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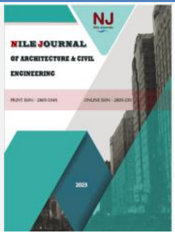

ASSESSMENT OF EXPOSURE AND ADAPTATION OF COASTAL MILLION-CITIES IN AFRICA TO SEA LEVEL RISE IMPACTS

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ABSTRACT

Many environmental and socio-economic issues impacted in many African settlements, especially the big cities. The study aims to identify the highly exposed cities to impacts of sea level rise (SLR) to recommend suitable adaptation strategies. The exposure analysis is based on some city's characteristics; population, area, density, elevation, and importance. Due to high changes in global climate and social circumstances, there are twenty-four vital million-cities in the African coastal zone (from the shoreline to +20 above sea) that exposed to SLR threats (i.e. coastal flooding, erosion, storms, saltwater intrusion). The strategic spatial planning for these cities should be based on a group of SR adaptation strategies that are appropriate to the circumstances of every city. The exposure analysis is an essential base to set an integrated framework to support their resilience against SLR impacts. Furthermore, proactive adaptation is more economical and more effective than reactive adaptation. Accommodation strategy is very urgent to redesign the building and the infrastructure to adapt to the raised SLR rate by the precise supervision of local authorities. A protection strategy is required for high-density areas, the hard works could be used in front of severe waves, while softworks could be used in high tides or weak waves that create wide and eco-beaches. Avoid strategy or do nothing is an appropriate strategy for the highly exposed open spaces. Retreat strategy could be used when the cost of protection is higher than the value of the assets. All of adaptation works in these strategies are shared between civil and governmental parts. Also, the developers and designers should be well trained and aware of all changes. Moreover, it should do a frequent reassessment of SLR hazards every seven years to be updated with changes.

Keywords: Sea level rise, Africa, coastal million-cities, exposure, adaptation.

INTRODUCTION

The negative reactions that resulted from activities of human and nature cross ages have resulted in a phenomenon of global climate change. It became a physical issue at the global and regional levels (IPCC, 2014). While Africa contributes slightly to the increased rate of global greenhouse gases emissions (GHGs), it is considered the most exposed to the impacts of climate change (UNEP, 2001). Sea level rise (SLR) is considered from the most serious impacts on Africa that sourced from the existence of climate change. SLR impacts have become a true fact that increasingly challenge coastal zones all over the world (El-Shahat et. al., 2020). There are many SLR scenarios based on the current rise, for example, the IPCC SLR scenarios. SLR is resulting in high waves, high tidal range, saltwater intrusion, storm surges, other extreme events. These hazards could generate a likely potential risk from the processes of inundation and erosion, which could be resulted in lost in lives and assets, as already happened in most African cities. The rise in sea level is accelerated that will change the shoreline around many coastal zones in every coastal country. Therefore, SLR impacts on the environment, urban, and activities are likely increasing negatively upon times especially in the coming decades.

The exposure rate of elements to SLR hazards varies according to many factors; such as topography, slopes, proximity to the coast, soil type, population numbers, and land cover. Population growth and rapid urbanization are among the driving factors behind the increased exposure of African settlements to natural hazards, Africa's urbanization rate is the highest in the world, which reached 3.3

percent annually between 2000 and 2005 (The world bank, 2010). African topography varies due to high dynamic changes in tectonic and climatic events. Most parts of the African coastal zone are classified as low-lying areas. The coastal cities in Africa are exposed to SLR impacts, especially those that are adjacent to the shoreline and/or existed in the low-elevated areas. The livelihood in African settlements is mainly connected to the site's resources, which means that any impact from SLR hazards can weaken the settlement's strength against the potential risks. Also, the poverty rate in the African coastal zone is growing up, especially due to unsustainable development and conflicts. As well as, the African shorelines are degraded due to damming rivers, pollution, fuel overexploitation processes, mining processes, and coastal engineering works.

Most coastal cities in Africa have habitats for ecosystems (i.e. forests, wetlands, mangroves, estuaries) that have large communities of flora and fauna. Also, they have many other natural resources and human capabilities. Despite this variety of resources, they are suffering from a cruel nature. As African cities suffer from low capacity to adapt to extreme weather events (El-Raey et al., 1999), the stressors could be more devastating on the urban system with time. Recently, African cities have suffered from slums growth, poverty, weak urban management, and low technology (UN, 2014). One-third of Africa's urban population is already concentrated in the region's 36 cities with more than one million inhabitants (million-cities), most of the remaining two-thