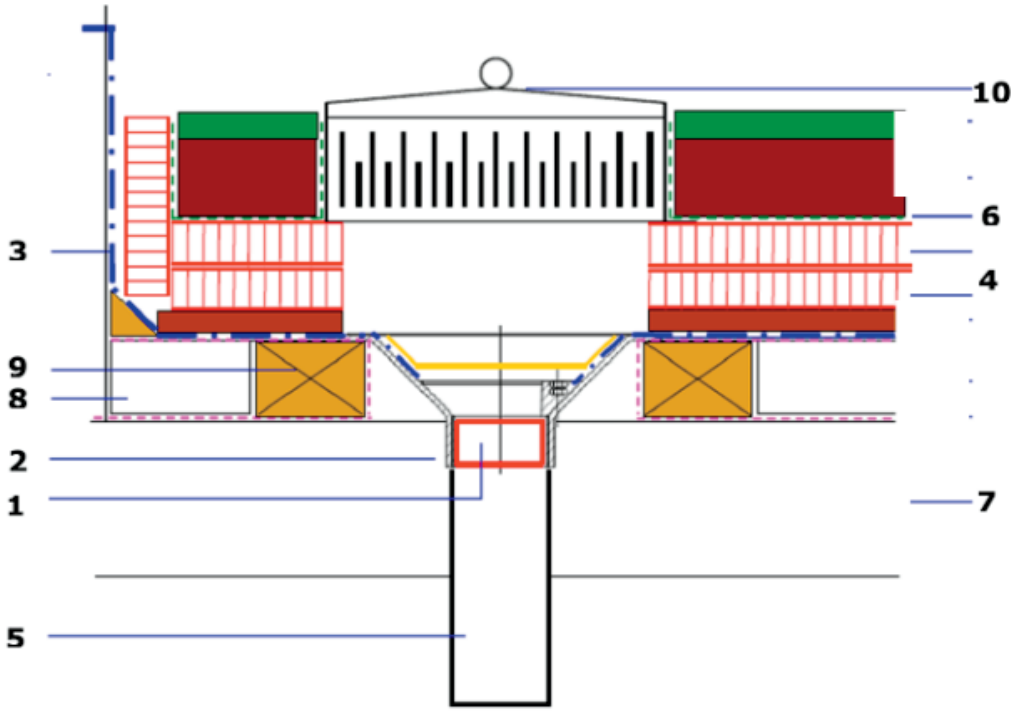

Figure 3 – Typical Blue Roof system with a green roof build-up

DESIGN, MANUFACTURE AND TESTING OF A NEW TYPE OF FLOW RESTRICTOR

The Concept Design

In seeking a solution for the Zenith Housing Project and following extensive testing and research, the author, in conjunction with Alumasc (a manufacturer of rainwater products), developed and manufactured a new product which enables rainwater discharge to be controlled at roof level. This control aspect is a key element and feature for the new method of stormwater management at roof level.

A number of iterations have been undergone before the final concept design of the flow restrictor was produced and agreed.

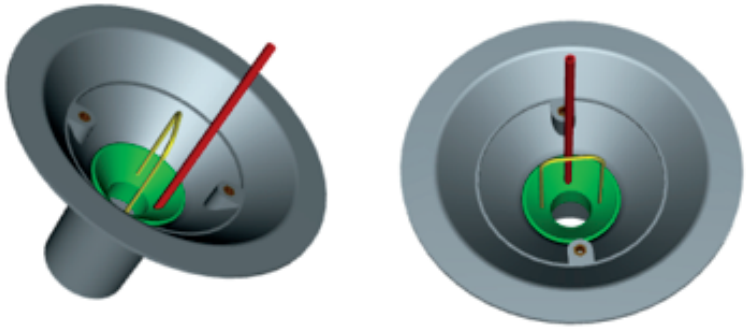

Figure 4 – The Concept Design

Manufacturing of the Prototype

A prototype of the rainwater outlet with integral flow restricted was manufactured by the rainwater specialist, based on concept design and parameters set by Ramboll.

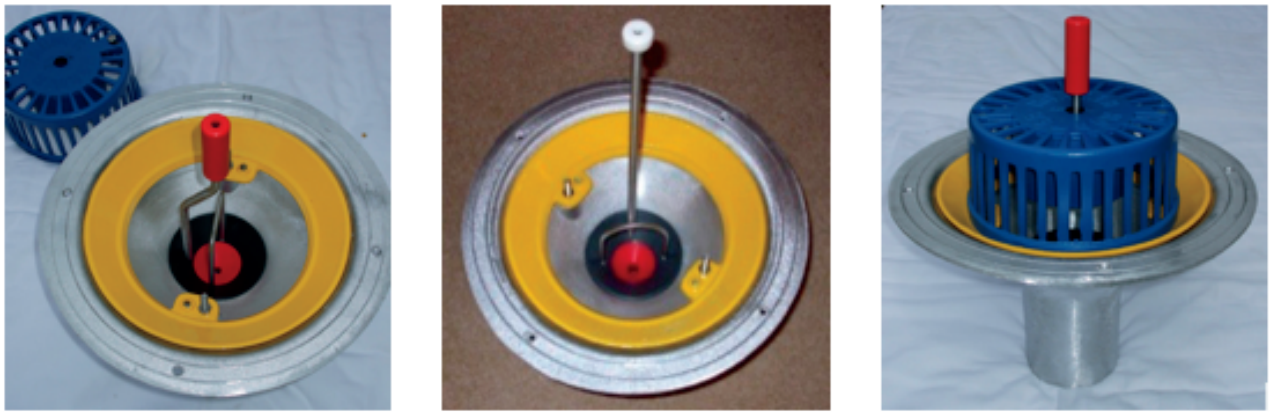

Figure 5– The Prototype – Rainwater outlet with integral flow restrictor

Testing

The outlet was set in a test tank with a free discharge below. Flow rate was increased in steps, and at each steady state flow rate a water depth was measured. All flow rates were measured volumetrically in an 80 litre volumetric container. All water depths were measured to +/- 0.3mm using a water surface follower.

Tests were undertaken on a 10 mm, 15 mm, 20mm diameter, 30mm diameter and 50mm diameter flow restrictor, all set in a standard 100 mm diameter rainwater outlet.
The results for the flow rates obtained from the tests were plotted against the hydraulic heads and a graphical representation is shown in Figure 7.

DATA ANALYSIS

Flow discharge through the orifice

The discharge through an orifice is directly related to the hydraulic head above the orifice. The equation used for the calculations of the discharge, Qo, through the orifice is given by:

$$\text{Orifice Flow, } Q_o = \frac{k_o D^2 h^{0.5}}{15000} \quad \text{(l/s)}$$

Where;

Q_o is the discharge through the orifice (l/s)

K_o is Coefficient of orifice

D is Effective diameter of orifice (mm)

h is the Hydraulic head above orifice (mm)

Theoretical calculations v/s Experimental data

The various calculated discharges through a range of orifice sizes against hydraulic head were calculated and results were plotted. Figure 5 shows typical stage discharge curves for various orifice sizes.

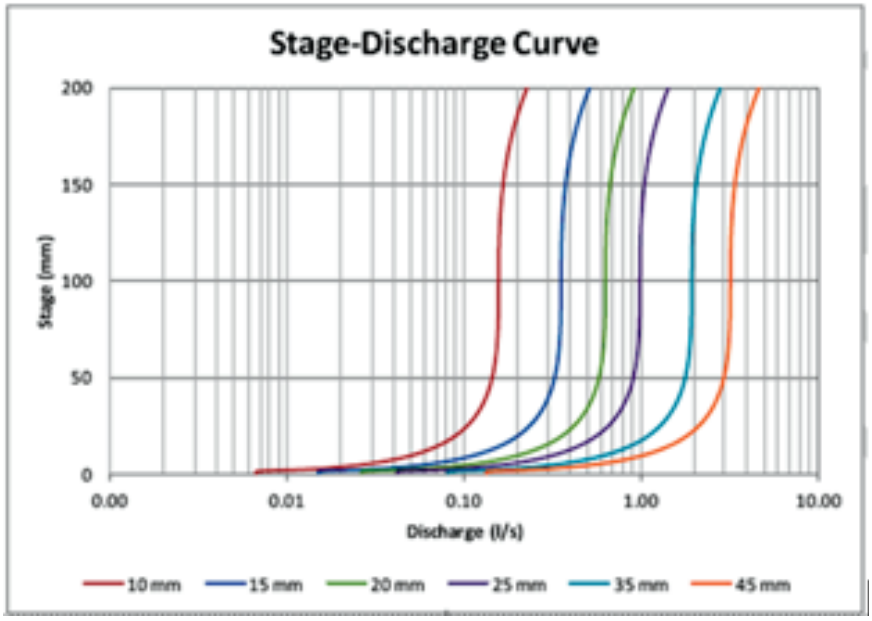

Figure 6 – Theoretical Stage Discharge Curve through orifice.

The results obtained from the testing of the various orifice diameters (as per test procedures set in previous section) were plotted against the hydraulic head and shown in Figure 7.

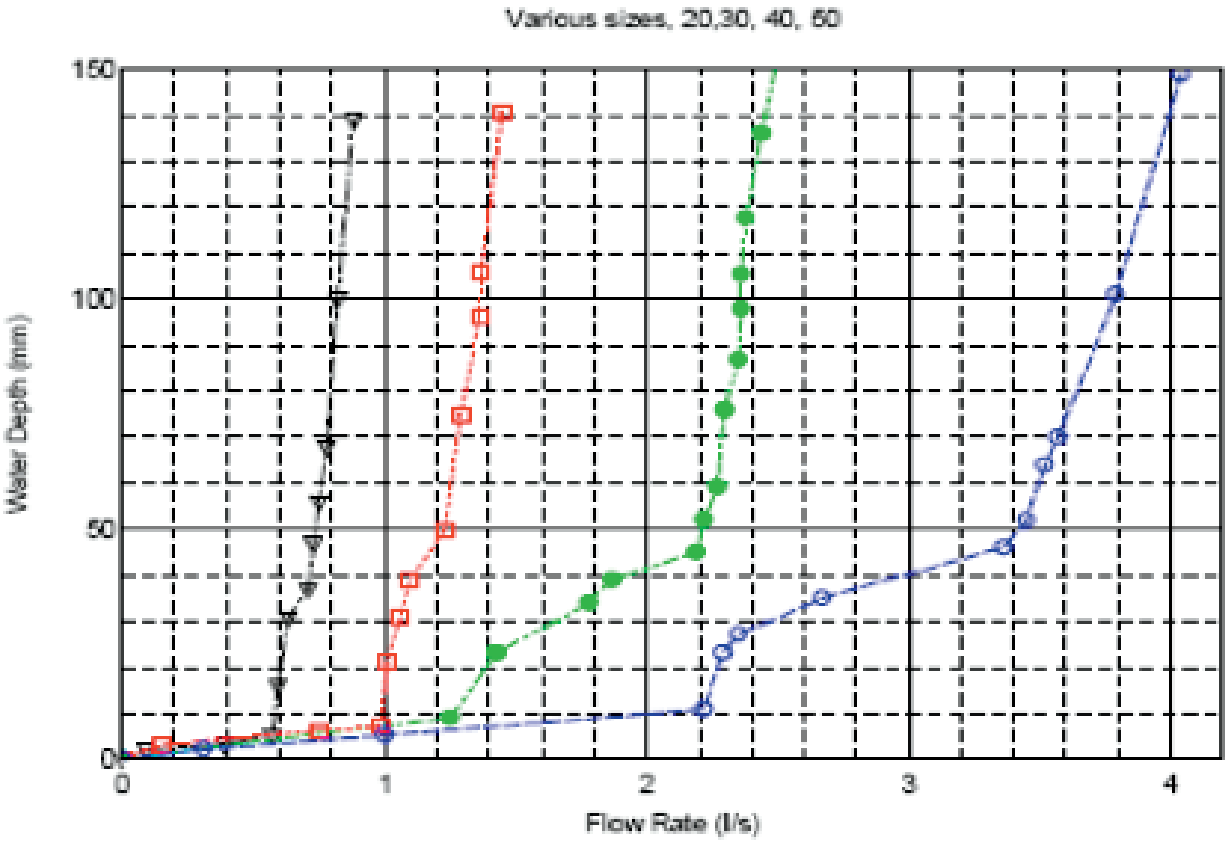

Figure 7 – Experimental Stage Discharge Curve through orifice

A typical representation which shows the correlation between rainfall profiles, stage discharge through the orifice and expected rainwater run-off with respect to time are shown in Figure 7 below.

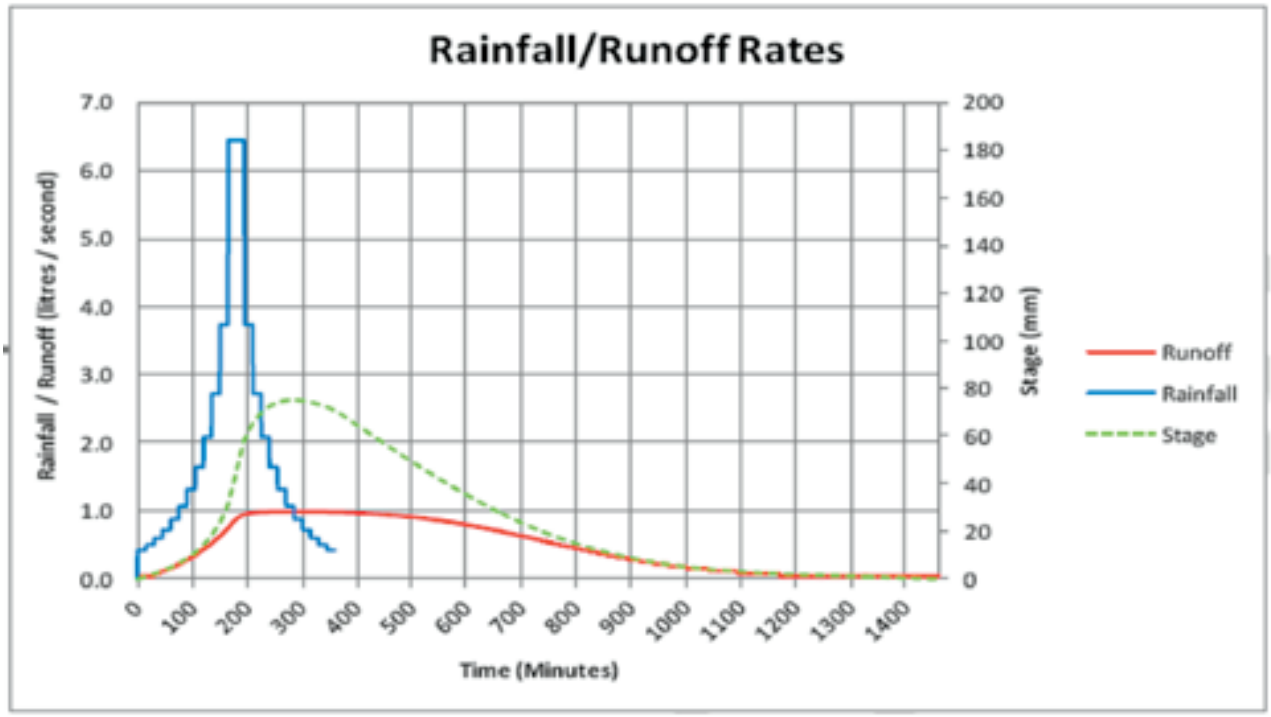

Figure 8 – Representation of inflow and outflow with respect to time.

The stage discharge curves from the theoretical calculations (Figure 5) and experimental data (Figure 6) were compared to validate the initial calculations. The analysis proved to be conclusive that the new type of flow restrictor will be able to meet the deign requirement which would enable the "Blue Roof" system to work as designed.

The product is currently available on the UK market and standard orifice sizes with technical data, including stage discharge curves are available, to assist in the selection and design of "Blue Roof" systems.

CONCLUSION

The Zenith House project was the first project in the UK to have stormwater attenuation at roof level with this new type of rainwater outlet with integral flow restrictors.

This Blue Roof concept can be considered as a design solution for stormwater management, specifically in urban areas with less space on site for stormwater attenuation or limitations in the maximum excavation depth.

Attenuation at roof level can be considered as a viable and cost effective option, specifically in situations where attenuation tanks cannot be located within or below a building or where an enhanced or greater attenuation volume is needed to supplement a traditional underground solution.

The additional structural load to accommodate a 150 mm of water build-up per square metre is 1.5 kN/m2, which in terms of structural cost is minimal as compared to excavation cost associated with a buried stormwater attenuation tank of the same volume.

Stormwater attenuation at roof level can be used in conjunction with underground tanks, hence possible cost saving with respect to earthworks and excavation.

KEY WORDS

SUDS, Green Roof, Stormwater Management, Surface-water Attenuation, NPPF, Blue Roof, Rainfall Profile, Climate Change, Sewer Surcharging.

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CONSTRUCTION SUSTAINABILITY IMPLEMENTATION IN GHANA WITH THE VIEWS OF PROFESSIONALS WORKING WITH CONTRACTORS

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Abstract

The study aims to establish the views of professionals working with contractors who provide design and construction solutions utilising environmentally sustainable construction practice standards. The core motive was the drivability and enabler to the local construction firms to have the adaptive capacity to deliver construction projects in an environmentally sustainable manner to contribute to global sustainable development goals. A qualitative research approach was complemented by face-to-face and virtual interviews. The data obtained revealed meaningful and socially salient findings to benefit construction sustainability implementation. The main interviewees were registered professional members from the Ghana Institution of Engineering (GhIE) working with contractors. Education and training and a centralised information hub with government support to ensure environmentally sustainable construction were the attributes which emerged from the findings of the interview survey. These studies have concluded that construction sustainability implementation is multi-faceted, as the current research corroborates. This study's results have theoretical, methodological and policy values because respondents for the interview survey were professionally registered members working with contractors and had a good working knowledge of the investigated issue. It is recommended that the professional institutions, corporate and government desire to preserve the country's ecosystem be guided by this study's adaptive capacity implementation guidelines.

Keywords *– Construction sustainability, Environmentally sustainable construction, Contractors, Sustainable development*

1. Introduction

Sustainable construction projects are foundational to a holistic pursuit of sustainable development goals (Dosumu and Aigbavboa 2020). Against this background, this study attempts to drive and enable contractors to have the adaptive capacity to deliver construction projects in an environmentally sustainable manner to contribute to global sustainable development goals. The remaining parts of the paper are organised into four sections. The first section reviews germane literature regarding environmentally sustainable construction implementation in developed and developing countries. However, the second section outlines the methodological approach adopted to achieve the aim of the study. The subsequent sections present the qualitative findings and discuss the literature's context and the conclusions based on the findings.

2. Literature review

Adjarko et al. (2016) posit that construction is a significant segment of the African economy. However, the sector is in its earlier stage of adaptation in ensuring Sustainable Construction (SC) due to several challenges, such as the lack of institutional structures promoting SC. The challenges conform to Abdullahi et al. (2019). They stated that sustainable construction practices could be difficult in progress by ignorance among the industry's key players due to a lack of shared information about sustainability, where the commitment of adaptive capacity becomes a barrier. Anugwo et al. (2018) identify the sustainable construction problems and challenges and point out the lack of information sharing and inadequate experience of most construction industry stakeholders. (Ofori et al., 2012) Opined that while many developing countries have achieved significant headway in improving the performance of their construction industries, in environmentally sustainable construction (ESC), the same cannot be said of the Ghanaian construction industry. The 2016 Infrastructure "Report Card" produced by the Ghana Institution of Engineering (GhIE) describes the state of Ghana's infrastructure stock as poor (GhIE, 2016). However, the infrastructure gap presents opportunities for stakeholders in the construction fraternity. Ofori-Kuragu et al. (2017) postulate that there is a need to meet the infrastructure need to provide sustainable work opportunities for Ghanaian contractors. However, maximising these requires effective partnerships in a well-structured and regulated construction industry.

The industry in Ghana needs to be modernised to keep pace with global industry advancements (Ofori-Kuragu et al., 2017). Ofei et al. (2016) acknowledge that the SC practices are the appropriate time in this generation which has emerged as a guiding paradigm shift from the traditional construction method. Djokoto et al. (2014) postulate that Ghanaian contractors have presented themselves as an industry yet to shift its traditional construction method practised. According to Ametepey et al. 2015, adaptability is about innovation change in the present action by the construction industry. Offei et al. (2016) conducted a survey and posited that the Ghana construction industry activity for socio-economic progress must be geared towards innovative adaptation. Adjarko et al. (2016) assert that a contractor's adaptive capacity for sustainable construction requires the zeal to serve public demand adequately. Nyakala et al. (2021) illustrate shortfalls in the organisations' awareness of the need to include environmentally sustainable approach considerations in their construction activities. The approach is too costly, and the documentation process is significantly complicated, leading to barriers discouraging contractors from seeking ecological certification (Shen and Tam, 2002). Adjarko et al. (2016) postulate that another identified problem is the lack of understanding of the sustainable procurement process and how to insert environmentally sustainable management requirements in a contract (Nyakala et al., 2021). Cooper et al. (2000) admit that employees' understanding of sustainable construction is one big issue. Construction firms are experiencing different drivers, barriers and practices regarding environmentally sustainable construction issues (Zhu, Sarkis and Geng, 2005).

3. Methodology

The data typology was accumulated through semi-structured interviews and was conducted amongst professionals working with contractors. The qualitative data interpretation consisted of conceptualising and transcribing the interviews under investigation. Interviewees were professionally registered members of the Ghana Institution of Engineering (GhIE), the Civil division only in good standing. The professionals who provide design and construction solutions and project supervision utilising environmentally sustainable construction standards were better suited to identify the main challenges confronting construction sustainability implementation. Case studies were conducted on four construction firms to gain in-depth knowledge regarding the construction sustainability and environmental practice in the construction firms.

One respondent was selected from each firm, summing to four interviewed respondents. The approach gave the participants a more significant opportunity to respond in their own words to bring out their actual understanding of the subject under study. Content analysis was used to analyse the data. Amadi (2021) submits that the content analysis approach enables the researcher to omit irrelevant words and terms by paraphrasing and summarising accounts. Thus, qualitatively, content analysis was used to analyse any occurrence of communicative language (Tembo and Akintola, 2021). Table 1 below outlines the interview layout.

Table 1: The outline of the interview layout

Theme No.	Theme	Question
1	The contractor's employees' knowledge of sustainable development	1
2	The implementation factors on adaptability and integration for best construction practices	2
3	The envisaged barriers preventing contractors from adaptation	3
4	The implementation aspects to adaptation success by the construction companies	4

4. Interview, Responses Discussion

Contractors employee's knowledge of sustainable development issues in the construction industry:

This section examines the interviewees' firm employees' knowledge of the construction industry's sustainable development issues through delivering construction projects. The responses of the interviewees are presented below.

Responses:

The professionals working with contractors shared their opinion as captured as follows:

"…the employees are categorised; we have the top management, line managers, supervisors and the operatives. The top management and line managers have some knowledge on sustainable development issues in the company, but the supervisory and the operative lack this knowledge…."
"…supervisors and operatives obtain instructions from their superiors. However, the understanding behind the reasons and idea is unknown due to their education and training level…."
"…we provide knowledge networks in small groups comprising of various stakeholders, which facilitates the global agenda of sustainable development…."
"…our people are within average when it comes to sustainable development issues in the construction industry…."

Based on this emphasis, the participants represented by the contractors indicated that the knowledge level of SD issues in the construction industry differs among different construction companies. The situation implies that employees' education and training influence employees' skill levels, as postulated by the study of Anugwo et al. (2018). The author argues that a sustainable built environment in Africa requires a solid education that equips the public, and the employees must be acknowledged. Accordingly, Ofei et al. (2016) also stressed the prudent nature of employee training relative to their ability to deliver environmentally sustainable construction at the workplace, consistent with the participants' assertion. Since the supervisors and the construction companies' operative takes instruction from their superiors, there is a piece of clearer

evidence that education and training are needed at the junior level on the grounds of adaptive capacity. Some professionals working with contractors posit that in comparing the current level of skills utilisation in the post-colonial era to the colonial era, there has been a downward trend in skills development. Interviewees pointed to a deteriorating quality of workmanship in buildings and other structures as evidence of a downward trend in skills development.

Implementation factors on adaptability and integration for best construction practices

The section aimed to establish the possible implementation factors on adaptability and integration among contractors for best construction practices. The responses of the interviewees are presented below.

Responses:

In response to the question, the professionals declared the following:

"…government should create an enabling environment; construction is about technology, innovation, profit, sustainability, health and safety, etc…."
"…for adaptability change to come, firms must be able to learn, although, there may be some mistakes, in the long run, firms would be able to learn some more…."
"…because sustainable agenda is fragmented, the understanding and the implementation principles are difficult; therefore, proper training must be maintained…."
"…there must be a tenacity to work through proper research and experimentation, if we can do that, then the adaptability integration of firms would emerge…."

The opinion of the professionals working with contractors is a point in the right direction. Their submission coincides with Nyakala et al. (2021), who admitted that adaptability and integration are by the willingness to adapt while assessing national adaptive capacity. Additionally, learning innovation and dissemination of appropriate technology transfer and sharing ideas within the construction industry would increase contractor adaptation. Therefore, if critical attention by the government, supported by the construction industry associations, focused on this shortage within the sector and instituted appropriate technology among players in the construction industry, it would lead to appreciable adaptive capacity.

Barriers preventing contractors from adopting environmentally sustainable construction

This section is aimed at establishing the possible barriers preventing contractors from adopting. The responses of the interviewees are presented below.

Responses:

In answering the question, the following has been noted:

"…most of the local contractors in Ghana do not have offices, and they operate without resources, contracts are given through what is term as whom you know…."
"…the size of the firm, profit levels, low consultation, workforce training, technology are some of the aspects…."

The professionals made revelations that affirmed Zhu et al. (2005) claim that some smaller firms sometimes do partnerships on a few occasions with changing workforce due to reduced number, usually due to resignation and wages payment. The assumption is that they sometimes experience a sudden rapid growth and occasionally drop in terms of the contract. Moreover, another suggestion is that the experienced persons

are not retained, which leads to imperfection, usually below expectation. It affects their performance in terms of environmentally sustainable construction. There is injustice in how contracts are obtained, a significant barrier preventing some contractors from adopting.

Possible factors that could influence the adaptation success of the contractors.

This section aimed to examine the possible factors influencing adaptation success among contractors. The responses of the interviewees are presented below.

Responses:

In response to the question, the professionals declared the following:

"…success would be achieved if construction companies are well organised…."
"…the construction companies must retain employees who have already acquired sustainable knowledge to be transferred to the next project rather than laying them off after one contract…."
"…the regulatory bodies and the consultancy firms must insist on sustainability principles right from the design stage…."
"…for adaptive success, there should be a willingness to search and understand to succeed, and that would influence the construction progress …."

The professionals working with the contractors opine that once there is belief in progress and adaptation, the industry players would automatically believe in change. Any research must be practised, and the players must decide on the rules and principles. The professionals working with contractors advocate that sustainability and a holistic approach to projects are founding principles of adaptive capacity. They have always attempted to have sustainability as a standard element in executing and managing projects (this is incorporated to varying degrees. They talk about it as a founding principle whilst projects are being done, but in reality, this doesn't always happen well). They occasionally have a good working relationship with the Green Building Council Ghana, developing Green Star tools, and have a specific sustainability team within certain projects. Much work now has sustainability elements or a key design principle, but something needs to be done to influence adaptation success.

5. Conclusion

The study aims to establish the views of professionals working with contractors who provide design and construction solutions utilising environmentally sustainable construction practice standards. The core motive was the drivability and enabler to the local construction firms to have the adaptive capacity to deliver construction projects in an environmentally sustainable manner to contribute to global sustainable development goals. This study's results have theoretical, methodological and policy values because respondents for the interview survey, including professionally registered members working with contractors, also had a good working knowledge of the investigated issue. These studies have concluded that construction adaptability implementation is multi-faceted, as the current research corroborates. The study results have provided indicators that will be a baseline for assessing contractors in Ghana. Furthermore, the validated conceptual thinking of construction adaptability implementation formulated in this study will reference researchers who will carry out studies relating to adaptive capacity implementation in the future. The practical implication is that construction adaptability implementation promotes environmentally-friendly construction activities.

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THE PATHWAY TO BUILDING RESILIENCE TO CLIMATE CHANGE IN SMALL ISLAND DEVELOPING STATES (SIDS)

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Abstract

This paper proposes several possibilities to building more sustainable infrastructure. More importantly, it highlights the findings of some of other researchers pertaining to the implemented solutions in their respective countries to address issues related to climate change. It focuses on 'what' to do rather than 'how' to do it since the how approach is extremely context dependent often due to the technical, managerial and financial barriers. Following the successfully implemented ideas in several countries, it leaves plenty of room for research in the Mauritian context so that Engineers can later incorporate these ideas in existing systems or new projects. Proper research allows for better planning and implementation of the projects. The barriers to implementing sustainable solutions seemed insurmountable mainly due to budgetary constraints and appeared unfeasible for small developing countries. While there seemed to have a huge reliance on the Government to implement sustainable solutions at a large scale, some have implemented the projects on smaller scales. The collaborative effect created by several small bodies to create a big system made the transition to green solutions easier to implement, run and maintain. This shows that small projects can be implemented step-by-step in small island developing countries like Mauritius to make a big difference in the long run.

Keywords: *sustainable development, infrastructure, resilience to climate change, SIDS*

Introduction

"Sustainable development meets the needs of the present without compromising the ability of future generations to meet their own needs" (The World Commission on Environment and Development, United Nations, 1987). Sustainability goes beyond controlling the emission of greenhouse gases to curb the effects of global warming, and also includes the preservation of our natural environment and effective use of resources. It targets economic growth that provides fairness and opportunity for all the world's people, not just the privileged few, without further destroying the world's finite natural resources and carrying capacity (Pronk & ul Haq 1992). It is an improvement in the quality of human life within the carrying capacity of supporting ecosystems (World Wildlife Fund). It should allow ecosystems to maintain its diversity and quality, and thus its capacity to support people and other life forms. It is also the potential to adapt to changes, be resilient and provide a wide variety of choices and opportunities for the future. It is a condition in which all members of society are able to determine and meet their needs and have a large range of choices to meet their potential needs and that of the generations in the far future.

How can infrastructures be made more sustainable?

Development of the civilisation has been at the expense of the natural environment. It is extremely difficult to make up for the deforested areas. The growth of dense forests occurs over centuries. The small amount of remaining natural environment, wildlife and nature reserves should be preserved. They should be integrated together with human development. The green environment has healing properties to human beings and is a necessity for the planet. There is a huge need for green spaces in urban areas in Mauritius. Agricultural lands are being converted into residential and commercial areas for one-off foreign investments. Buildings are being constructed with the concern for parking spaces. Mauritians are afraid that our little paradisiac Island will turn into a reinforced concrete platform. This should be prevented at all costs. Modern architecture should include green areas that can enhance or beautify the interior of buildings and entire cities with plants and flowers. The plantation of fruit trees are being considered in public areas and work environments. In times of crisis, self-sufficiency is a must. And if the fruits are not used by people, they are left to the natural environment or returned back to the earth, which leads to an increase in the fertility of the soil. Trees have been here for millennials, before mankind – we need them more than they need us.

After studying the problems associated with constructing an eco-city in Shanghai, the use of the near-natural method to construct an urban ecosystem in the city was proposed and introduced a theory and methodology for creation of "near-natural forests" and "near-natural water systems (such as rivers)." All the cases studied demonstrated that restoration using the near-natural method could be more effective, long lasting, and economical than existing methods, and that the method is now worthy of promotion as a means of constructing environments for human settlement. (pp. 203, Da & Guo 2014, in Kaneko et al. 2014) Human development have altered the flow of rivers and streams. If the early natural flow is successfully studied, models can be generated to restore or at least mimic the natural flow and transport of sediments. Similarly, for forests, the natural ecosystems should be studied and promote new development that is in harmony with nature. While it seem impossible, this was the challenge resolved in Shanghai.

Green Buildings

There are many types of Green Buildings researched, designed and built in many parts of the world. Some are self-sufficient and use only sustainably sourced energy. They can be equipped with PV panels for producing electricity, have low energy consumption devices and appliances, use natural light, use solar powered water heating, and in cold parts of the world, there are houses that rely solely upon the heat of the sun for heating in cold winters. In Europe, the Passivhaus (German for Passive house) is a voluntary standard for energy efficiency in a building, which reduces the building's ecological footprint. It results in ultra-low energy buildings that require little energy for space heating or cooling.

The inclusion of plants and green areas in buildings are not only to reduce the carbon footprint, but to also serve as a purpose. The future demand for food is expected to rise. The concept of Urban Farming is being implemented in big cities such as Paris. Old buildings, parking spaces and free spaces are being converted to productive spaces. The vegetables from one restaurant can originate from a building next door, thus allowing tremendous savings on transportation and reduction of carbon emissions. Singapore is increasing the technique of 'aquaponics' on the rooftop of their skyscrapers. Aquaponics refers to a food production system that couples aquaculture (raising aquatic animals such as fish, crayfish, snails or prawns in tanks) with hydroponics (cultivating plants in water) whereby the nutrient rich aquaculture water is fed to hydroponic grown plant, involving nitrifying bacteria for converting ammonia into nitrates. Therefore, no additional traditional fertilisers are required for the growth of fruits and vegetables. Even the luxurious hotels are now sourcing their food locally and are able to meet the demand.

Sustainable Electricity

Solar energy can be harvested in many ways. Solar farms convert and store this energy for everyday use. The heat energy can be used directly for heating water or even for cooking. Together with wind turbines and hydropower, all can meet the current demand and replace thermal power stations. Of course, there will be several barriers before it is fully implemented, but due to global warming issues, the time factor becomes a priority. The speed at which transitions are being made should increase drastically.

With sustainable electricity in hand, there can be sustainable public transport systems with solar powered electric trains/light rail or high speed trains using the harvested sustainable electricity. Factories can also run on the same electricity grid or produce their own. Many solutions are easily implemented on individual levels, but harder at industrial levels, which not to be forgotten, are major consumers.

Management of Resources

The over-extraction of minerals is creating a concern for the future generations. The future might be short of virgin construction materials. This can cause a problem in many industries. There should be more responsible mining, extraction of minerals and resources. Afforestation programs should be implemented. It calls for the implementation of modern techniques in agriculture on larger scales.

Intensive agricultural activities are reported to lead to loss of soil biodiversity. The soil biodiversity is a key factor in determining the quality of the crops and its productivity.

Preventing this loss or its restoration can necessitate simple technologies such as compost using local materials available or more advanced natural techniques such as the addition of biofertilisers or the introduction of specific microorganisms for each plantation.

The same problems on land is occurring in the oceans: over-fishing and consumption of petroleum. If petrol is successfully replaced in the near future, this will no longer be a concern. However, responsible fishing should be practiced. Fish farming can be practiced in many regions of the earth to meet the population's demand. This will allow enough time for natural aquasystems to recover and help them to survive.

Environmental and Institutional Management

Despite the fact that technically there are many possibilities and recommendations, they are not being actually implemented. As mentioned earlier, there are many barriers when it comes to transitioning to sustainable systems. These can also be in the form of policies and laws, staffing, budgetary issues, knowledge and current technology, law enforcement, and capacity-building. Capacity-building is defined as the process of developing and strengthening the skills, instincts, abilities, processes and resources that organizations and communities need to survive, adapt, and thrive in a fast-changing world (UN 2021). Innovative technologies emerge and people have to be ready for changes. The transition to sustainable systems comes with a high initial cost, similar to all transitions. If policies and laws are not strict enough, industries will keep doing what is more profitable for them and disregard environmental concerns. In Mauritius, it would be tough to rely on the private sector for a good sustainable approach since they do not have the best interest of the planet at heart. They are only running businesses with their best interest found in maximising their monetary profits in their current lifetime. It is now at least up to the Government to facilitate major changes.

There should be improvements in EIA system such that it has more control over what to execute. Projects that are harming the environment should not be executed even if it is a source of high initial revenue. The cost at rehabilitating the environment will be even more. There should be improvements in the management of waste, including solid, liquid, and gas. Problems should be tackled right at the source. Nowadays, there is the concept of using the 3R's – Reduce, Reuse and Recycle, which has a very wide applicability.

For example, in-process pollution reductions are referred to as "cleaner production," and are often much more economical than end-of-pipe treatment. In addition, wise water use, such as recycling and counter flow washing, contributes to raising the concentration of pollutants in the water and making treatment more efficient.

Solving these issues appeals for the participation of all citizens to handle environmental issues. Environmental issues, ecological thinking and sustainable development should be incorporated in education systems. In Japan, these educational programs have demonstrated an increased awareness in environmental concerns. When people acquire ecological understanding, they tend to also consider their position and role in the ecosystem (Orr 1992, and van Weelie 2002 in Balgopal and Wallace 2009, as cited in Esa et al. 2014 in Kaneko et al. 2014). Table 1 shows an example of the Environmental risks and their associated benefits and trade-offs. A better Risk Management and Leadership Development helps to anticipate problems and initiate protective actions.

Primary environmental risks	Typical countermeasures	+ / −	Environmental benefit and trade-off risks	Economic benefit and trade-offs	Social benefit and trade-offs
Climate change	Promoting biofuel	−	Deforestation, changes in land use	Investment cost	Competition with food
		−	Biodiversity loss		Loss of access to forest resources
		+	Reduced fossil fuel use	Revenue from the sales of biofuel	Employment opportunities
		+	Reduced GHG emissions		
Biodiversity loss	Increasing protected areas	−	Possible increase in incidents of wild animal attack against humans	Increased demand for budget	Restriction of productive activities Social disturbance by visitors
		−	Possible increase in pests		
		+	Increased flora and fauna	Possible revenue from park admission fees	Increased employment and income generation opportunities
Increased waste generation	Promoting recycling	−	Possible leakage of hazardous substances from recycling plants	Investment in the construction of recycling plants	Need to develop social systems conducive to recycling such as segregated waste collection at source
		+	Reduced demand for resources	Development of recycling businesses	Increased social unity and vigilance
		+	Reduced waste		
Water scarcity	Harvesting rainwater	−	Possible increase in mosquitoes and insects	Investment in installation of micro rain harvesting system	Possible increase in vector disease
		+	Reduced demand for piped water and irrigation	Reduced revenue/increased cost for the water service corporations	Increased water supply sufficiency Reduction in conflict over water use
Land degradation	Implementing agroforestry	−	Reduced sunlight on farms	Reduced income from crops	Requirement for coordination with forestry and agriculture groups
		+	Prevention of soil erosion	Diversified income sources	Stability in income
		+	Wind breaking	Averting risks of poor harvests	Respect and self-esteem from innovation and entrepreneurship
		+	Reduced heat and evaporation	Investment in timber production	
		+	Enhanced moisture level		
		+	Improved nutrient cycle		
		+	Enhanced biodiversity		

Table 1: Environmental risks and their trade-offs (pp. 4, Table 1.1, Kobayashi et al.)

Environment Rehabilitation Plans

Afforestation programs are among the few possibilities. The productivity of agricultural lands decrease with time. There is a need to focus on improved agricultural techniques, to test and implement new researches on larger scales.

Due to increase of average sea temperature and rising sea level, the death of coral reefs have eroded many beautiful sandy beaches. The future generations might not be able to enjoy a day at the seaside as we did. Therefore, coastal protection works against coastal erosion have to be undertaken. This not without consequences since the aesthetics of the beach environment can be lost if too many hard measures are implemented. In this case, prevention is better than cure.

The demolition of old buildings have always created a concern with the waste products. As seen before with the 3R's, the waste can be reduced, reused and recycled. New buildings can be designed and built using windows, doors, openings, electrical sockets and other fixtures recuperated from other buildings before demolition. The concrete and steel waste can be separated and recycled. For this to happen, the country should be equipped with the relevant facilities and equipment to perform the recycling exercises. It needs to be incorporated in corporate environmental practices and become a culture.

Socio-economic Considerations

Sustainability science is said to consist of two key components, namely a descriptive analytical mode based on an advanced form of complex system analysis, and a transformation mode oriented toward developing practical solutions for sustainability problems. An increasing emphasis is now given to the latter component to facilitate a socio-economic transition toward achieving stronger sustainability (Dedeurwaerdere 2013, as cited in Kobayashi 2014). While the importance of participation is already emphasized and a number of initiatives have been launched to promote access to information, participation indecision-making, and judicial proceedings over environmental matters, many countries still lag behind in developing the required legislation and enforcement mechanisms (Kobayashi 2012, as cited in Kobayashi 2014). Bringing the legislation is a good starting point, but the facilitation for successful implementation brings things to another level. Implementing, running and maintaining thus becomes a top level practice.

Conclusion

Technically, there are many ways infrastructures be made more sustainable. The pathway to building resilience to climate change exists. The transition to sustainable solutions encounters many barriers. There is a price to pay to prevent future damages and this is the consequence of our past actions. It is not too late to take the necessary actions. The environmental, social and economic factors need to be sustained. These include the natural resources and human-made infrastructures. Our future generations need to be able to have sufficient resources to have a good quality of life. There is an urge to control greenhouse gas emissions, preserve the natural environment, effectively use and reuse building materials, produce sustainable food and improve agricultural techniques. Sustainable energy, green building and sustainable production are only the starting points. The efficiency of the use of resources is another step. To reduce, reuse and recycle is not far from reality. The techniques need to be refined to eliminate scepticism in their applications. The implementation of sustainable projects requires commitment at a national level to incorporate these practices and for capacity-building. While new sustainable infrastructural systems are being established, environment rehabilitation plans will have to be implemented for a very long time, together with all development until hopefully, they will no longer be needed.

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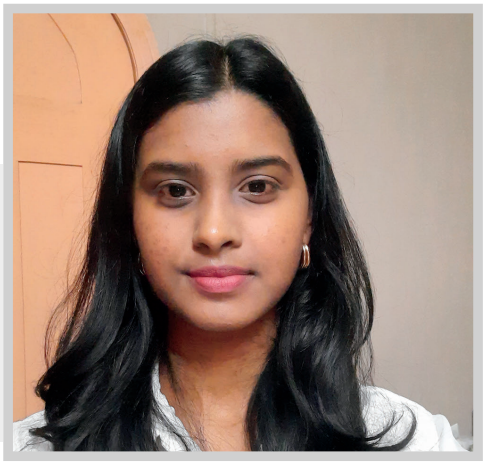
COASTAL SENSITIVITY ASSESSMENT TO THE IMPACT OF CLIMATE CHANGE IN MAURITIUS USING THE COASTAL SENSITIVITY INDEX (CSI) METHOD



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Abstract

Coastlines are highly prime economic and recreational areas for small islands. Growing impacts of climate change have added to the challenges facing coastal areas, whether it the form of stronger winds during cyclonic events, sea level rise owing to higher surface temperatures, stronger storm surges, marine pollution, loss of habitats for the marine ecosystems, coastal erosion or receding shorelines. Given that several stakeholders operate in these areas, the importance of understanding the vulnerability of these areas is growing. The vulnerability of any area is influenced by a number of physical parameters characterising the area. The Coastal Vulnerability Index (CVI) method is one of the first geospatial concept that was developed to map the vulnerability of the coastal zones. It is a rating method and scientists have combined its concept with geospatial technology to map the relative variations in vulnerability along coastlines. This method considers the following factors: Geomorphology, Shoreline change rate, Coastal elevation, Coastal slope, Wave height, Tidal range and the degree of relative sea-level change throughout history. An improved version of the CVI, is the Coastal Sensitivity Index, CSI, which is particularly relevant for coastal sites rich in coastal and marine ecosystems. A CVI/CSI map can serve as a working tool to support the development of Integrated Coastal Zone Management Plan, for effectively managing this area and to support the development of coastal resilient infrastructures. The CSI analysis combined with geographical information systems was conducted in the region of Roches Noires, located in the north east part of the island and which will be used as a case study. This region was chosen as a study area since during the last few years, it has been subjected to numerous coastal infrastructural developments and also, it includes several environmentally sensitive areas such as mangroves and wetlands. The CSI analysis was mapped and it could be noted that the analysis returned an estimate of 13% of the study area fall into the very highly sensitive group.

***Keywords**: Coastal Vulnerability Index (CVI); Coastal Sensitivity Index (CSI); Coastal zones: Coastal Vulnerability; GIS and Mapping.*

Introduction

As carbon dioxide emission levels continue to climb, global surface temperatures are reaching new record levels. These will inevitably lead to extreme climatic events such as accelerated sea level rise, erratic rainfall and flood patterns, and unstable temperature rise and falls among others. These conditions are regrettably expected to worsen over time, further accentuating coastal deterioration. As evidenced in

IPCC's (Intergovernmental Panel on Climate Change) 4th assessment report, around 70% of the world's coastline will experience an average projected increase of 62cm (Roberts 2013).

The World Risk Report highlights Mauritius's precarious situation to the deleterious effects of climate change in its ranking whereby the island is ranked the 13th most disaster risk-prone country (Houlder 2017). Boasting a 322km long coastline with mostly sandy beaches and part gravel beaches and rocky cliffs, Mauritius has long been lauded for its beauty. However, over the years, developments along the coastline coupled with the accelerated effects of climate change have made coastal environments particularly sensitive (Doomun 2016 and Fakun 2018).

This study hence focuses on the sensitivity to climate change impacts of part of the north eastern coast of Mauritius, more precisely at Roche Noires.

Problem Statement

Coastal environments are home to various economic, social, and recreational activities, which can have a major impact on a community. Therefore, the whole ecosystem is particularly vulnerable and sensitive. Impacts brought about by climate change can disrupt the community, especially for small islands such as Mauritius whereby coastal environments provide a source of livelihood for local communities through activities such as fisheries, algae farming, tourism to name a few. It is therefore of crucial importance to evaluate and constantly monitor the coast's response to the changing effects of climate change and prepare adaptation measures accordingly.

At the national level, Mauritius lacks expertise in dealing with the study of coastal environments due to a limited expertise and technical assistance. Risk assessment of the coastal zones of Mauritius has just recently begun with the CVI project of the MOI in 2018. Accordingly, a CSI was developed during this study in order to assess the impacts and response of the coastal ecosystem to the effects of climate change. The objectives of this study was therefore to assess the current situation of coastal zones throughout the island through desktop studies; identify coastal hazard risks inherent to the study area through site reconnaissance and interviews in order to determine variables for the CSI study and consequently to produce a CSI map which, in combination with GIS can serve as an assessment tool to study the impacts and response of the coastal environment to climate change effects, as well as serve as a guide to long-term coastal management and integrative decision making.

Study Area

For the purpose of this study, the coastal village of Roche Noires, located in the north eastern coast of Mauritius, with a geographic coordinate of latitude -20 06' 40" and longitude 57 42' 44" was selected. Roches Noires displays several land use developments such as residential, recreational and commercial. Figure 1 below show the geographical location of the study area which is found within the district of Riviere du Rempart. The focus of the study is along the coastline from Pte de L'Embarcadere to Bras des mers des Fregates.

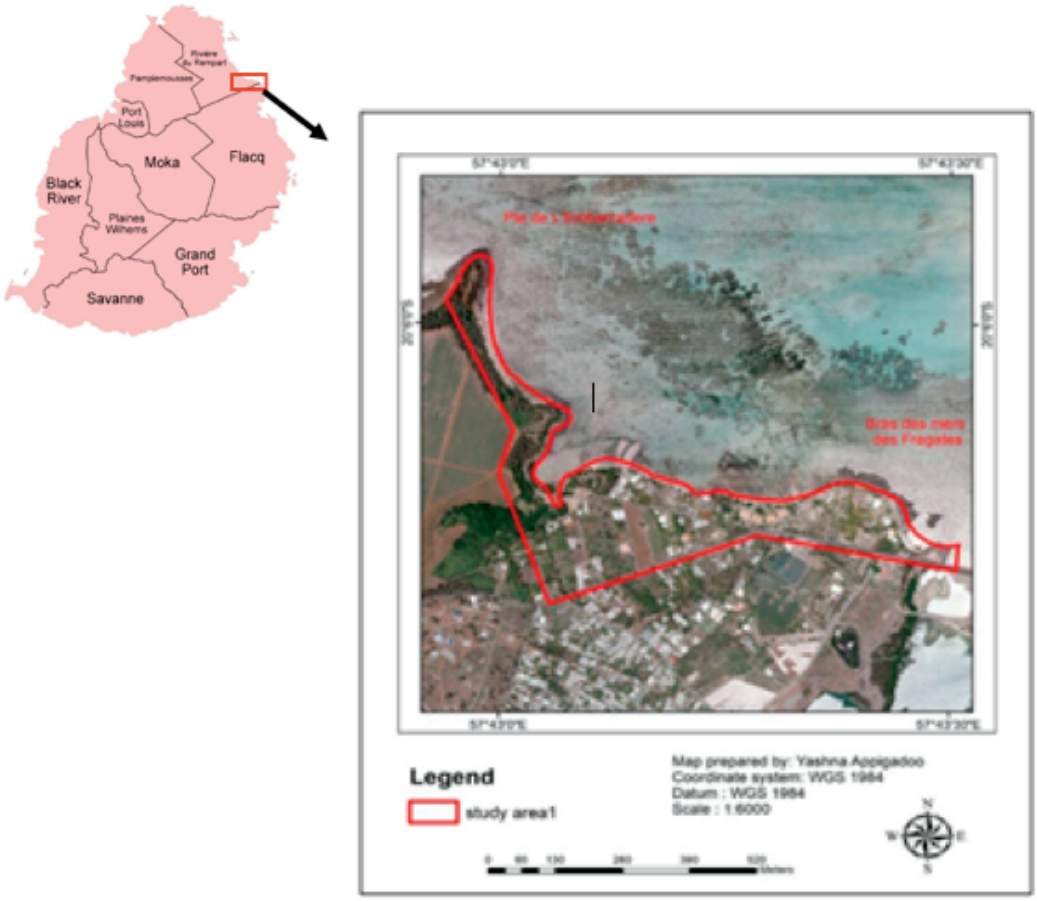

Figure 1: Study area of Roches Noires

Natural and Physical Features of the Study Area

This part of the coastline is bordered by a mix of both sandy and rocky beach. Environmentally sensitive areas such as mangroves marsh land and wetlands form part of the coastal ecosystem. A seawall of about 600m in length, extending alongside the frontages of the seafront properties and varying between heights 1 m to 2m has also been observed on site.

Over the last 10 years, infrastructural developments such as the Smart City of Azuri Project and construction of the Radison Blu Hotel have been sources of disruption to the coastal ecosystem.

As well, the coastal geomorphology has been influenced by extreme weather events such as storm surges, sea level rise and coastal flooding over the years.

Literature Review

While most use climate change and global warming interchangeably, scientists prefer to use the former term with reference to complex shifts in weather patterns and climate systems.

The Intergovernmental Panel on Climate Change (IPCC) indicated in its fifth assessment report that the world's climate is heading toward a state that will very certainly have lasting negative effects on a number of sectors, including the economy, the environment, and the lives and means of subsidence of people, particularly for those living in land-locked nations, small island developing states, and least developed countries (Doomun 2016) given their lack of resources and resilience which will make getting back on their feet afterwards more challenging.

Coastal areas in particular are essential for socioeconomic developments like transportation and navigation, shipping and port activities, providing means of recreation and tourism, and providing space for agriculture in some regions in addition to energy production. Moreover, they contain sensitive ecosystems such as wetlands, mangroves, coral reefs and beaches that are equally important for a community or nation to sustain.

In line with this, climate induced coastal hazards not only put in peril lives of people living along the coast, but also the livelihood of a whole community. Sea level rises are threatening basic utilities and services such as water; electricity and communication; road and building infrastructures; emergency services; as well as the environmental ecosystem through wetland flooding, causing loss of habitat for marine creatures and destructive erosion.

The impact of these natural events has been greatly exacerbated, producing 1) wind driven waves of increasing height, resulting in storm surges, 2) an increase in intensity and frequency of cyclones and storms, and 3) rising sea levels. With 2018 being recorded as the fourth hottest year by NOAA following 2016, 2017 and 2015 (Schmidt 2019), the escalation in global temperature is further expected to worsen and cause irreversible effects on our coasts.

Oceans absorb more than 90% of the heat from greenhouse gases. As per IPCC, the global sea surface temperature changed on average by 0.11°C (Doomun 2016), with an 8.5cm rise in sea level observed during the past 25 years. According to IPCC's 14th special report, the average sea level will rise between 26 to 77 cm by 2100 (Nunez 2019).

Mauritius as a Small Island Developing State and owing to its geographical location in the cyclonic belt of the Indian Ocean is highly susceptible to the impacts of climate change, specifically along its coasts (UNDRR 2020). Mauritius is listed as the 14th country with the highest disaster risk and the 7th country with the greatest exposure to natural hazards in the most recent World Risk Report 2014 (Houlder 2017). Threatening climate change effects can already be seen at the local level as Mauritius continues to experience a rise in temperature by 1.39 0C and an estimated sea level rise of 5.6mm/year. While the global average rise in sea level is 3.3 mm/year, the analysis of sea level at Port Louis has grown by 8 mm/year over the past ten years (2011 to 2020) compared to a long-term mean rise of 4.7 mm/year (between 1987 and 2020).

According to a research conducted by Carretero et al. in 2013, a projected sea level rise of 1 m in low-lying areas could lead to landward seawater intrusion of 25 to 40 m, and in the worst case, up to 200 m. Sea water intrusion has already been noticed in 19 locations in the southeast, including Belle Mare, Palmar, Bambous Virieux, and Quatre Soeurs, among others (Ragoonaden et al. 2017). These sites have consequently been prioritized by the government for rehabilitation and coastal protection works (Ministry of Foreign Affairs, Regional Integration and International Trade 2021).

Coastal inundation is further anticipated to worsen due to an increase in the frequency and severity of natural disasters in our area, affecting a larger portion of coastal areas farther inland because, in conjunction with sea level rise and high tides, storm surge waves will be stronger.

It has been anticipated that in fifty years, structural damage due to coastal inundation will account for 1.4 billion USD and 43 million USD, respectively, for Mauritius and Rodrigues (Ministry of Environment and Sustainable Development 2012, JICA 2015).

Further studies along the west coast have shown that around 26 km of beaches that are essential to the tourism industry will likely vanish with the projected 1 m sea level rise in 2100 (Beebeejaun 2000) and by 2050, tourism revenue might be reduced by up to $50 million per year due to rising sea levels and coral reef degradation brought on by coral bleaching spurred on by warming ocean temperatures (Houlder 2017).

Additionally, coastal erosion in Mauritius is rapidly getting worse, seriously affecting a number of the island's well-known beaches. An article written by the Ministry of Foreign Affairs, Regional Integration and International Trade, Human Rights Division (2021) claims that over the last decade, erosion in certain locations has resulted in a 20-meter reduction in beach width. Another research study conducted by the Mauritian government on fourteen study sites (JICA 2015) shows that roughly 17% of the island's beaches are experiencing long-term erosion, while about 23% are accreting. At Pointe aux Cannoniers, a coastal village in the north of the island, the coastline has retreated by 10 m on average from 1967, with the volume of sediment loss amounting to 10,000 m3. This is primarily the effect of cyclones and heavy swells which is a frequent occurrence for the island. The shoreline in La Preneuse, a seaside community on the western coast, has also dramatically changed from 2011 to 2014, resulting in significant beach loss (Ragoonaden et al. 2017).

A coastal setback regulation was implemented by the government in the early 2000s as one of the climate change adaptation strategies for the National Climate Change Adaptation Policy Framework for the Republic of Mauritius. The 15 m setback specified by the Ministry of Housing and Lands was in use until 2005 and was changed to 30 m from the high water mark in 2004 to account for the more pronounced effects of sea level rise, storm surge, beach erosion, and coastal flooding during the past few decades. The Environment Protection Act of 2002, the Pas Geometriques Act, the Integrated Coastal Zone Management Framework (ICZM), and the Planning Policy Guidelines (PPG), to name a few, are further documents that govern developments in the coastal zones of Mauritius.

Other adaptation initiatives on the island include the million-dollar Riviere des Galets protective gabion wall project some 15 years ago but which regrettably continued to be ineffectual against recurrent storm surge events. After the gabion wall failed to keep coastal villagers safe, a second vertical boundary wall was built a few years later; though it lessened the effects of waves, it did not prevent flooding of the coastal village. When these precautions failed, Riviere des Galets was selected as an urgent case needing protection, and a rehabilitation project was established (Ragoonaden et al. 2017).

Regarding protection against beach erosion, the first coastal protection projects began in 1999 in some of the island's most affected communities, including Saint Felix, Cap Malheureux, Grand Baie, Pomponnette, Flic en Flac, and Morne Brabant. The intense storms of the 1990s, particularly Hollanda in 1994 caused damage to a number of physical, cultural, and social infrastructures, including public beaches, cemeteries, and coastal roads. Massive 7-meter-tall gabion walls were erected as part of the first beach erosion control plan, especially in the north, to protect sand dunes. However, the resiliency of the beach in places like Pomponette caused this pseudo attempt at beach conservation to be futile and ineffective as a result of lack of knowledge in the field of coastal dynamics (Duvat 2009).

Analyzing the coast is therefore a critical first step before proposing and putting into action adaptation measures, which depends on the assessment of coastal vulnerability and sensitivity to climate change. If not, ineffective actions may result in additional coastline disruption.

Materials and Methods

The analysis of the area under study was carried out in three parts namely; (1) survey questionnaire and interviews, (2) shoreline change analysis using aerial photographs, and (3) coastal sensitivity index assessment whereby only the physical characteristics of the coast were assessed and not the socio-economic factors such as population.

1. Survey Questionnaire and Interviews

This exercise formed part of the primary data collection to gather field data about the risk perception of the residents about coastal hazards. The questionnaire was a mix of close-ended and open-ended questions as well as Likert scale-based questions with the aim of (a) assessing the local community's knowledge and awareness about coastal hazards (b) identifying hazards that the community has had to face in the past (c) identifying parts of the coast most vulnerable to rising sea levels, storm surges and coastal erosion, including settlement areas as well as environmentally sensitive areas; and (d) assessing effectiveness of existing adaptation strategies.

2. Shoreline change analysis

Aerial photographs for the region of Roches Noires were used to digitize the shorelines for the years 1967, 1991 and 2013 which were then used for the shoreline change analysis. They were georeferenced on the ArcGIS software and the DSAS extension was used to carry out the analysis. This extension allows the analysis of shoreline change by representing rate of accretion and erosion. The area was divided into transects of 25m intervals and the Linear Regression Rate was calculated. These were classified into four classes demonstrating low, moderate, high and very high sensitivities whereby positive LRR values represented accretion and negative values represented erosion. This classification was then used as an input for the coastal sensitivity index assessment tool.

3. Coastal Sensitivity Index Assessment

A. Terrain Analysis

A digital elevation model of 10m horizontal resolution and 1m vertical resolution was used to model areas likely to be affected by a projected sea level rise of 1m from the high water mark and storm surges with wave heights ranging from 2.5m to 5m. This modelling was carried out using the raster calculator in ArcGIS and a coastal inundation map highlighting built ups at risk within the 30m coastal setback was generated.

B. Coastal Sensitivity Index Indicators

The coastal sensitivity index method is a method developed to assess the different levels of sensitivities of the coast to climate change impacts based on their geomorphology, land use, vegetation and slope (Shaw et al. 1998). This modelling enables evaluation of the coast's response to sea level rise and global warming (Hereher 2015), and provide coastal managers and planners with a framework for undertaking adaptation and resilience measures (Abuodha and Woodroffe 2010).

The CSI for this study was based on the following equation:

$$\text{Coastal Sensitivity Index} = ((a \times b \times c \times d \times e \times f \times g)/7)^{1/2}$$

Where a: coastal geomorphology, b: coastal slope, c: land use, d: flora and fauna, e: relative sea level rise, f: exposure to storm surges of different wave heights, g: historical shoreline change rate.

Each indicator was ranked based on a linear scale of 1 to 4 as shown in table 1. The ranking was slightly adapted from the study carried out by Doomun (2016) at the Blue Bay Marine Park in order to fit to the local conditions of the coast of Roches Noires. As well, other local documents and reports such as the Disaster Risk Reduction report from the Ministry of Environment coupled with knowledge about the site were considered when assigning the rankings.

#	Variables	Low (1)	Moderate (2)	High (3)	Very High (4)
1	Coastal geomorphology	Rocky beaches; Low cliff	Sandy rocky beaches	Sandy beaches backed with bedrock & artificial structures (seawall, rock revetment and groynes)	Sandy beach; sandy beach with cobbles beneath; sand beach dune
2	Coastal slope (degrees)	9.0 – 12.0 (Steep)	6.0 – 9.0 (Moderate)	3.0 – 6.0 (Almost flat)	0.0 – 3.0 (Flat)
3	Land use	Inaccessible, Abandoned Agricultural Lands	Parking spaces; Barren lands	Public infrastructures: jetties, kiosks, public beaches, parks used for recreational activities	Bungalows, residential area
4	Flora/fauna	Rocky beaches; Low cliff	Thin vegetation on sandy beaches; coconut and filao trees	Shrubs	Reef systems; mangroves
5	Relative sea level rise	0.0 – 0.9	0.9 – 2.0	2.0 – 3.0	>3.0
	(mm/year)				
6	Storm surge (wave heights in m)	5.0	4.0	3.0	2.5
7	Historical shoreline change rate (m/year)	(1.0) – (2.3)	(-1.0) – (1.0)	(-2.0) – (-1.0)	(-2.83) – (-2.0)

Table 1 - Ranking of CSI variables

Using the fishnet polygon from ArcGIS 10.4, grids of the size of 50m by 50m each were used (Figure 3) to store and represent data for each variable and classified according to their sensitivity based on the table above. The gridded cells method provides the basis for study within one specific area at a time for each parameter and also retains its scale during spatial analysis and displays information at a glance for the study area., This method is similar to that used in one of the studies for part of the Australian coast (Abuodha and Woodroffe 2010).

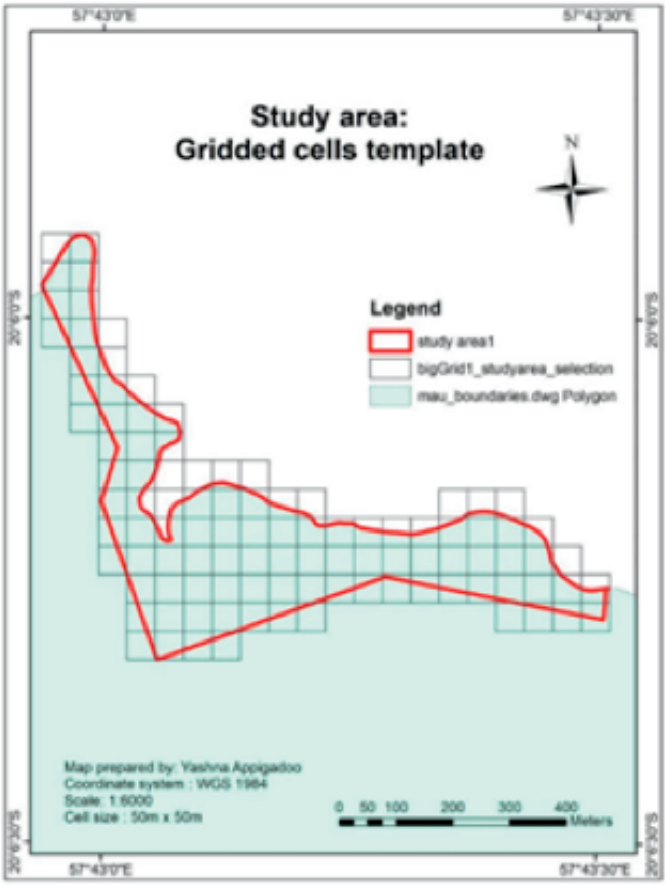

Figure 3: shows the study area divided into grid cells of size 50m x 50m each

Following the classification of each variable, the resulting shapefiles were then converted into raster formats and the raster calculator from the spatial analyst toolbox of ArcGIS 10.4 was used to compute the CSI for the study site using the above-mentioned equation.

Data Collection

Early on in the project, a field reconnaissance survey was conducted to identify the seven factors that would later be used to create the CSI. These seven factors were coastal geomorphology, coastal slope, land use, flora and fauna, relative sea level rise, storm surge wave heights, and historical shoreline change rate. It was crucial to identify and choose acceptable variables that are most suited to the study area to effectively monitor the coast's reaction to climate change effects.

Primary Data Collection

The walkthrough survey allowed collection of primary data relative to the local geomorphology, slope, vegetation type and land use. The following was observed.

1. The geomorphology primarily comprises of rocky and sandy beaches, with varied slopes that make different areas vulnerable to varying degrees.
2. The vegetation included filao trees and mangrove plantation.
3. Field observations have also revealed that a significant portion of the beach is bordered by seawalls, offering protection to seafront properties; and coastal erosion is occurring along a portion of the beach that is about 200 m long due to a lack of natural wave breakers like seagrass and vegetation.
4. A water channel, serving as a critical infrastructure for storm water dispersion opposite to the mangrove marshland was surveyed using a total station.

Secondary Data Collection

Further data for the development of the CSI map was acquired through secondary means and processed where necessary.

1. The Ministry of Housing and Lands provided the DEM of 10m horizontal resolution and 1m vertical resolution (for modelling of coastal inundation due to the projected sea level rise of 1 m and storm surge); and aerial photographs for the year 1967 and 1991 (for the shoreline change analysis).
2. The Ministry of Social Security, National Solidarity, and Environment and Sustainable Development (Environment and Sustainable Development Division) provided the coastline UTM 2013 and shapefiles of environmentally sensitive areas such as mangroves plantation and wetlands.

Results and Discussion

A. Analysis of survey questionnaires / interviews

The interviews and survey questionnaires have enabled a better understanding of the residents' feelings over what is taking place along the coast. They've all had some sort of coastal hazard experience, so it's safe to say that the danger is genuine and constant. The participants also appeared to understand that their own safety is their own responsibility and were open to taking part in mitigation strategies like community response plans and campaigns to raise awareness of the dangers of beachside living so that they are informed and better equipped to face, respond to, and cope with future disaster conditions. It was found that those who have lived longer and closer to the shore have higher levels of knowledge about the risks.

Additionally, it was inferred from their interviews that while the majority of the residential area in the study area consists of second homes that are frequently rented to tourists, a small number of the houses are also permanent homes that are thought to be extremely vulnerable to sea level rise and storm surges during cyclones. Additionally, it was discovered that the locals attribute the beach's current condition to human involvement, which they claim has sped up erosion and increased sediment loss, destroying the beach's aesthetic attractiveness.

B. Shoreline Change Analysis

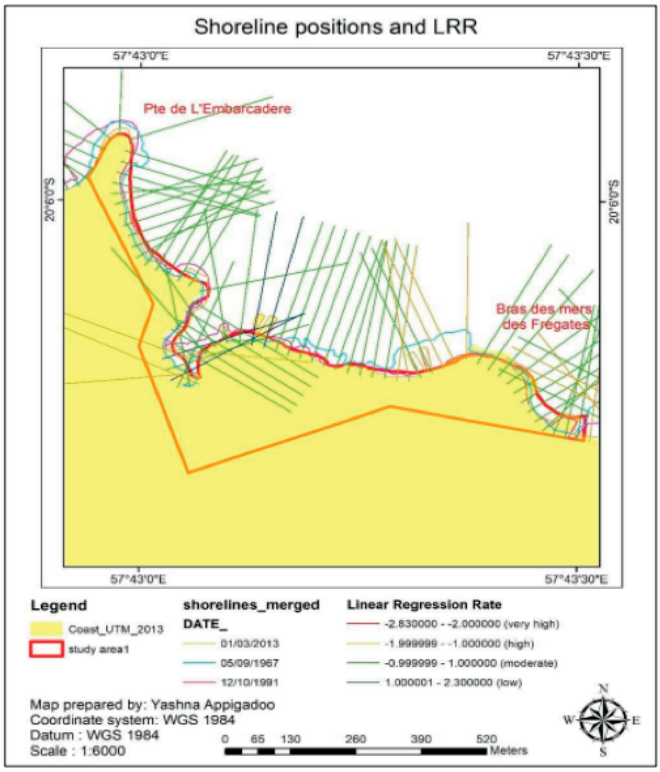

Figure 4: shoreline positions for 1967, 1991 and 2013

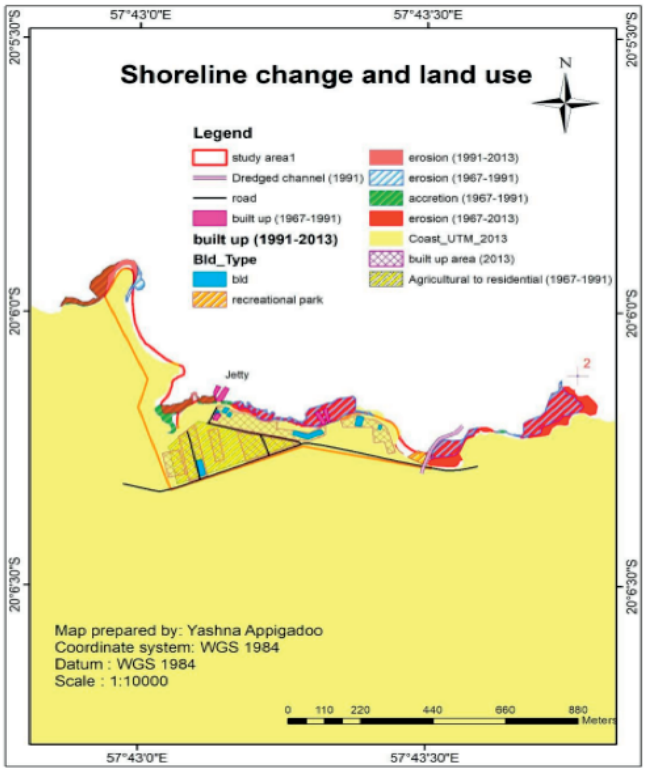

Figure 5: Shoreline change and land use

The coastline of UTM 2013 is used as a baseline from which the change in shoreline for the years 1967 and 1991 are observed. Positive Linear regression rate values denote accretion while negative values denote erosion. For this particular study area, the LRR ranges from -2.83 to 2.33 m/year. Therefore, the LRR range values were classified into four categories depicting very high, high, moderate and low sensitivity along the shoreline (Figure 4).

In Figure 4, the relationship between coastline retreat, erosion, and accretion is more clearly displayed and it is seen that over the 46 years, from 1967 to 2013, the beach at Roches Noires has seen significant erosion with very little accretion. The amount of erosion was determined to have surpassed the amount of accretion between the years 1967 to 1991, and this trend persisted between 1991 and 2013 while only getting worse.

The construction of the jetty (figure 5) in addition to the conversion of agricultural land use to residential use directly on the beachfront may have all contributed to this significant shift in shoreline between 1967 and 1991. Since there were numerous developments near the coast between 1991 and 2013, the further damage may have been caused by human interference. Possible contributory factors include the construction of the Radison Blu hotel and the Azuri coastal smart city, both of which are located on opposite sides of the study area approximately a kilometer away. Additionally, the development of

beachfront properties during this period prompted the construction of seawalls which changed the dynamic of the beach, resulting in a massive wash away of the sand and a subsequent acceleration of erosion. Moreover, the fact that the beach has not yet fully recovered since the restriction on sand mining in 2002 highlights just how much the shoreline has actually changed.

C. Coastal inundation map analysis

The DEM with a horizontal resolution of 10m and vertical resolution of 1m was utilized to create the coastal inundation map. The resulting map was then used to reclassify the sensitivity levels of the coast based on the areas inundated from the projected sea level rise of 1m and wave heights from storm surges (Figure 6).

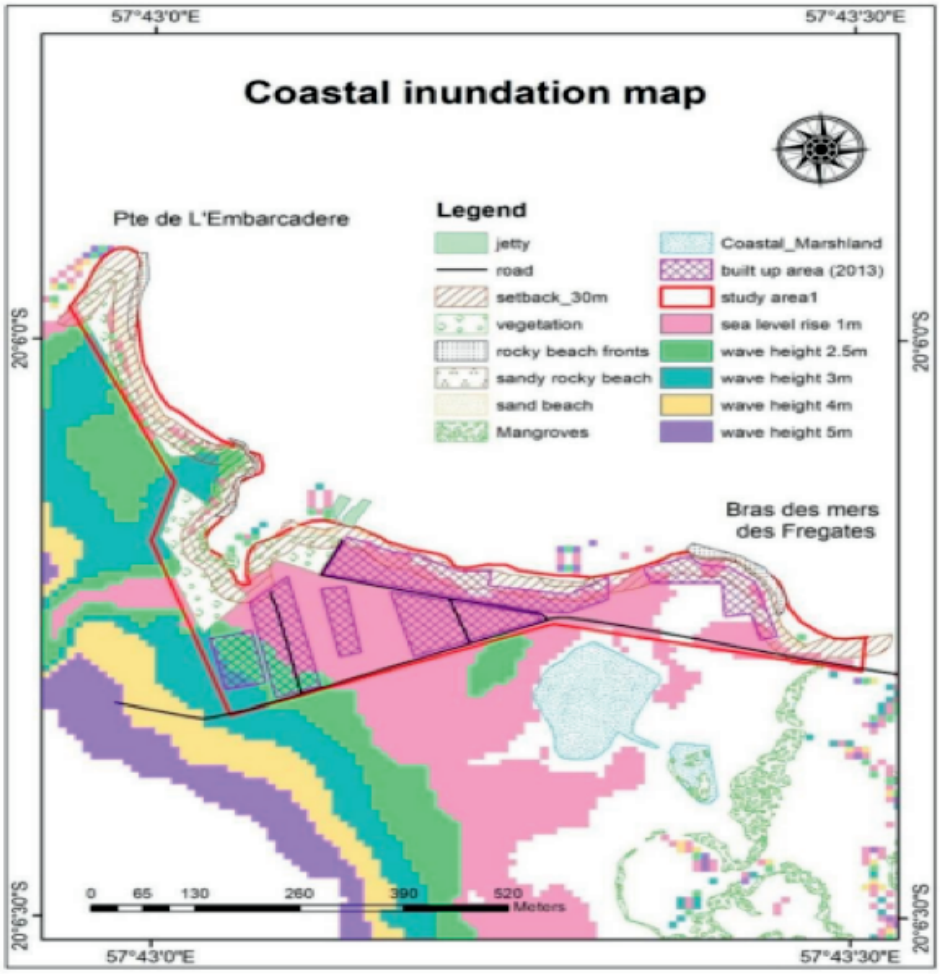

Figure 6: Coastal inundation map (sea level rise and storm surge)

However, the resultant map is not as realistic to depict the actual scenario of the region flooded given the resolution of the map. This is supported by field observations whereby it was noted that the slope within the study area varies from moderate to steep, therefore restricting the horizontal inland reach of the waves.

Additionally, during the production of this map, elements like tides that could result in the inundation of a broader area of land were not taken into account; instead, the map was constructed from the DEM's 0m elevation. As a result, while using the above map for coastal management and developments, this numerical projection cannot be relied upon totally and must be verified through site visits.

While coastal inundation maps can certainly help coastal communities visualize flooding threats, combining this data with knowledge of past flooding, natural landscape features, and erosion will produce a more thorough understanding of flooding and help a community better identify the areas most vulnerable to future hazards.

D. Coastal Sensitivity Index

Table 2 shows the individual classification of each variable under study along the coast at Roches Noires. Once each parameter is analysed, then using the equation mentioned in the Materials and Methods section, the CSI for the study area was calculated using the raster calculator from ArcGIS 10.4. The resulting CSI was then classified into four classes using the natural breaks (jenks) showing the different levels of sensitivity of the study area in relation to the seven variables as shown in Table 3 and the CSI values were displayed as a colour-coded sensitivity map (Figure 7).

With reference to Figure 7 and 8, spatial analysis of the CSI estimated 13% of the shoreline within the study area to be very highly sensitive, 28% within the same stretch displays high sensitivity, 40% shows moderate sensitivity while 19% reflected low sensitivity to the effects of climate change, such as sea level rise, storm surges, and coastal erosion.

#	Variables	Percentage sensitivity levels	Remarks
1	Coastal geomorphology	56% low, 16% moderate, 11% high, 17% very high	About half of the stretch of the beach consisted of a rocky or a sandy rocky shore which explains its higher percentage of low sensitivity.
2	Coastal slope	3% low, 11% moderate, 66% high, 20% very high	Percentages are relative to field observations since coastal slope varied quite a lot throughout the area, being especially lower near the sandy beach as compared to the rocky beach.
3	Land use	19% low, 12% moderate, 20% high, 49% very high	The high and very high percentages of sensitivity are explained by the presence of residential areas within the coastal setback and throughout the study area.
4	Flora/fauna	39% low, 49% moderate, 12% high, 6% very high	Moderate percentage is the highest since it represents plants such as coconut trees or filao plants which were present on a long stretch while the very high percentage represents the mangroves plantation. The ratios are approximately representative as that on the beach.
5	Relative sea level rise	10% low, 19% high 71% very high,	The highest percentage justifies the sensitivity with regards to the percentage of the study area that can potentially be flooded by a sea level rise of 1m. However, this percentage is derived using a numerical analysis and is not exactly representative of the coast due to its variations in the coastal slope.
6	Storm surge	9% high, 91% very high	The numerical solution has yielded such a result but this does not correspond completely with the real case scenario due to irregularities and variations in coastal slope within the study area.
7	Historical shoreline change rate	51% low, 43% moderate, 5% high, 1% very high	Despite of what the DSAS software has displayed, site observations, visual analysis of aerial photographs and interviews has shown that the shoreline was highly sensitive which might have been due to the effect of dominant waves in
			The high percentage of the low sensitivity may be due to the overall effect of the shoreline change from 1967 to 2013, i.e. it might have suffered from both accretion and erosion.

Table 2: CSI analysis at Roche Noires

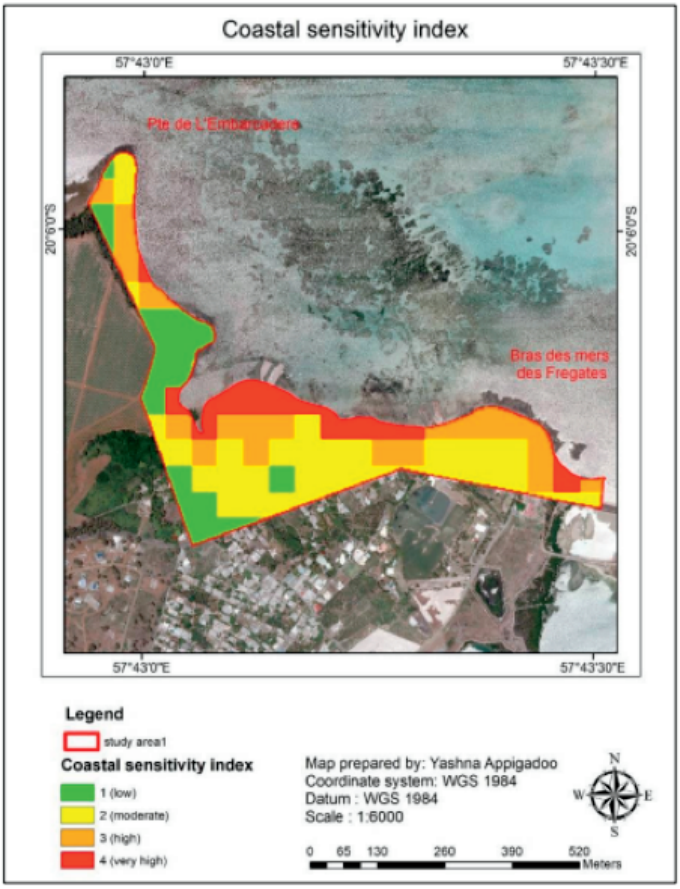

Figure 7: Coastal sensitivity index map of study area

Table 3: Classification of CSI indices in four categories

CSI ranges	Sensitivity level
1 – 4.366374745	Low
4.366374745 – 8.967086897	Moderate
8.967086897 – 15.5876239	High
15.5876239 – 29.61418533	Very High

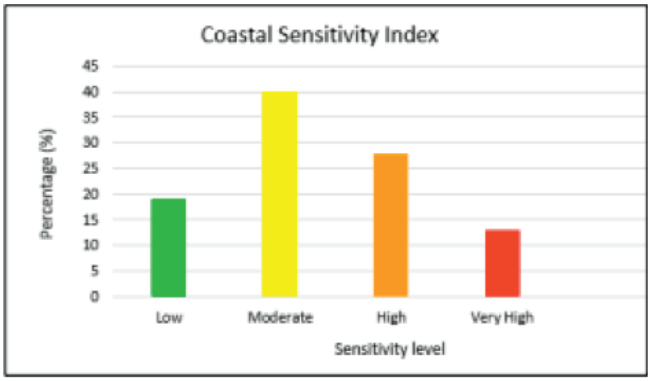

Figure 8: Coastal sensitivity index in terms of bar charts

These high sensitivities are particularly prevalent on the portion of the shore that directly faces the sea. This is due to the fact that these areas are more directly vulnerable to the effects of coastal hazards than areas farther inland. Additionally, as observed through site observations, areas with high sensitivity are primarily coastline sections with sand beaches, sand beaches protected by seawalls, or sand beaches with cobbles beneath as they are unable to provide adequate resistance to the action of the waves given the lack of natural wave breakers like seagrass or patch reefs, which could help absorb some of the energy of the waves. Moreover, seawalls are hard engineering solutions that alter the dynamics of the coastline and encourage scouring at the base of the barrier, speeding up the process of coastal erosion.

Other factors contributing to the high sensitivity of the coast relate to 1) the comparatively flat slopes in certain areas making them particularly vulnerable to storm surges and sea level rise since the horizontal reach of the water increases along an almost flat or moderately flat slope as compared to steeper slopes; 2) the presence of environmentally sensitive areas such as mangroves wetlands flanking the shoreline and the residential land use within the 30m coastal setback.

Conclusion

Over the years, climate change has resulted in irreversible damage along various coasts, affecting not only human and business operations, but also coastal ecosystems such as mangrove forest, saltwater marshes and coral reefs. Therefore, it is of utmost importance that detailed assessments of the coastal zones of Mauritius are undertaken to evaluate the vulnerability and sensibility of our coasts to the effects of rising air and ocean temperatures, leading to an accelerated increase in mean sea levels and loss of beach.

The Coastal Sensitivity Index Map gave an indication of the sensitivity of part of the coast under study at Roche Noires. The customisation of this model has allowed a combined analysis of the essential parameters influencing the study area, including but not limited to coastal slope, land use, storm surge, and anticipated sea level rise. Areas with a low sensitivity are better able to withstand the action of waves or rising sea levels as a result of their topography and geomorphology as compared to areas having very high or high sensitivities. It is also noteworthy that coastal ecosystems or residential developments contribute further to the sensitivity and vulnerability of coastal communities and as per the analysis, 41% of the study area yielded high and very high coastal sensitivities.

The DEM used to simulate the coastal flooding during the study proved to exaggerate the reach of inland waves as the resolution of the map for such a small area under study proved to be inadequate. The results of this study could instead have been improved with the use of DEM generated from LiDAR survey and, use of bathymetry data.

Finally, given the dynamic nature of coasts and the heightened effects of climate change, continuous assessment and evaluation of the coast must be undertaken to effectively plan for adaptation and resilience measures.

This study has contributed towards the analysis of the Roches Noires coast and highlighted zones most likely affected by climate change in terms of coastal flooding and beach erosion. These sites therefore require investigation and implementation of protective measures.

Acknowledgements

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ENGINEERS DAY
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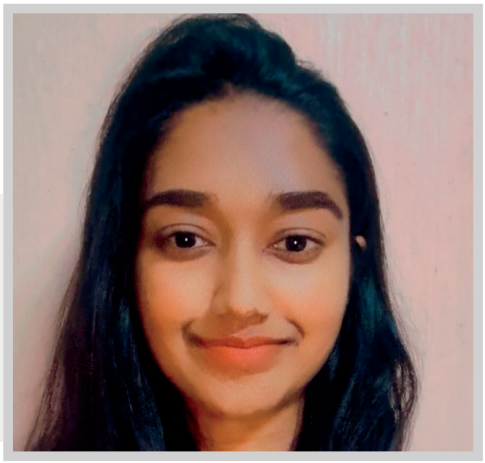
BUILDING RESILIENT INFRASTRUCTURES IN HIGH-RISK FLOOD PRONE AREAS



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1.0 Abstract

While floods may benefit the flora by making lands fertile, most of the time floods are unwanted. Floodwater threatens human lives, infrastructures and economies. To add to that, the effects of global warming and climate change are triggering more intense floods more frequently around the globe.

The island of Mauritius is also not spared to such disasters. Floods are occurring quite often nowadays affecting several regions all over the country. The island counts a total of 219 identified flood prone areas and 48 of these are on the high-risk flood prone list. This shows that the situation is becoming alarming and therefore, flood assessments should be executed in order to find measures to control floods and alleviate their impacts.

This research paper delves into how conceptual modelling and simulation techniques can help in flood risk assessments. Two different flood prone areas, Virahsawmy Lane and La Louise, found in Mauritius were examined as study areas. The procedure to evaluate the possible flood risks consisted of using three software namely: ArcGIS PRO, HEC-HMS and HEC-RAS. The first software was used to construct a visual or conceptual model for the catchment of the two flood affected areas. The other two software were used to build flood flow models for Virahsawmy Lane study area with respect to different rainfall return periods. Through analysis of the constructed models and simulation, the flood risks were pointed out. The Virahsawmy Lane region is low lying and its existing channel capacity is not adequate to the new drastic rainfall intensity trend (e.g., climate change effect). La Louise struggles mainly from urban flooding due to its impervious nature (e.g., urbanisation). Ultimately, measures to control flood and alleviate impacts specific to the two areas could be proposed; soil conservation techniques, low impact development techniques, channel improvement, floodplain zoning.

Compared to traditional flood assessment method, it was concluded that numerical modelling greatly enhances the quality of flood assessments and hence, is essential in flood management measures. With more accurate models and simulations, future scenarios can be project and from there better solutions can be devised to make infrastructures resilient to flooding.

***Keywords**: Flood; HEC-HMS; HEC-RAS; Climate Change; Future Scenarios*

2.0 Introduction

A flood or deluge is a body of water that immerses or overflows land that is usually dry (National Geographic 2011). While floods may benefit the flora by making lands fertile on which crops can thrive, the majority of the time floods are unwanted. Floodwater may ravage infrastructures which are incapable to endure the destructive forces; trees may be uprooted; small houses and vehicles can be carried away. For example, in 2007, a flood hit Bangladesh which left million homes damaged. Flood can pose heavy tolls on the economy. The Louisiana Flood in 1995 costs the US a total of $585 million losses.

Moreover, the aftermath of a flood may cause the contamination of the environment from deposition of rubbles, fuels, pesticides, wastewater and so on. Thus, outbreaks such as cholera or malaria can be triggered. In 2000, the Limpopo River in Mozambique flooded houses and people sought shelter nearby. Unaware of thriving mosquitoes due to the floodwater that was carrying malaria, many people fell sick and died.

Only some places exist on the planet where humans do not have to worry about flooding. In addition, floods are considered to be the most frequent natural calamities second only to wildfires. WHO (2021) added that, from the year 1998 to 2017, it was recorded that more than 2 billion persons worldwide were affected by flood events.

Experts have classified flood size in accordance with their probability of happening in a given period of time (National Geographic 2011). For instance, we can have a 100-year flood which simply means that this type of flood occurs only one time every century. There are also 5-year flood or 10-year flood which are common. The higher the return period or recurrence interval, the more intense and rarer the flood is. However, return periods are not always true as it is just a probability. Besides, the effects of global warming and climate change are affecting the recurrence interval triggering intense flood more often.

The island of Mauritius is also not spared to such disasters. Floods are occurring quite often nowadays affecting several regions all over the country. As at April 2021, a total of 219 flood prone areas around the country were identified and 48 of these are on the high-risk flood prone list (DefiMedia.info 2021). This shows that the situation is becoming alarming and therefore, solutions have to be found to alleviate flood impacts.

3.0 Literature Review

Normally, a flood takes several days or at times hours, to form, thus, allowing people to evacuate in time (National Geographic 2011). In some circumstances, floods may form in very short amount of time. In addition, the development of a flood varies. Most floods develop naturally such as when rivers start to overflow, known as river flooding (Ghosh 2014, p.1). Flash flood, another type, is caused due to intense rainfalls that it requires only few hours for water bodies to rise to dangerous height. Urban flooding occurs as built-up areas create more rainwater accumulation. When precipitation reaches 100mm depth in few hours, it has been proved to cause harmful effects to structures. Tidal flooding happens when storms or cyclones generate heavy rainfalls near coastlines, making sea level rises and eventually there is flooding inland. Man-made flood cause also exists such as dam failure causing flooding.

The occurrence of a flood is influenced mainly as per Şen (2018, p.2) by:

- the distribution and amount of rains happening in catchment areas (e.g., return period of rain)
- the characteristics of these catchment areas (e.g., relief of land, drainage aspects)

Şen also added, to assess floods, we need to know about the meteorology, hydrology, topography and the geology of the catchment areas. Generally, areas more likely to be prone to flood have the following aspects (Şen 2018, p.6):

- Low lying: Surface run-off tends towards the lowest point and hence, this implies a higher probability of flooding than at higher lying regions.
- Close to channels: Channels can reach high levels when there are heavy rainfalls, thus, overflowing nearby development.
- Small drainage areas: They are more vulnerable to flash flood as heavy rainfall makes small catchment areas exceed its capacity in draining the water more easily compared to larger catchments areas.
- Close to shorelines: In some countries, sea level can get to such points that it starts to flood inland (e.g., tidal flooding).
- Close to alluvial fans: This sediment deposit with relatively steep slopes can cause flash floods specifically in arid regions due to formation of run-off with high speed.

Most floods are naturally occurring phenomenon and the natural environment is equipped in dealing with floods (National Geographic 2011). Water bodies such as wetlands, streams, lakes help in absorbing flood water. Plants, in addition reduce flow of floodwater and dampen the energy. Unfortunately, the globe is gradually becoming urbanised. The characteristics of the ground are being modified from their natural pervious to less pervious state with construction happening. The backfilling of water bodies is also worsening the situation (Waghwala and Agnihotri 2019, p.1). As per the U.S Congress's Office of Technology Assessment cited Sen (2018, p.4) the main factors to growing flood problems are:

1. rising population residing nearby flood prone regions,
2. destruction of wetlands,
3. higher run-off with increase in impervious ground and
4. construction in flood plains.

The deterioration and destruction of wetlands in the Mississippi have decreased significantly the storing capacity of flood water in that region from 60 days to only 12 days of flood water (National Geographic 2011). Another very important factor is the climate change effect. Climate change can be defined as "the state of climate that alters the composition of the global atmosphere, and that is in addition to natural climate variability observed over comparable time periods" (United Nations Framework Convention on Climate Change cited National Audit Office 2019, p.5). As climate change is taking place, this is causing more intense flood events to occur frequently in many regions across the globe. Unluckily, climate change is not going to stop. For this reason, the effect of climate change on flood events will have to be taken into account (Şen 2018, p.343).

SIDS are islands defined by their small dimensions and seclusion in tropical/subtropical zones making them susceptible to natural calamities (Chacowry 2018, p.1). An increasing concern for SIDS is the impacts of climate change on weather patterns. For the case of Mauritius, the country is ranked 13th on the highest risk list globally and 7th as the one most exposed to natural hazards (World Risk Report 2017 cited National Audit Office 2019, p.5). Flood events are occurring frequently of which some have even taken lives. For instance, the island faced a fatal flash flood event in March 2013 in Port-Louis, killing eleven people (National Audit Office 2019, p.1). Moreover, it has being predicted that infrastructural damage due to flood in the country will amount to approximately to US $ 2 billion in the next five decades (DRR Report 2013 cited National Audit Office 2019, p.1). As mentioned in the introduction, the island of Mauritius counts a

total of 219 flood-prone areas among which 48 are at very high risk (DefiMedia.info 2021). A study in 128 regions affected by flood exposed the main causes of flooding as follows (National Audit Office 2019, p.6):

1. Low lying regions.
2. Decrease in run-off infiltration into the ground due to development.
3. Decrease in capacity of natural channels due to development on floodplains.
4. Wetlands being backfilled.
5. Obstructions in drainage systems (e.g., silt deposits).

From the 128 regions studied, the proportion of the flooding causes were evaluated as shown below. From the study, it was deduced that the major reason for flooding in the island was due to low lying regions followed by problems related to drainage system. A report 'DRR report 2013' made by the authorities of Mauritius to support the Sendai Framework 2015-2030 made four important recommendations for flood mitigation in the island (National Audit Office 2019, p.11);

1. FRM schemes specific to catchment areas should be developed. It should consist of several actions to decrease flood impacts.
2. Mapping of zones at risks should be made to eventually come with efficient land use actions and mitigating measures.
3. The conservation of natural environment should be implemented. There has been a decrease in the amount of vegetation and wetlands. Authorities should see that restoration takes place.
4. Sound (special) Data Infrastructure should be developed for a more effective management of disaster risk.

As floods endanger safety of humans and causes economic loss, it is therefore important to understand more about this phenomenon. Flood assessments should be executed in order to find measures to control flood and decrease the effects. The research focused on how to predict flood risks in flood-affected areas based on return period of rains and catchment features. More particularly, the research revolved around how computer techniques, modelling and simulation, can help to point out flood risks and infrastructures' risk level to flooding.

4.0 Methodology & Conceptual Model

A flood study was undertaken at Virahsawmy Lane (Figure 1) to identify main causes of the flood problem and to propose potential solutions. Found in the Savanne district in the south, according to the Ministry of civil service and administrative reforms (2017), the Virahsawmy lane is considered as a flood prone area.

Figure 1 – The study area

According to L'Express.mu (2017), there are 6 houses at the site classified as high flood risk and these houses are believed that with big flood, they can become submerged. Some images demonstrating intense flooding at the site as show in Figure 2.

Figure 2: Flooding problems at Virahsawmy Lane (L'Express, 2015)

Site visits, walk through surveys, surveys with the inhabitants and a desk study was initially conducted to get thorough understanding of the flood problem at this site. Next a 10m Digital Elevation Model was used to conduct a morphometric analysis and drainage density maps were derived to get further insight of the type of hydrographical network in the area and how fluvial flooding was affecting the site (Figure 3).

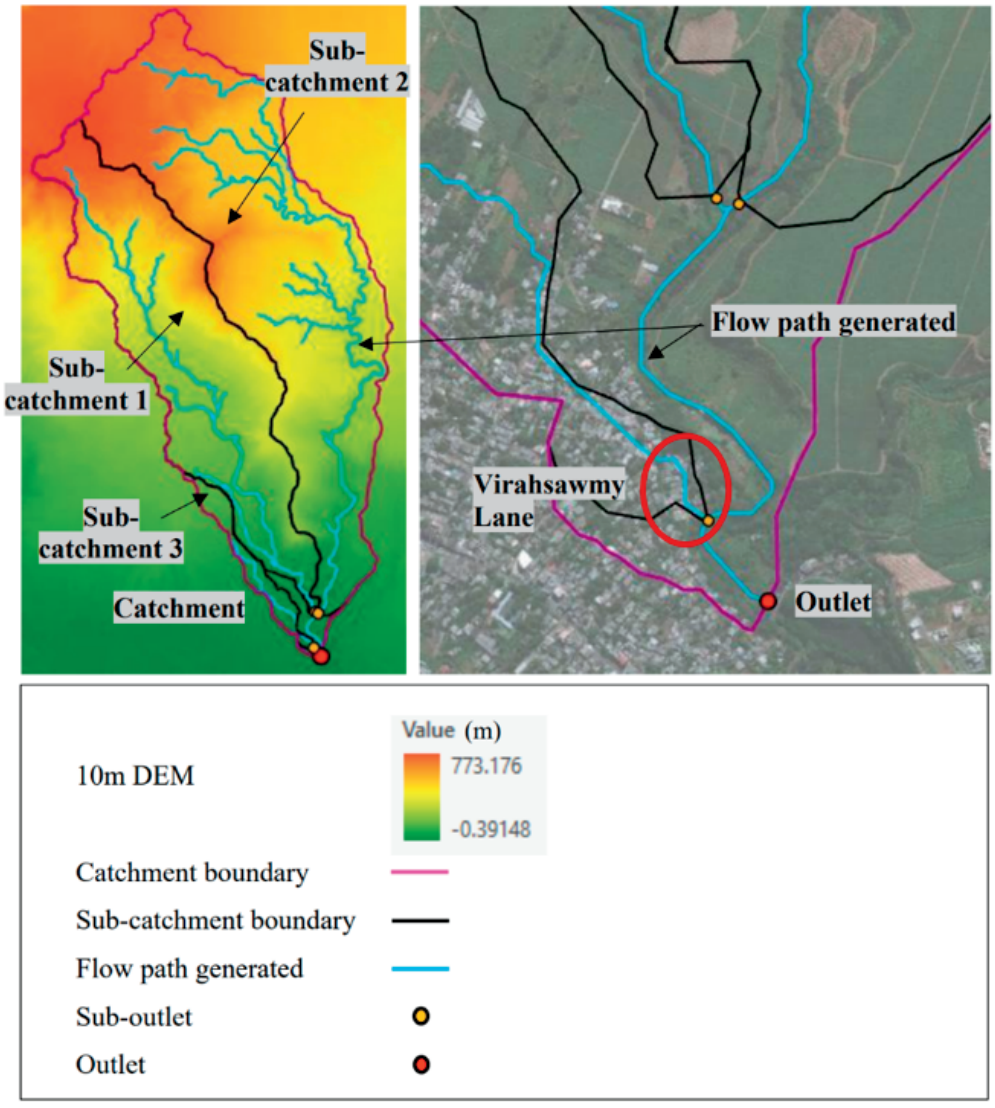

Figure 3 – Flow path and topography

A drainage density map was prepared to highlight the vulnerability of the site to fluvial flooding (Figure 4). The drainage density map indicated a few flood prone sites in this region. However, the study area is the one where buildings have been constructed and hence relatively more vulnerable to flood problems. Having developed the conceptual model, a one dimensional numerical model was developed for the study area using the open source software HEC-HMS.

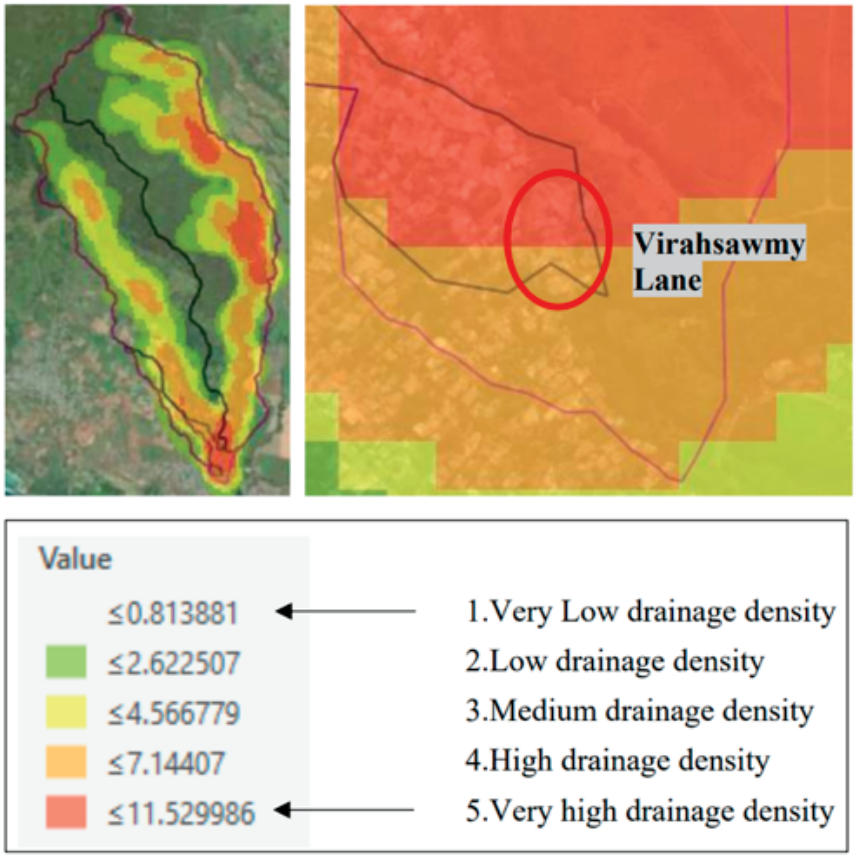

Figure 4 – Drainage density map at Study Area

Elevation profiles around the study area, confirmed that the site is located in the depression zone (Figure 5).

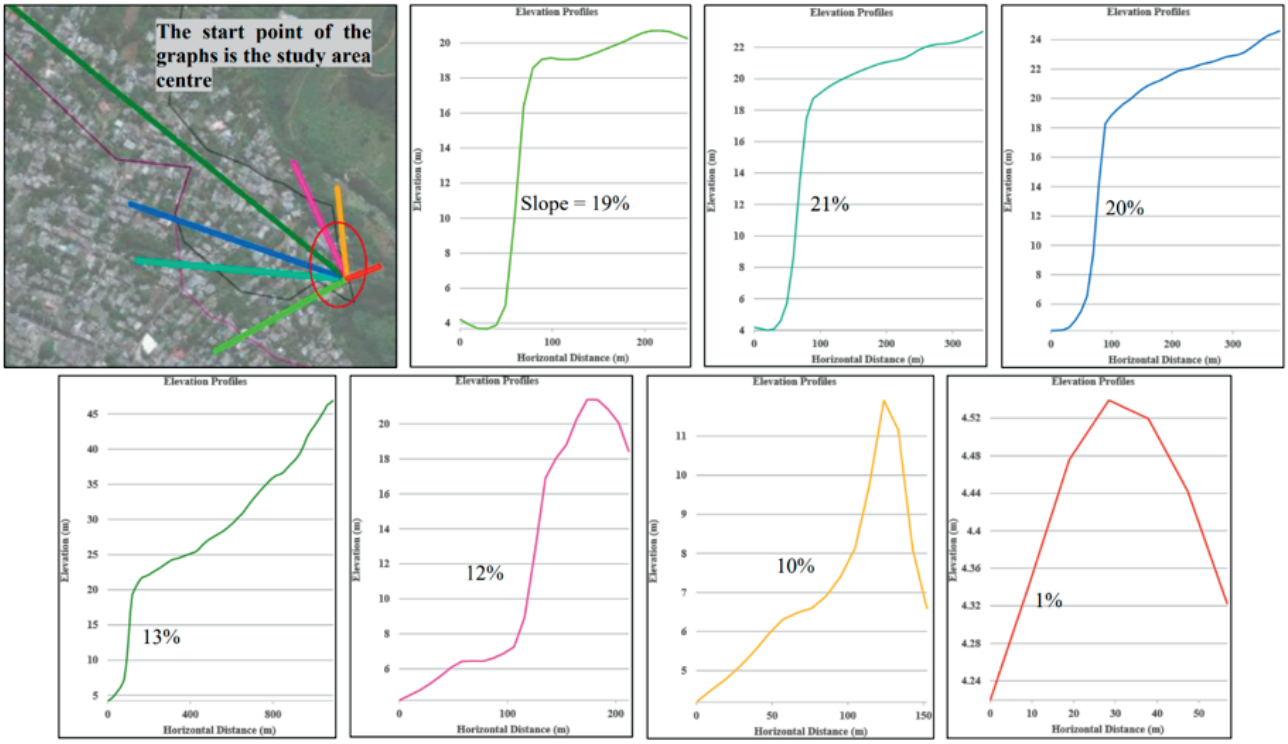

Figure 5 – Elevation profiles around the study area

5.0 Numerical Data Analysis

HEC-HMS software was used to generate discharge output (Table 1) of different return periods for the study area. To build the hydrological model, a basin model, a meteorological model and the control stations were set up to simulate the depth of flood expected for different rainfall return periods.

Return period	Peak discharge at outlet (m^3/s)
2-year	12.6
5-year	51.2
10-year	96.8
25-year	154.7
50-year	213.6
100-year	277.5

Table 1: Estimated peak discharge at study area for different return periods using HEC-HMS

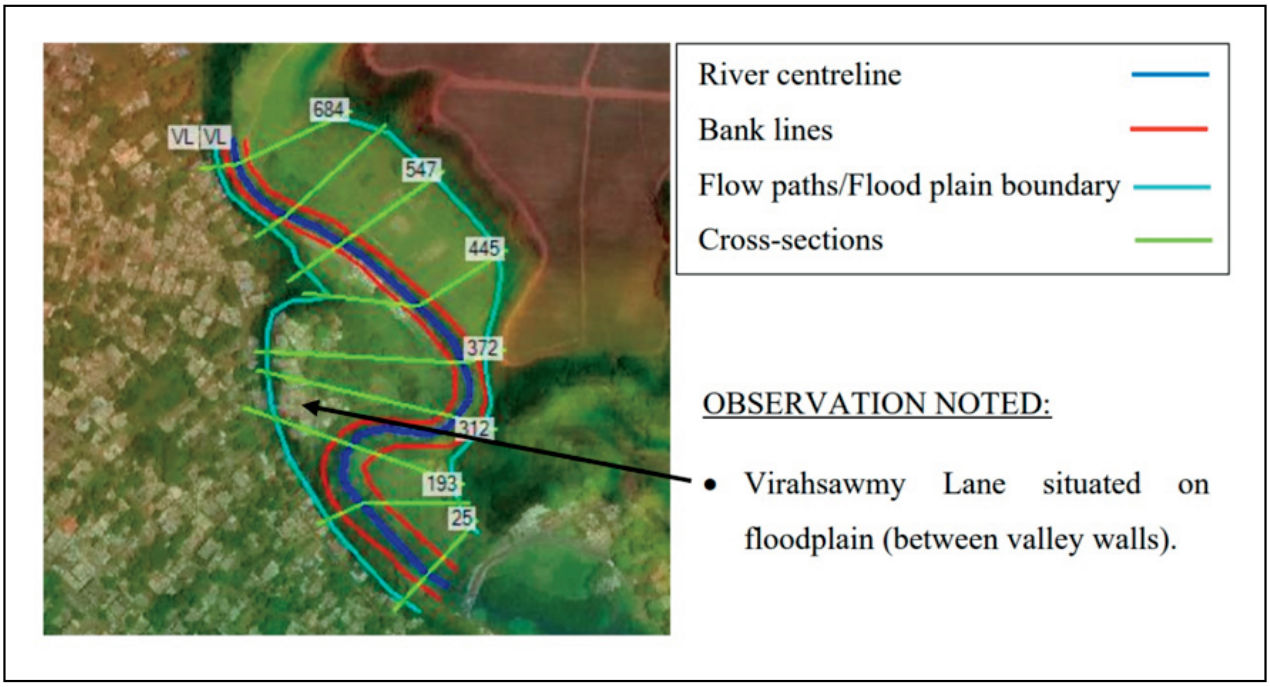

Figure 6 – Control stations to simulate depths of flood water

The simulated flow rates and flood depths with HEC-HMS and the HEC – RAS softwares, at different return periods, indicated that flood problem at this study area starting becoming a problem as from 25 year return period design rainfall. This simulation indicated that apart from fluvial flooding, runoff generated directly over the study area, also contributed significantly to the river flows, as from rainfall of return period 25 years.

Figure 7a – Flood depth

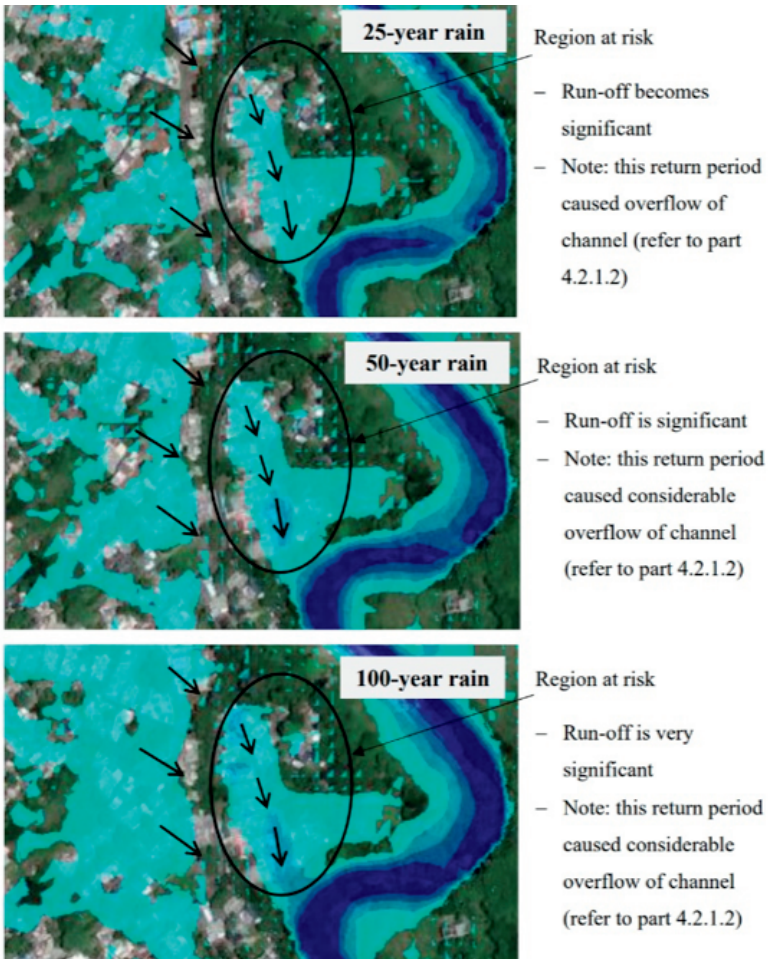

Figure 7b – Flood depth including surface flooding

Figures 7a & 7b – The estimated flow depths simulated using different return periods

6.0 Mapping Infrastructure at Risk

From the flood risk analysis performed, the following flood risks in Virahsawmy Lane were deduced as follows:

1. The region is found in a low-lying one, below steep land slopes and actually situated within river flood plain (between river valley walls) thus, increasing chance of water accumulations.
2. Most of Virahsawmy Lane region is found just before the outlet of a sub-catchment implying that all run-off not intercepted flows through the region first before being discharged. Virahsawmy Lane is actually situated on the flow path of the sub-catchment.
3. The presence of impervious surfaces and steep land slopes in this sub-catchment decrease interception/infiltration of run-off which then would flow in greater amount through Virahsawmy Lane. Therefore, this causes high accumulation in low-lying areas during intense rainfalls.
4. The channel capacity adjacent to Virahsawmy Lane gets exceeded from return period of 25-year and becomes much overflooded from return period of 50-year. Nowadays, due to the effect of climate change, higher return periods are happening more frequently and therefore, the channel may overflow more often. This shows that the capacity of the channel is no more adequate to the new regular intense rainfall trend.

The risk levels of the existing infrastructure has been mapped as a support to flood management (Figure 8).

Figure 8 – Map showing risk levels of existing infrastructure

7.0 Conclusion & Recommendation

The purpose of this research was to demonstrate how through modelling and simulation, more particularly, through development of conceptual model and flood flow simulation, one could perform flood risk assessments; the factors encouraging flooding in flood prone areas and furthermore, to define the risk severity of buildings in such areas. While numerical flood models come with their own complexities and inherent level of accuracy, a detailed conceptual model is the way towards building a reliable numerical model.

To conclude, with floods intensifying worldwide due to climate change and other factors such as urbanisation, deforestation or wetland destructions, lives, infrastructures and economies are being jeopardized. It is becoming imperative to study floods in order to devise appropriate flood management solutions. With technological advancement, such as flood modelling and simulation, flood assessment can be considerably ameliorated, thus proving their importance in the present times.

Numerical flood models form part of the working tools of hydrologists and with the future climate scenarios indicating even more extreme such a tool can provide technical support for identifying more effective flood management measures appropriate to the study area. Thereupon, to avert the aggravating flood impacts, it is now time to act for the welfare of societies.

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WATER-ENERGY-FOOD NEXUS: AN INTEGRATED APPROACH FOR EFFECTIVE RESOURCES MANAGEMENT

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1.0 Abstract

Water, Energy and Food are essential for well-being, but overconsumption and wastage have put much stress on the limited resources. Demand for water, energy and food is increasing, with increasing population, rapid urbanization, changing consumption patterns and economic growth. In addition, decision taken in one sector, often impacts negatively in another. The Water-Energy-Food Nexus is an integrated approach which promotes sustainable development of resources. A Nexus approach forces decision makers to think about these interrelated sectors. It helps decision makers appreciated the extent to which decision made in one sector will affect other sectors. It provides for a basis to discuss trade offs in a particular sector, while taking into account their impacts on other sectors. While the need for applying a nexus approach is very high, the interest in developing this approach is positive, but the way about this approach is challenging. Two studies have been undertaken, the first one for a national project and the second one for an organisation. The FAO WEF Nexus 1.0, Rapid appraisal method was applied to several national projects while the Analytic Hierarchy Process (AHP) method was applied to an organisation. The FAO WEF Rapid appraisal tool, is an iterative process, which enables users to add more complexity in the analysis and is focused on resource planning. The AHP method is based on a rating analysis, and goes in detailed on resources uses, with each process being assigned a score. A pairwise comparison matrix is then developed to allocate an index (a value) according to the Saaty's AHP method. The results in both cases are expressed in the form of radar diagrams, which illustrate visually the sustainability of each sector. However, for a balanced and sustainable resource utilisation and management, the AHP noted that the institution must aim to enable the sectors to reach the highest score of 3.5 or the index of 0.37 to obtain a regular shape of the polygon in the radar chart. This study concluded that both methods have their strengths and their application, and both methods are equally important for us to promote a more effective use of resources at national level.

***Keywords**: Water-Energy-Food Nexus; Analytic Hierachy Process (AHP); FAO WEF Rapid Appraisal Tool; Resource Planning; Rating Method*

2.0 Introduction

Water, energy and food securities are crucial for poverty reduction and paving the way for more sustainable development. Due to unequal distribution of natural resources across the planet, services such as access to potable water, energy and food supply are often interrupted. In addition, global factors like climate change,

population growth, urbanisation and economic development are putting additional pressures on the availability of resources. These factors will contribute to an increase demand of water, energy and food and will eventually constitute a real challenge for developing countries (Bazilian et al. 2011).

It has therefore become mandatory to address water, energy and food problems together because the decisions taken for a particular sector can affect the other either in a positive or a negative way (Vittorio et al. 2018). For instance, inadequate accessibility to water resource can affect food supply and lack of energy services can hinder the treatment and distribution of water. Hence, the interconnectedness between the resource sectors is referred to as the WEF Nexus. As such, there are several WEF Nexus approaches and frameworks which are being developed by organisations like Food and Agriculture Organisation of the United Nations and the South African Development Community (SADC) to address the issues (Pfaff et al. 2018). Furthermore, there also exists scientific methods like the Multi Criteria Decision Making (MCDM) tools which perform quantitative analysis for better resource management.

As far as the approach implementation is concerned, it has been focused mainly on national levels. This disregards the fact that the major nexus challenges are faced by institutions, projects, communities as well as households. There is a need to implement the nexus approaches at all levels in order to ensure global water, energy and food securities and at the same time to achieve the sustainable development goals.

Among the several factors affecting the vulnerability of resources, climate change is the extreme one. According to IPCC (2014), climate change is expecting to severely affect Small Island Developing States (SIDS) in terms of resource availability, accessibility and productivity. Mauritius is highly vulnerable to the critical climatic phenomenon and the key sectors which are prone to be affected include agriculture, water resources and infrastructures. It is estimated that, if no measures are taken, water availability may reduce by up to 13% which in turn may decrease the agricultural productivity by 25% in the next 30 years (Kauppaymouthoo 2018 cited Fakun 2018). Eventually, the clean energy production will also be compromised since availability of food for biofuels will decline.

Thus, the consequences of climate change are going to stress the existing natural resources in view of the increasing demand. This impact of limiting resources will be felt at all levels. Moreover, this will pose a big challenge for Mauritius to achieve the sustainable development goals by 2030. Scientists, engineers, communities and policymakers will play an important role to address the urgency of the situation. In order to prevent the Mauritian population from experiencing resource insecurities and conflicts, it is important to manage the resources sustainably. Considerations must be made mainly to institutions and projects since they are the ones which face the greatest challenges and thus can make a huge difference in the overall sustainable management of resources at national level. The WEF Nexus approach will help in determining the interlinkages among the sectors and in establishing areas requiring urgent intervention through a radar chart. The latter will identify the unsustainable resources and help in determining how it is impacting the other sectors. This in turn will help the government, engineers and other relevant stakeholders to deduce sustainable practices, mitigation plans and the need for additional specific policies for the WEF securities at local level.

3.0 Literature Review

The WEF Nexus describes the interlinkages between the three sectors namely: water, energy and food. For example, energy is required to treat and distribute water; water is needed to produce energy in thermal power plants and to grow crops; food is required for biofuel production (Susnik et al. 2020). The WEF Nexus has the objective of identifying possible synergies and minimising trade-offs between the mentioned

sectors (Hoff 2011). Synergies are recognised as the positive effects of a goal on ecosystem services which in turn would enable achieving other goals across the sectors. Trade-offs are understood where one goal uses the resources intensively thereby limiting the achievement of goals within other sectors (Fader et al. 2018).

A Nexus framework has been developed by Hoff (2011) which demonstrates the interaction between the WEF sectors that would allow strategy evolution for achieving sustainable development.

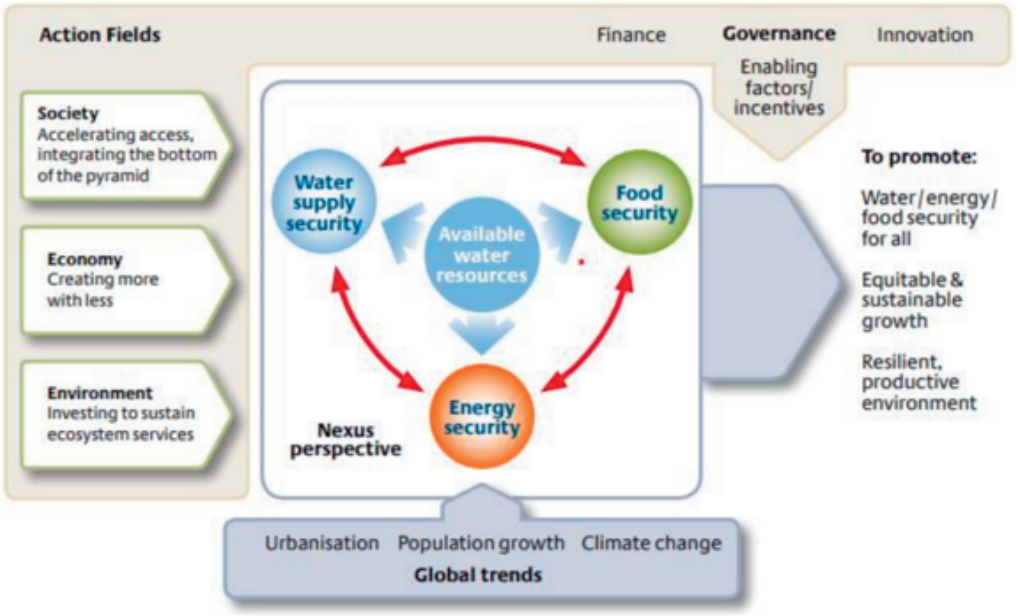


Figure 1: The water, energy and food security nexus (Source: Hoff 2011)

Liu et al. (2017) put forward that the water-energy-food nexus is being considered as a prioritydue to emerging difficulties in sustaining the world's growing population. There are numerous constraints on the availability of the water, energy and food resources. A study by Flammini et al. (2014 cited Liu et al. 2017) projects that 60% more food and 80% more energy will be needed by 2050. The total water withdrawals will be increased by 50% in developing countries and 18% in developed countries by 2025.

Considering the growing interconnectedness across the sectors, the nexus approach can increase the efficient use of resources and secure human access to water and food which form part of the sustainable development goals (Hoff 2011). The nexus approach acknowledges the need of involving environmental, economic, social and political aspects to achieve sustainable outcomes (Lawford et al. 2013 cited Albrecht 2018).

The WEF nexus has surfaced as an approach to manage the three resource sectors sustainably in the late 2000s and early 2010s. Converging ideas from various political activities, educational research and policy papers have assisted in the realisation of the WEF nexus (Simpson et al. 2018). Following this, the development of the WEF nexus approach is mainly based on scientific publications and conferences. Several organisations are developing their own WEF nexus frameworks which enable decisionmakers to unfold proactive responses and develop rapid mobilisation during a crisis. These adapted frameworks are built on the work from the Bonn 2011 conference which specifically address the nexus concept in professional and academic communities (Aboelnga 2018).

The publication of the World Economic Forum is recognised as one of the most important report for the development of the WEF nexus. The World Economic Forum (2011) has presented a risk focused WEF nexus framework in its Global Risks Report. This approach as illustrated in figure 2 shows the interconnectedness of WEF securities and their associations with the failure of governance systems and economic differences.

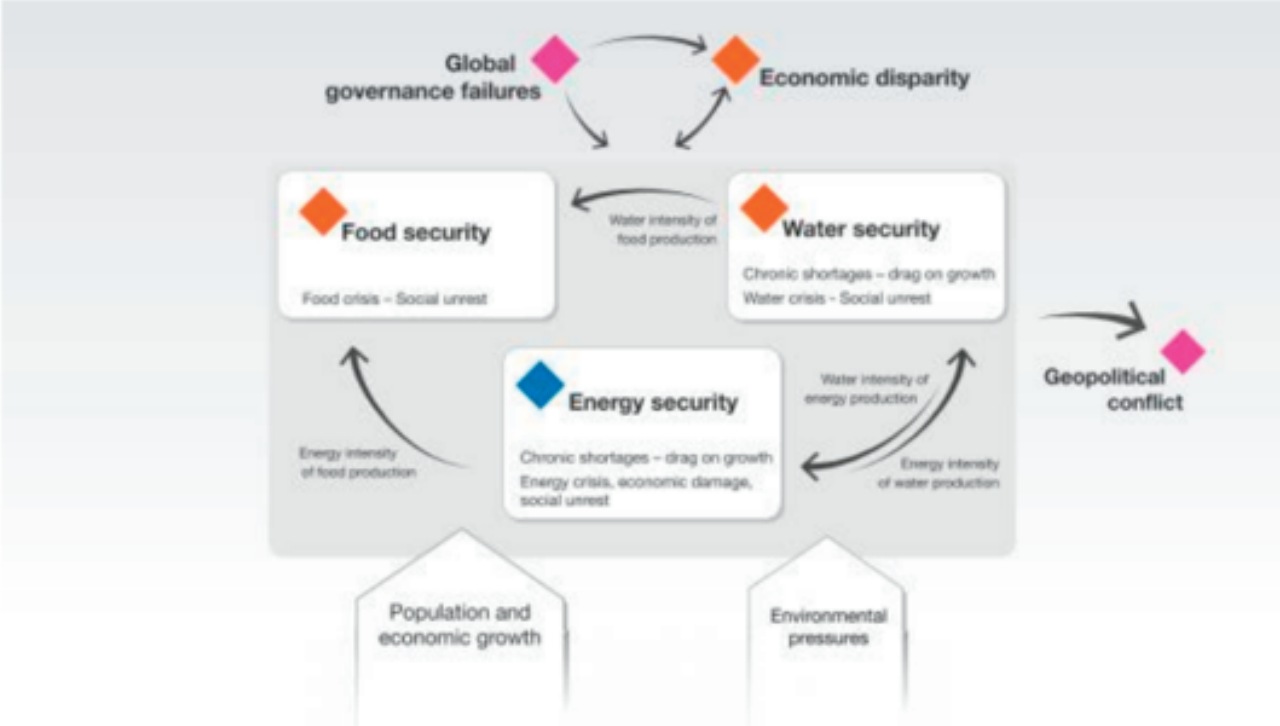


Figure 2: WEF Nexus adapted by World Economic Forum (Source: World Economic Forum 2011)

The Food and Agriculture Organisation (FAO) has developed its own approach in assessing the interlinkages between resources which refer to both natural and socio-economic resources (Flammini et al. 2014). The figure below gives an overview of the approach with land, water, energy, capital and labour as being the resource base. In addition, stakeholders' opinions are also taken into consideration to achieve the objectives. FAO has also developed the Nexus Assessment 1.0 which helps policymakers to understand the seriousness of the prevailing situation and identify possible measures.

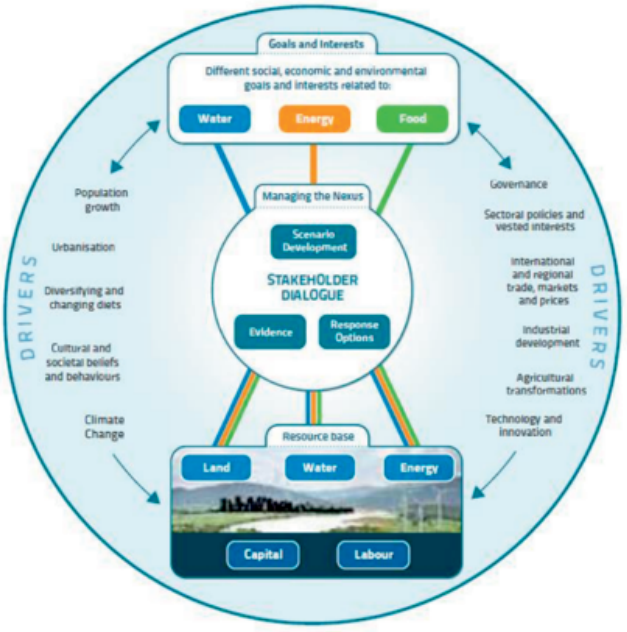


Figure 3: FAO approach to the WEF nexus (Source: Flammini et al. 2014)

The South African Development Community (SADC) has conceptualised a framework for the WEF Nexus. It is an adaptation of the model developed by Hoff. This framework, illustrated below, integrates both the human and natural system. The human system comprises of water, energy and food security to sustain life. The natural system refers to the available resources: water, land and energy (SADC 2019). The framework intends to promote the synergies between WEF sectors that would optimise potential development of the area for economic growth.

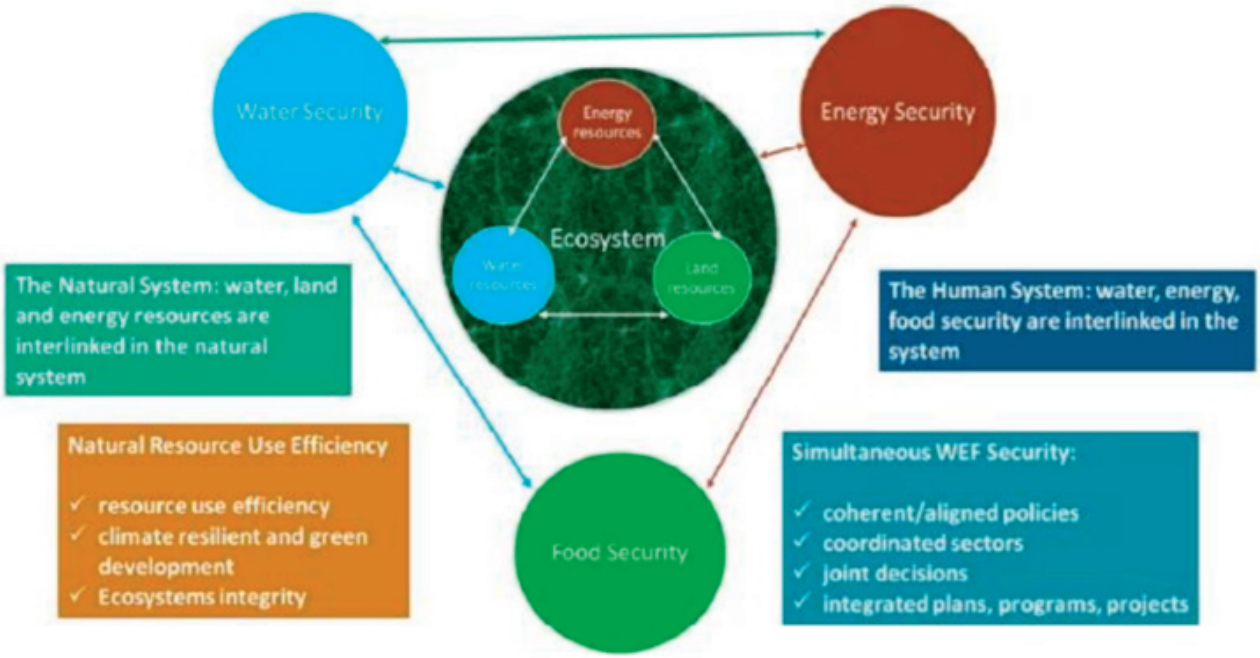


Figure 4: SADC Framework for WEF nexus (Source: SADC 2019)

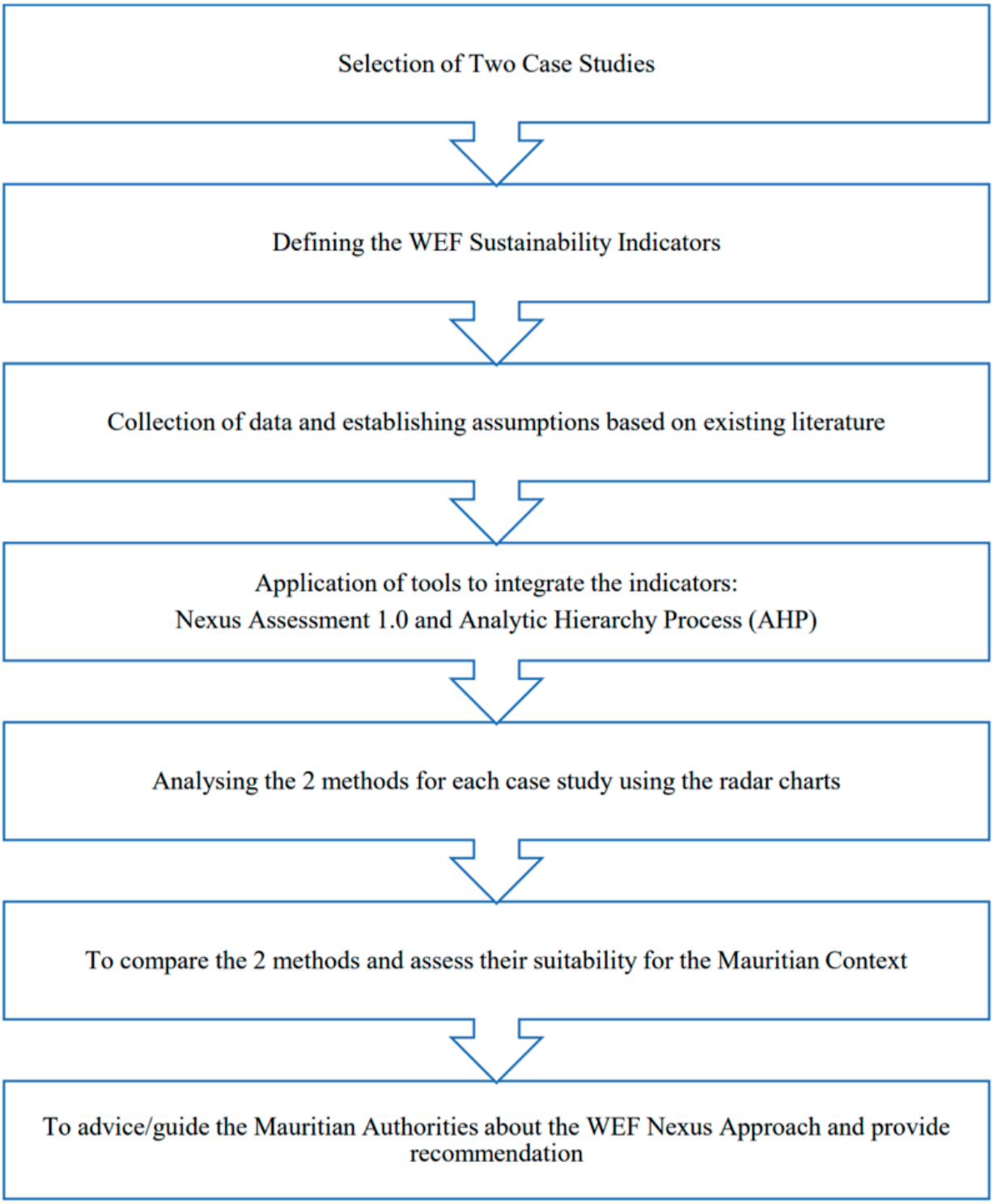
The ICIMOD has derived a Nexus framework from the Hoff approach for the Himalayas and the South Asian regions (Aboelnga 2018). As shown in Figure 5 below, this framework integrates the Himalayan ecosystem services with the water, energy, food and agriculture services. This triangular framework has highlighted the central role of resilience and productivity of ecosystems to achieve the WEF security in the region.

Figure 5: WEF approach in the Himalayas and South Asian regions (Source: Aboelnga 2018)

4.0 Methodology

From the literature search, it was noted that the Water – Energy – Food Nexus approach can be applied at any level that is on a national level, project level and institution level. For the purpose of this research, the WEF analysis was undertaken at an institution A using the FAO Nexus Assessment 1.0 and the Analytic Hierarchy Process (AHP) methods.

The approach adopted is illustrated in the flowchart 1:



Flowchart 1: Methodology

The procedures to carry out the Nexus Assessment 1.0 are detailed below and are according to that described by Flammini et al. (2014). This approach works by identifying pertinent indictors. The indicators are expressed as a percentage value with reference to a similar context. This is known as benchmarking. The benchmarks can be decided by the local stakeholders or using comparable projects with similar characteristics. Then, the actual calculated indicator is compared with the benchmark data and expressed as a percentage. The indicator value obtained can either be positive or negative. Every indicator is weighted from 1 to 3 by the assessor on the basis of which aspect the assessor feel that it must be given more importance in the overall performance. Scores are then assigned to each indicator scaling from 0 to 5 and depends on the percentage value of the indicator, where a high score indicates that the intervention has a significant impact on the sustainability of that particular nexus element. A score of 1 specifies that the intervention has a low impact and is reducing the pressure on the nexus element while score of 0 means that the indicator was not assessed.

The AHP works around establishing numerical relationships among the indicators. Each indicator is compared to one another and is allocated an index (a value) according to the Saaty's AHP pairwise comparison matrix. The relationships have a scale ranging from 1/9 to 9 and the diagonal elements have the value of 1 (they are compared with themselves). The range of 1 to 9 represents the important relationship while the range of 1/3 to 1/9 insignificant relationship. A ratio scale of 9 in the matrix indicates that the row indicator is 9 times more important than the column indicator. The ratio scale can be allocated based on available baseline data.

The indicators were selected based on the performance of the institution (Institution A) and the services it provides to the users. The indicators were mainly focused on resource availability and accessibility.

- Water
  1. Water consumption per day / capita – W1
  2. Water required for irrigation / area of irrigated land – W2
- Energy
  1. Energy consumed per year / capita – E1
  2. Energy intensity required per unit area of irrigated land – E2
- Food/Land
  1. Area occupied by campus / water consumed – F1
  2. Area occupied by campus / energy required – F2

Bench marks for each of the indicator was obtained from published data. For both methods, the results are represented using the Spider or Radar Diagram, which visually illustrate the impacts of the project on each of the three sectors; Water-Energy and Food.

5.0 Results & Discussion

5.1 Nexus Assessment 1.0 – Institution A

Table 1 summarises the data used to obtain the individual score for each indicator and the combined score for each of the three sectors.

Indicator	Main Resource	Actual Value	Benchmarked values	Weight Assigned	Value of Indicator	Score	Combined Score
W1	Water	19.66 L/capita/d	26.6 L/capita/day	2	-26	2.48	1.59
W2	Water	0.00785 m^3 /m^2	1.68 m^3 /m^2	3	-100	1.00	
E1	Energy	1110 kWh/yr/capita	237 kWh/year/capita	2	-10	2.80	2.05
E2	Energy	0.0384 kWh/m^2	0.25 kWh/m^2	2	-85	1.30	
F1	Food/land	1.13 m^2 /m^3/year	0.92 m^2/m^3 /year	2	23	3.50	2.01
F2	Food/land	0.0072 m2 / kWh	0.66 m^2 / kWh	3	-99	1.02	

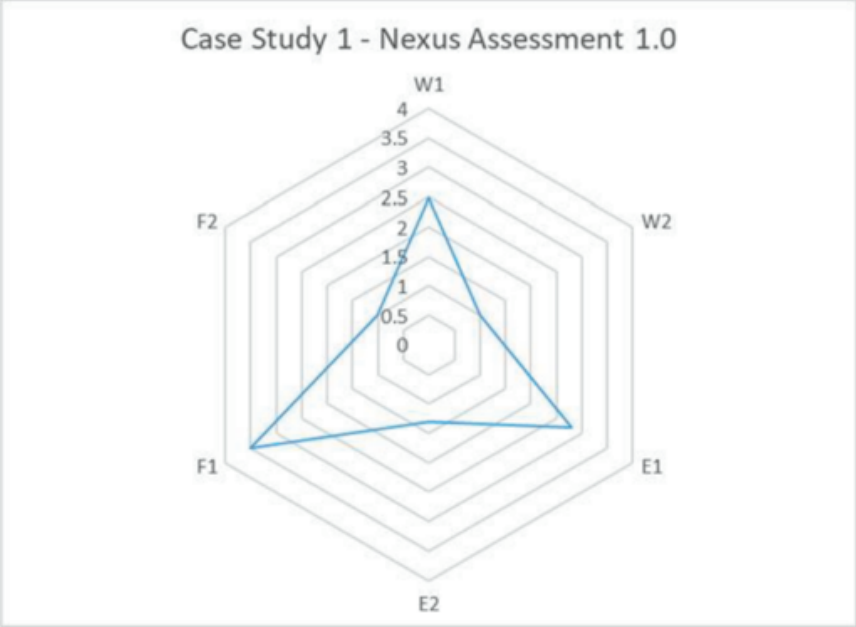


Figure 6: Radar Chart for Institution A using Nexus Assessment 1.0

5.2 Analytic Hierarchy Process (AHP) – Institution A

For the AHP method, the results obtained from the sustainability indicators together with the Saaty's scale were used to designate the importance with regards to the indicators being compared (Table 2). Following the allocation of Saaty's ratio scale to obtain the pairwise comparison matrix, it is then normalised using equation 1 as follows:

$$bij = aij / \sum j{=}1\ n\ aij \quad \text{.....equation 1}$$

Where *aij* represents the ratio scale allocated when the indicators are compared and $\sum j{=}1\ n\ aij$ represents the sum of ratio scales in a particular column. The average weight of each parameter was then determined from the normalized PCM table (Table 3). A consistency ratio was carried out and a value of 0.0983, less than 0.1, confirming the validity of the results.

	W1	W2	E1	E2	F1	F2
W1	1	3	1	3	1/3	3
W2	1/3	1	1/5	1/3	1/5	1
E1	1	5	1	3	1/3	3
E2	1/3	3	1/3	1	1/3	1
F1	3	5	3	3	1	3
F2	1/3	1	1/3	1	1/3	1

Table 2: Pairwise Comparison Matrix (PCM) for Institution A

	W1	W2	E1	E2	F1	F2	Indices
W1	0.17	0.17	0.17	0.26	0.13	0.25	0.19
W2	0.06	0.06	0.03	0.03	0.08	0.08	0.06
E1	0.17	0.28	0.17	0.26	0.13	0.25	0.21
E2	0.06	0.17	0.06	0.09	0.13	0.08	0.10
F1	0.50	0.28	0.51	0.26	0.39	0.25	0.37
F2	0.06	0.06	0.06	0.09	0.13	0.08	0.08

Table 3: Normalised PCM

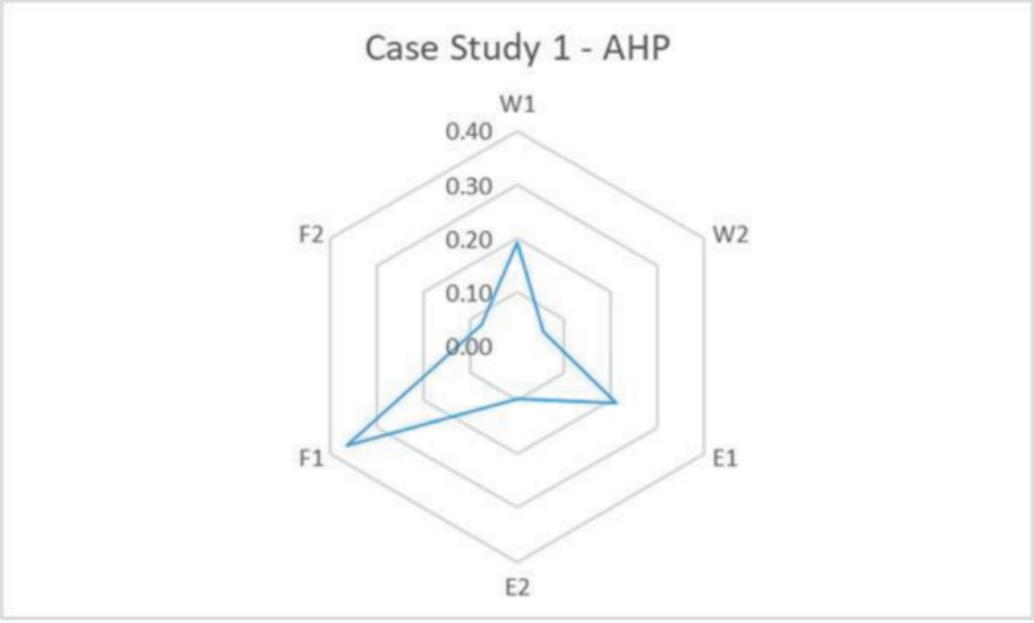


Figure 7 – Radar Chart for Institution A using the AHP method

From the charts in figures 6 and 7, it can be distinguished that the shape obtained is similar irrespective of the axis which in turn outline the same general performance of the WEF sectors at the Institution A. The further the distance the indicator is from the axis, the higher the level of sustainability. Thus, for this institution the results have shown that there is imbalance in resource utilisation and management. The worst performing indicator is water availability (W2) for irrigation purposes while water consumption is one of fairly well-managed sustainable component. In this case study, it is regarded that there is loss of water during traditional method of watering the ground and is thus regarded as unsustainable.

However, for a balanced and sustainable resource utilisation and management, the institution must aim to enable the sectors to reach the highest score of 3.5 or the index of 0.37 to obtain a regular shape of the polygon in the radar chart. The deformed shape of the polygon in the chart may suggest that it is the result of sectoral approach in managing the resources as pointed out in the literature review. As such the existing approach would continue to create imbalance unless sustainability approaches are implemented to balance the resources.

Conclusion & Recommendation

This study first confirmed that both method follow a logical approach and hence the results are comparable. The Nexus Assessment 1.0 is an iterative method, relatively easy to implement and can be applied at any level of analysis. As per the FAO guidelines, sustainability indicators, benchmarks, weightage and scoring were prepared. These were then combined to evaluate areas of intervention for the WEF sectors. The methodology emphasised the importance of stakeholders' participation for the determination of the indicators, benchmarks and weightage as well as to successfully apply the WEF Nexus approach in the local context. It is primarily a qualitative tool that would lead institutions towards better decision making. The AHP considers both qualitative and quantitative data, and requires thorough understanding and expertise to take decisions in the planning and allocation of resources. The AHP used the concept of Pairwise Comparison Matrix (PCM) and involved the application of technical parameters such as eigenvalues and eigenvectors. The methodology helped to assess the sustainability indicators, indicate areas of intervention and determine the need for a balanced resource management. Simultaneously, it can be used to assess the country's progress towards SDGs.

Similar to Nexus Assessment 1.0, the AHP tool also requires stakeholders' participation to allocate Saaty's ratio scale when comparing the indicators in view of obtaining the matrix. The study recommended the adoption of more sustainable resources exploitation at the Institution
A. For example;

1. The institution could consider the installation of a green roof in the UoM campus can be of great help. The rainwater captured from the green roof can be used for irrigation purposes. This system is also energy efficient as it minimises heat losses and thus less energy will be required for cooling the building.
2. Smart drip irrigation system can be implemented which will use the water stored in green roofs to water the plants and at the same time this will reduce the amount of potable water used for irrigation.
3. The institution A could also consider investing in solar photovoltaics, to promote cleaner energy usage and relieving the strain of fossil fuel usage for electricity production.

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SIMULATING SEAWATER INTRUSION USING A COMBINATION OF GEOPHYSICAL AND NUMERICAL MODELLING TECHNIQUES

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Seawater Intrusion (SWI) generally defined as the movement of seawater into coastal aquifers has long been recognised as a global phenomenon affecting to a great extent supply of freshwater to coastal communities. Seawater intrusion is a natural activity which cannot be eliminated and hence posing a serious threat to coastal aquifers worldwide, specially when aquifers are in hydraulic contact with the sea. This phenomenon has been under study for many years now and with the ongoing impact of climate change, its occurrence, investigation and management have been of prime importance in a view to achieving the objectives of Sustainable Development Goal 6 which is to ensure access to drinkable and clean water to one and all. The complexity of SWI made its study difficult due to the lack of primary data. However, with the collaboration of other field of studies and advancement in technology, measurement of SWI has been made possible allowing water authorities to better manage the situation. Electrical conductivity characteristics of seawater led to geophysics being a breakthrough in the study of SWI since the use of geophysical methods made characterisation of seawater/freshwater interface easier which is one of the main factors symbolising the extent of SWI inland. Therefore, this research project aimed at using the geophysical method of electrical resistivity for primary data collection at Flic-en-Flac, Mauritius to generate a conceptual model in order to understand the prevailing situation at the site. Numerical models using MODFLOW software were then generated to predict the reaction of the seawater/freshwater wedge when subjected to different conditions including; dry condition, sea level rise, pumping of wells and groundwater recharge due to precipitation. Results from the numerical models showed that sea level rise and pumping of wells were the major factors which led to an increase in the inland lateral movement of the seawater/freshwater interface while groundwater recharge was the only factor which led to the recede of the interface. The numerical model illustrated the dynamism of the groundwater/seawater interface and highlighted the need to monitor groundwater to minise the potential of seawater intrusion. This study confirmed that groundwater numerical modelling tools need to be part of effective groundwater management plans.

***Keywords**: Groundwater numerical models; Seawater Intrusion; Geophysics: Electrical Resistivity: Groundwater Management plans*

Introduction

The year 2015 has been described as a landmark year when the Paris Agreement on Climate Change had been agreed and signed by nearly all the world's nations. A list of 17 Sustainable Development Goals to be achieved by 2030 had been set, among which Goal 6 Clean Water and Sanitation has the objective of ensuring access to drinkable and clean water to one and all. Achieving this could would definitely be

impossible unless global freshwater resources are safe. With the impact of climate change, seawater intrusion is posing a serious threat to the quality of the greatest provider of freshwater which is groundwater. Groundwater is under threat because it is out of sight and thus out of mind.

The hydrological network of Mauritius is such that whereby perennial rivers originate from the center and move radially towards the coast through a dense and heterogeneous river network. In most regions, the rivers interfere with the rich and versatile ground water systems of the island. Hence, the aquifers receive their recharge mainly from the Central Plateau in an area where they are exposed at the surface. Surrounded by the sea, Mauritius has not been left unaffected by the phenomenon of seawater intrusion. The island consists of five main aquifers which are permeable basaltic lava rocks that lie between two relatively impermeable strata and are in constant hydraulic contact with the sea. These aquifers provide about 50% of the freshwater supply to the population.

Most of our coastal regions rely on groundwater as their main source of fresh water for domestic, industrial and agricultural purposes since most of the country's reservoirs and dams are located in the Central Plateau where rainfall intensity is known to be greater. With a substantial increase in the coastal population over the past years, the natural process of seawater intrusion will undoubtedly be subject to major disturbance which would affect the water production and provision in the coastal regions. Therefore, the importance of predicting the extent of sweater intrusion in the coming years and measures to alleviate this issue.

Aim

The aim of my research project was to develop a model using a combination of geophysical and numerical modelling techniques to analyse and predict the extent of seawater intrusion into groundwater.

Objectives

The aim was thus achieved through the objectives defined below:

- Performing literature reviews about seawater intrusion processes, methods of data collection and analysis techniques.
- Selection of site for investigation
- Collection of primary and secondary data
- Use of ModelMuse software for predicting results.
- Interpretation of results obtained and give recommendations

Literature Review

Seawater Intrusion

Seawater intrusion (SI) is one of the most challenging and widespread environmental problems that threaten the quality and sustainability of fresh groundwater resources in coastal aquifers (Husain et al 2019, p. 1).

The extent of saline water intrusion coastal areas is influenced by the following (Himi et al 2016):

- the nature of geological formations present
- hydraulic gradient
- withdrawal and recharge rates of groundwater
- the type of aquifer porous, fractured or karstic

- dispersive mixing
- tidal effects
- density effects including unstable convection, surface hydrology (e.g., recharge variability and surface–subsurface interactions)
- paleo-hydrogeological conditions (i.e., leading to trapped ancient seawater)
- anthropogenic influences
- geological characteristics that influence the degree of confinement as well as aquifer hydraulic and transport properties

The interactions between these and other processes such as geochemical reactions, tsunamis and other episodic ocean events, beach morphological controls on shoreline water table conditions, unsaturated zone flow and transport provide for a seemingly infinite array of possible settings in which seawater intrusion can occur.

This poses a significant challenge for water resource managers in identifying the primary seawater intrusion controlling factors and considering these in both the evaluation and optimization of groundwater use. (Werner et al 2013, p. 4)

Seawater and Freshwater Interface

Under natural conditions, the seaward movement of freshwater prevents saltwater from encroaching on freshwater coastal aquifers. This interface between freshwater and saltwater is maintained near the coast or far below the land surface and allows the mixing of fresh and sea water. This zone is referred to as the zone of dispersion or the zone of transition. (USGS n.d)

The first physical formulations of saltwater intrusion were initially made by Drabbe and Ghyben (1889) and Herzberg (1901) by assuming that they are immiscible. (Vengadesan et al 2019, p. 384)

Ghyben-Herzberg Relationship

The upward or downward movement of seawater into the coastal aquifer is governed by a well-established mathematical relationship known as the “Ghyben-Herzberg relationship”.

The Ghyben-Herzberg relationship assumes, under hydrostatic conditions, the weight of a unit column of freshwater extending from the water table to the salt-water interface is balanced by a unit column of salt water extending from sea level to that same point on the interface. (Solinst 2020)

According to this relationship, the rate of freshwater flow to the sea above the interface determines the length of the seawater wedge intruding into the aquifer. As this discharge is reduced, e.g., by pumping a larger proportion of the natural replenishment, the length of the seawater wedge will increase, causing wells to start pumping saline water. (Bear et al 1999, p.3)

Identification of Seawater Intrusion using Geophysical Method

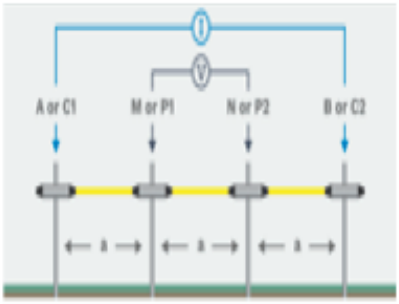
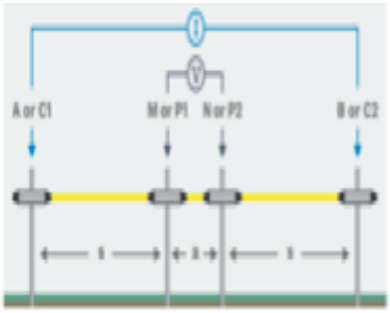
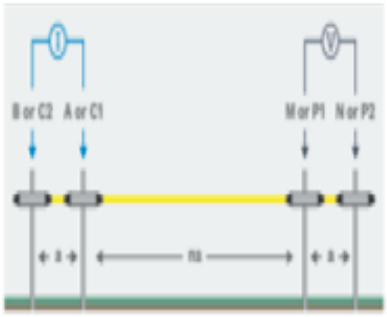
Seawater intrusion causes high levels of Na and Cl concentrations in coastal groundwater which in turn is reflected in the form of high electrical conductivity values. Conductivity values are indirectly proportional to resistivity values. Groundwater has high resistivity values (low EC), and lower resistivity values (high EC) in coastal regions indicating the presence of seawater.

All the types of geophysical methods mentioned above can be used in the identification of seawater intrusion but the most commonly used are Vertical Electrical Sounding (VES) and Electrical Resistivity Tomography (ERT).

Principles of VES and ERT

The principle of both methods is to induce a current of known intensity into the ground using two current electrodes. The electrical potential drop is then read using two other electrodes. The investigation depth is proportional with the distance between the power electrodes.

Different electrode array configurations are available, but all configurations are aimed at gathering data that can be used to estimate lateral and vertical variations in ground resistivity values.

Wenner array	Schlumberger array	Dipole-Dipole array
		

Numerical Models

Groundwater Flow Equation

Saline movement is dominated by advective transport. An essential prerequisite for an accurate simulation of transport is an accurate description of the flow in the aquifer, which is obtained by applying Darcy's law and the law of conservation of mass to a control volume

Using the notation of Konikow and Bredehoeff (1978), the groundwater flow equation can be written as:

$$\delta/\delta_{x_i}\left(T_{ij}\ \delta h/\delta_{x_j}\right) = S\ \delta h/\delta t + W \qquad (i = 1, 2)$$

where T_{ij} = transmissivity tensor (L^2T^{-1})

h = hydraulic head (L) above a reference point (usually sea level)

S = storage coefficient (-)

W = source or sink volume flow term (LT^{-1}), positive for outflow (= W (x_i, t), i = 1, 2. This is usually recharge, pumping and evapotranspiration)

x_i, x_j = Cartesian coordinates (L)

t = time (T)

(FAO 1997, p. 28)

Advection-Dispersion Equation

The advection-dispersion equation is derived in a similar manner to the groundwater flow equation. Using the notation of Konikow and Bredehoeff (1978), it can be written as:

$$\delta(Cb)/\delta t = \delta/\delta_{x_i}\left(bD_{ij}\ \delta C/\delta_{x_j}\right) - \delta/\delta_{x_i}\left(bCV_i\right) - C'W/\epsilon$$

where: D_{ij} = coefficient of hydrodynamic dispersion (L^2T^{-1})

V_j = seepage velocity in the direction of x_i (LT^{-1})

C = concentration of the pollutant (ML^{-3})

C'= concentration of the pollutant in the source or sink fluid (ML^{-3})

B = saturated thickness of the aquifer (L)

ϵ = effective porosity of the porous medium (-)

The first term on the right-hand side of this equation represents the change in chemical concentration due to kinematic dispersion and diffusion since the two cannot be split up. The second term represents the effect of advective transport which means the movement of the fluid due to the movement of the water. The third term represents the contribution and removal of pollutant due to fluid sources and sinks.
(FAO 1997, p. 28-29)

Methods of solving these equations include:

1. Finite Difference Method
2. Finite Element Method
3. Method of Characteristics

Due to the complexity of these methods, they have been incorporated in software which are therefore used for modelling of seawater intrusion.

Geophysical Modelling Approach

A conceptual model was at first developed using the Geophysical method of Vertical Electrical Sounding (VES) test to understand, interpret and relate the resistivity values obtained from the test to the static situation of seawater intrusion at the site. The test was carried out in accordance to **BS 1377-9:1990 Clause 5.1 Determination in-situ of the apparent resistivity of soil.**

The procedure for the VES Test involved the following steps:

1. The equipment was first set up as shown in the figure below and the electrodes connected as per Wenner Configuration.
2. The resistivity meter was turned on and values of current and resistance taken when fluctuations in the readings stopped.
3. Distance between the electrodes were increased to cover a larger area and a series of resistance values taken.

Segments/Layers	Depth (m)	True Resistivity (Ωm)	Conductivity (S/m)
AP	≥34	2.75	0.3636
AB	6-34	38.89	0.0257
BC	3.5-6	23.81	0.0419
CQ	3.5	342.47	0.0029

4. Resistivity was finally calculated using the formula below followed by the reciprocal of the former.

$$\rho_a = 2\pi aR$$

5. A graph of (1/2π R) vs (a) was then plotted and using the inverse slope method the true resistivities of each segment/layer was calculated.

6. The reciprocal of the true resistivity values gave the conductivity values in siemens per meter.

The graph of True Resistivity against depth satisfied the relationship of seawater and resistivity. Seawater is known to have low resistivity accounting for its high conductivity properties. Hence, the decrease in resistivity indicated the presence of seawater as depth into the sand increased.

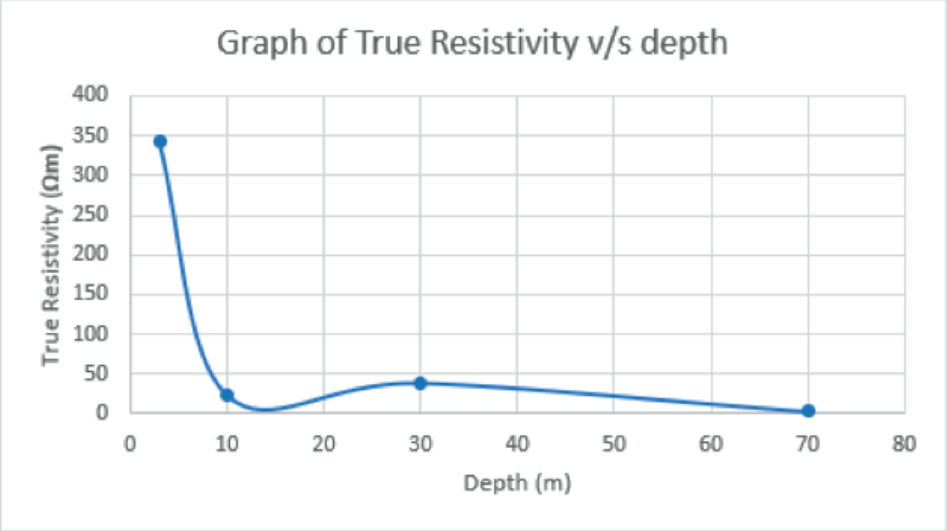


Figure 1: Graph of Resistivity against Depth

From the Geophysical data, it could thereafter be deducted that the seawater/freshwater interface at Flic-en-Flac was indeed very close to the land as at the year 2015 since resistivity values were encountered as at depth 3m itself and from depth 34m and onwards a major decrease in resistivity indicated the presence of seawater to a greater extent.

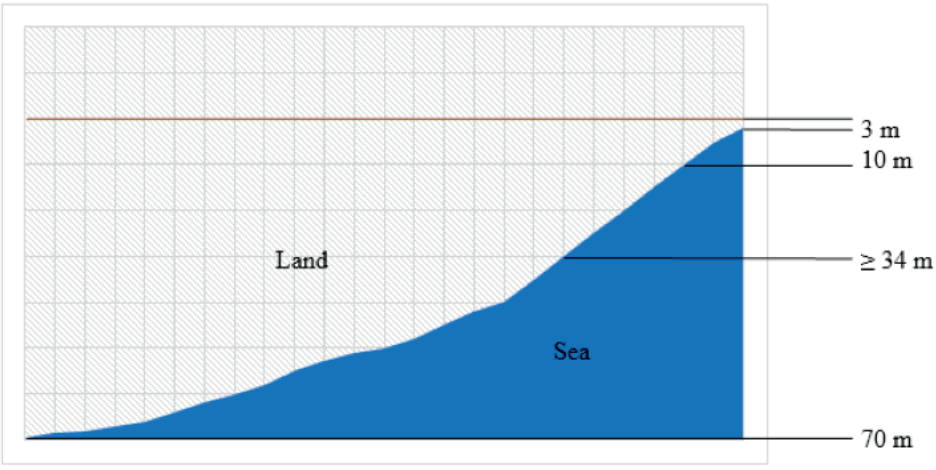


Figure 2: Conceptual Model of Flic-en-Flac

Numerical Modelling Approach

For the purpose of this research project, ModelMuse software, graphical user interface for MODFLOW-2005, a finite-difference groundwater flow model developed by the U.S. Geological Survey (USGS) was used. The approach used in solving the Groundwater low equation and advection-dispersion equation in MODFLOW is the finite-difference method wherein the continuous system described by is replaced by a finite set of discrete points in space and time, and the partial derivatives are replaced by terms calculated from the differences in head values at these points.

The development of an accurate and reliable model firstly required an understanding of the features of ModelMuse and all the critical parameters involved. The parameters used for the development of Flic-en-Flac model were thereafter explained below.

Model Grid

1. The size of the model grid was specified in terms of the number of rows, number of columns and number of layers. These terms defined a three-dimensional grid of cells in the form of a rectangular box.

	Number	Width (m)
Rows	50	10
Columns	50	10
Layers	1	-

Table 1: Grid Dimensions

Hydrologic Flow Packages

1. The model MODFLOW-2005 was chosen for analysis and five models had been generated with the same model grid size but subjected to different conditions.

Model Number	Conditions	MODFLOW Packages
Model 1	Dry Condition	SWI2, LPF, GHB, ET
Model 2	Sea level rise	SWI2, LPF, GHB
Model 3	Pumping of wells	SWI2, LPF, GHB, WEL
Model 4	Groundwater recharge	SWI2, LPF, GHB, RCH

Table 2: MODFLOW Package used

- The density was kept constant between surfaces as per Ghyben-Herzberg Relationship.
- Presence of two distinct zones seawater and freshwater with a difference in density of 0.025 g/cm3.
- The Pre-Conjugate Gradient (PCG) method was used as solver with 200 iterations for the finite-difference equation.
- Layer AP was assumed to be an unconfined layer since water was seen after digging to some depth on the site.

Boundary Conditions

- All the five models had two main boundaries, the sea and the land.

- Under the GHB Package, the sea (ElevationSea) was assigned a head of 0m while the land (RegionalHeadFlux) a head of 4m, the value for Flic-en-Flac was taken from the Hydrology Data Book 2002.
- An active surface elevation was defined which was a region where only seawater was allowed out of the system.

Object	Name	Head (m)
Polygon (rectangle)	ElevationSea	0
Polyline (line)	RegionalHeadFlux	4
	ActiveSurfaceElevation	0
	SeawaterElevation	-3
		-10
		-40
		-70

Table 3: Boundary conditions

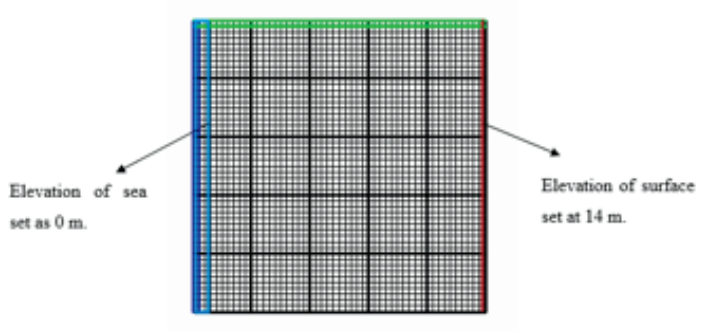
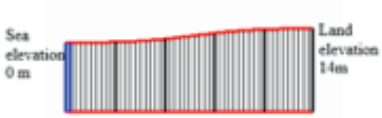
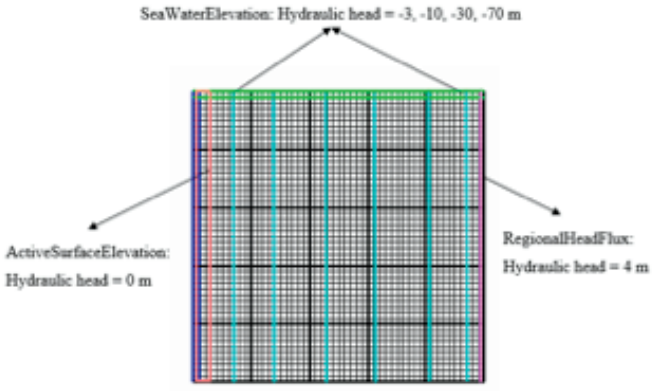
Top view of model for elevations	Cross sectional view for elevations
	
Top view of model for Boundary Conditions	
	

Table 4: Views of Model

Model Predictions

Model 1: Dry Condition

For the first model, dry condition implied the loss of water from the system which was therefore modelled by the parameter of evapotranspiration. An evapotranspiration of 1330 Mm3 for the year 2015 was taken. The extent of seawater intrusion from sea boundary was measured to be at a distance of 185 m and 14.5 m below the water table.

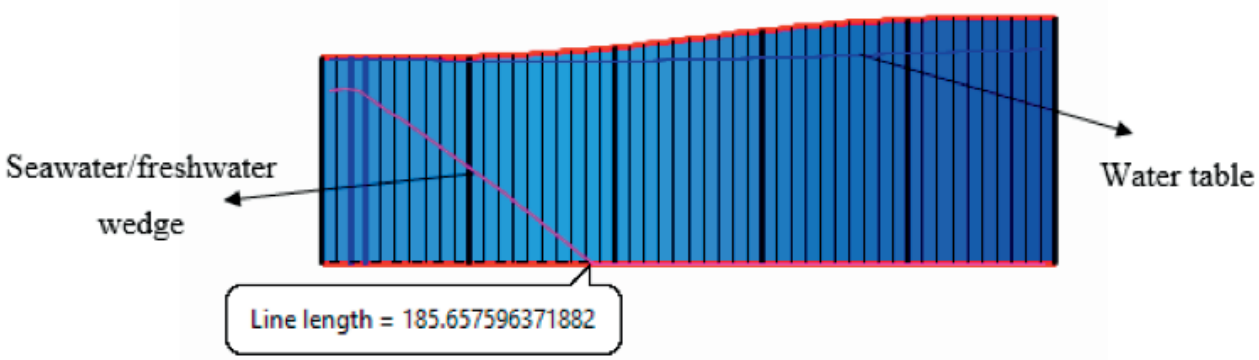


Figure 3: Seawater/freshwater interface with no effect of external factors

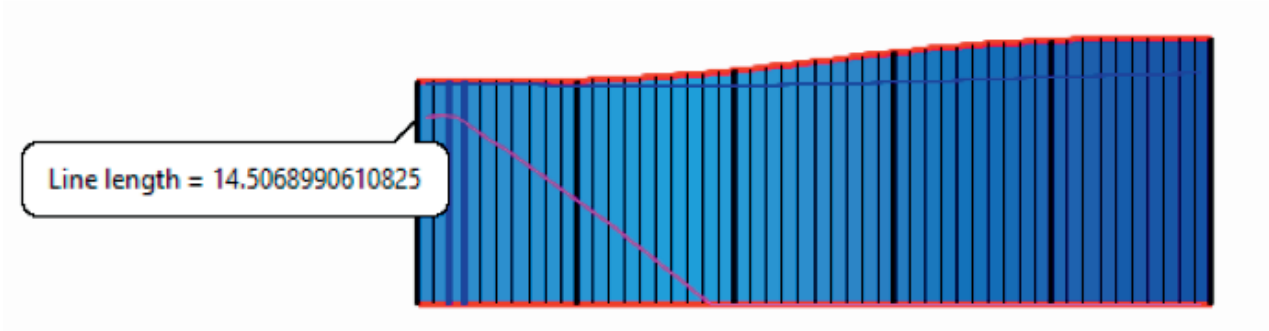


Figure 4: Depth of interface from water table

Evapotranspiration is a major source of loss of water in Mauritius. Rate of evapotranspiration is usually higher in summer. It can be deduced from these two figures that evapotranspiration does not have a major effect in the movement of the interface both relative to sea boundary and the water table.

Model 2: Sea level rise

The state of Flic-en-Flac beach has been a major concern for the local authorities since the beach is being eroded. The position of the high-water line has moved and coastline has receded by 2m near Flic en Flac public beach (Bhagwant et al 2003) making erosional scarps visible. This clearly shows that if sea level rise is already having its impact inland, hence, the subsurface has undoubtedly not been spared.

Sea levels in Mauritius have been monitored since 1986 by tide gauges and as from 1993, altimetry data has been gathered. A study by Lalouviere (2018 cited Holgate et al 2013; PMSL, 2018) states that fitting a linear line to the yearly average water levels of the 31 years of tide gauge data from the Port Louis station show a 4.8 mm/yr. rate of local increase in local sea levels. Hence, an increase of 1.31 m/day (4.8 mm/yr) in sea level was modelled which gave the following result.

The interface rose higher to meet the water table and moved further inland a distance of 494 m as compared to 185 m and 165 m for the two previous models. This major increase inland distance shows that with the melting of ice bergs leading to sea level rise, coastal aquifers globally would be threatened to contamination and the supply of freshwater worldwide would decrease drastically.

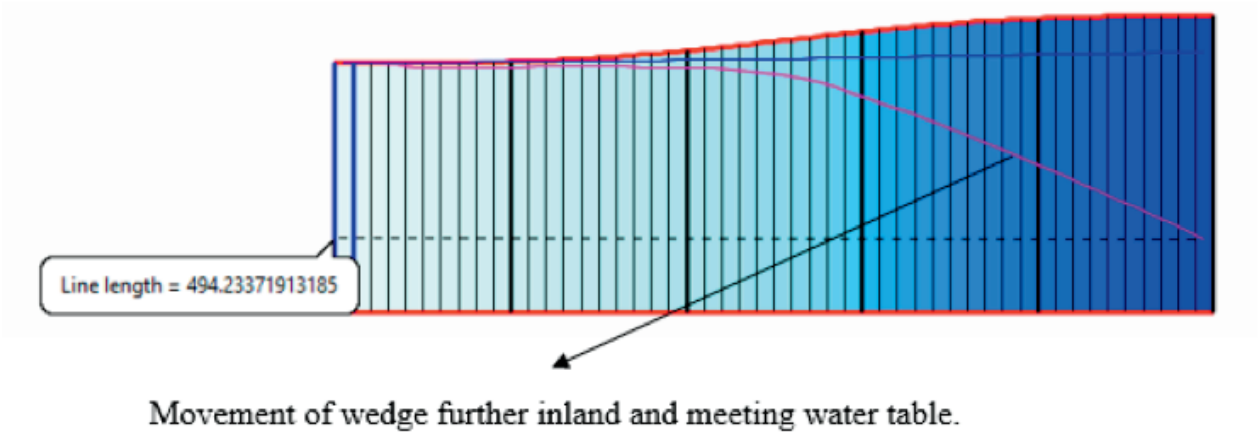


Figure 5: Effect of sea level rise on seawater/freshwater interface

Model 3: Well Abstraction

In Mauritius, water from our aquifers is abstracted from 604 boreholes out of which 163 are for domestic purposes, 211 for irrigation and 230 for industrial (Ministry of Energy and Public Utilities 2020). As at 2015 groundwater constitutes some 54% of total water production. The flow rate, Q, for a proposed borehole to be dug at Flic-en-Flac is 20 m3/hr (CWA 1989). It must be noted that, pumping was simulated in the second stress period that is in the transient state.

Flic-en-Flac forms part of the most visited beach in Mauritius, the coast of which is aligned with many hotels. The pumping rate for coastal boreholes are usually lower. A well of pumping rate 20 L/s was firstly placed at the site. The pumping rate was then doubled to 40 L/s.

For the first pumping rate it was observed that the interface did not move further inland but the it rather moved up to meet the water table. The lateral distance was about 194 m and lowering of the water table was also observed.

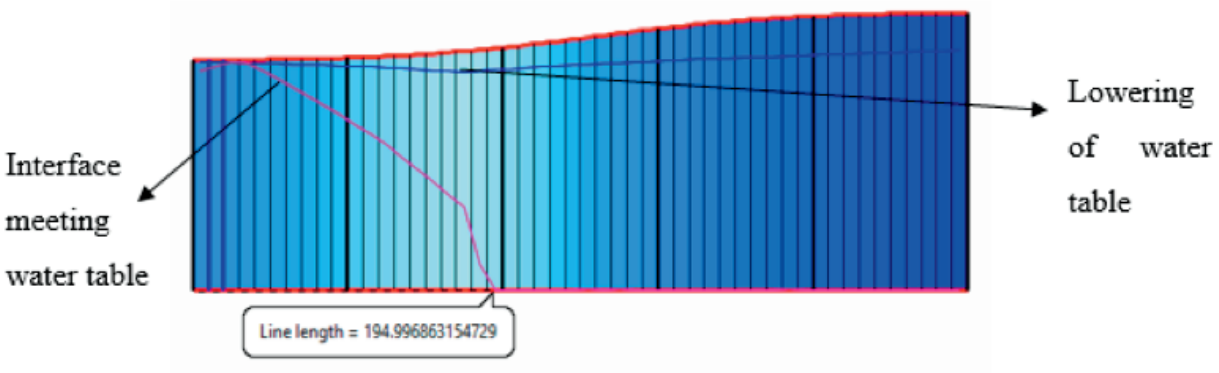


Figure 6: Effect of pumping on the interface just next to the well

When the pumping rate was doubled, a disturbed interface was observed with drawdown of the water table, the lateral distance was not measurable.

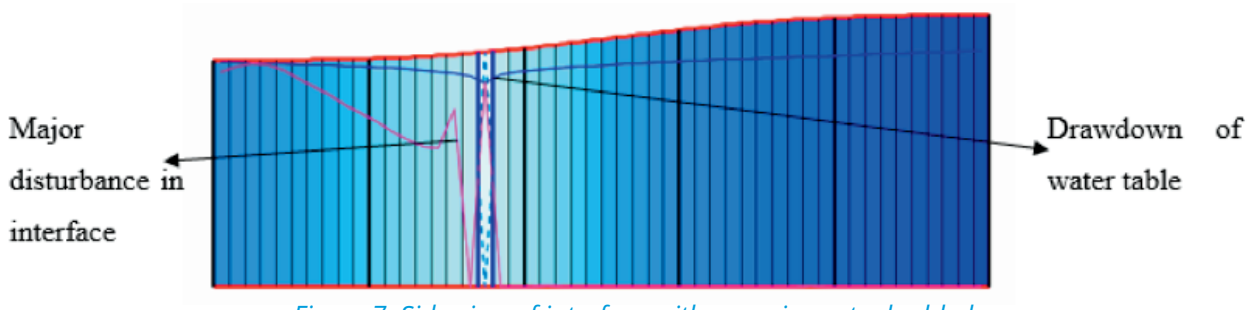


Figure 7: Side view of interface with pumping rate doubled

The front view of the model showed coning of the interface occurred at the well as pumping was done, which implies that with a doubled pumping rate, brackish water will be pumped.

When moved into the well, an undisturbed interface was observed both in the cross-sectional view and front view. Coning of the water table was also observed as pumping occurred.

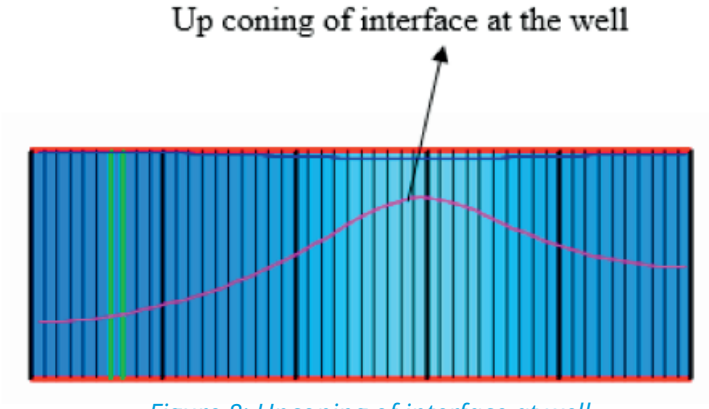


Figure 8: Upconing of interface at well

Model 4: Groundwater Recharge

So far, sea level rise and pumping from wells have had negative impact on the groundwater causing seawater to intrude more into groundwater. Groundwater recharge has however been seen of having a positive impact. In Mauritius, the main source of groundwater recharge is precipitation.

During the year 2015, the mean amount of rainfall recorded around the Island of Mauritius was 2,377 millimetres (mm).

A recharge rate of 8 % was taken for simulation and the results showed that the seawater/freshwater interface receded in case of groundwater recharge. The extent of seawater intrusion decreased to 108 m laterally while from the water table the interface decreased to 70 m.

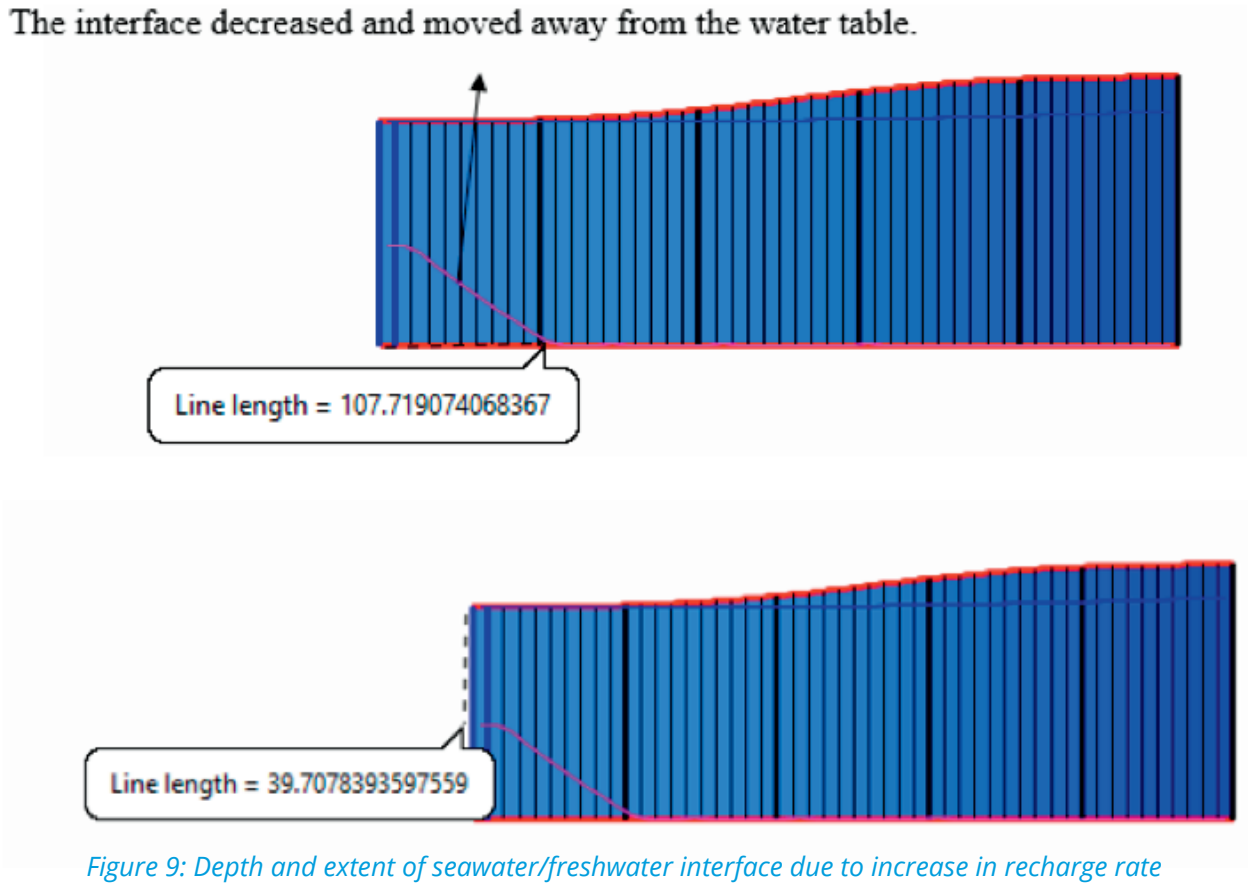


Figure 9: Depth and extent of seawater/freshwater interface due to increase in recharge rate

Conclusion

This research was aimed at showing how the combination of Geophysics and Numerical Modelling could be applied to the study of seawater intrusion. Data from the Geophysical method of Electrical Resistivity was firstly used to get the conceptual model of the current situation (static level) of seawater intrusion at Flic-en-Flac and secondly Numerical Modelling was used to predict what could happen in case of changes in factors governing seawater intrusion. The conceptual model showed that seawater was encountered starting from a small depth of 3 m underground. Results from the numerical models showed that sea level rise and pumping of wells were the major factors which led to an increase in the inland lateral movement of the seawater/freshwater interface while groundwater recharge was the only factor which led to the recede of the interface.

Seawater intrusion is a natural phenomenon which cannot be eliminated but with proper measures taken it can be sustainably managed. Data provided about the water resources in Mauritius showed that island relies on groundwater for about 50% of its portable water production. With industrialisation and increase in population, water demand will undoubtedly rise as well which will require tapping of more groundwater through boreholes. However, the recharge rate of groundwater is about 10% as compared to 60% of surface water and this study showed that groundwater recharge is dominating factor in preventing the ingress of the seawater/freshwater more inland. As at 2015, the then Director of Water Resources Unit stated that, Mauritius is already water stressed equivalent to 1083 m3/person/yr. and is suspected to suffer from water scarcity by 2020 with a forecasted supply of 974 m3/person/yr. It is therefore high time to consider how the Mauritian water resources could be managed to ensure freshwater supply to everyone in todays without jeopardising the supply for future generation.

Recommendations

While reading published papers and going through the different studies performed for sea water intrusion, it was noted that various methods have been established in a view to managing the sea water intrusion which include the following:

1. First practical way to manage sea water intrusion is to have controls over groundwater pumping to regulate groundwater extraction. This can be enforced through introduction of legal sanctions. Ground Water Act 1969 which is available on the website of the Ministry of Energy and Public Utilities should amend the rules and regulations concerning the abstraction of groundwater.

2. Reducing discharge to or enhancing recharge from terrestrial surface systems containing freshwater. Natural groundwater recharge occurs as precipitation falls on the land surface, infiltrates into soils, and moves through pore spaces down to the water table. Natural recharge also can occur as surface-water leakage from rivers, streams, lakes, and wetlands

3. Artificial recharge can be done through injection of water through wells. This method often is applied to recharge deep aquifers where application of water to the land surface are not effective at recharging these aquifers. This method has to be developed and used in Mauritius prior to the deterioration of the situation concerning the sea water intrusion and to maintain the sea water/freshwater interface nearer to the sea.

4. Enhancing aquifer recharge through wastewater injection or artificial recharge ponds. Wastewater injection implies construction of an injection well to place wastewater fluid underground into porous geologic formations. These underground formations may range from deep sandstone or limestone, to a shallow soil layer.

5. The installation of physical subsurface barriers to inhibit sea water intrusion and/or retain groundwater. Barrier wall materials suggested to be used are bentonite clay, concrete grout, bituminous substances or sheet piles.

6. In addition, subsurface dams can be built whereby the dam is rooted at the impervious bottom layer of the aquifer and impedes its lower part only, while leaving an opening above it in order to allow the natural discharge of freshwater to the ocean.

7. Cut-off walls can be constructed whereby the wall extends from the top of the aquifer to a predefined depth. The cutoff walls become more effective of increases when they are closer to the coastline and have greater penetration depth. The shorter the distance of the cutoff wall to the coast, the larger the volume of fresh groundwater.

8. The concept of injecting air to reduce aquifer permeability can also be applied in worst cases in order to diminish movement of water around the aquifer.

9. In California, a dual project whereby both a surface basin and seawater barrier is being used to defend against saltwater intrusion and to recharge the groundwater aquifer. This implies the managing techniques detailed above can be used together, wherever practicable, in an organised way, in order to reduce the sea water intrusion process.

10. All the methods mentioned above can be utilised in Mauritius as well in order to prevent the aftermath which will occur as sea water intrudes our main aquifers.

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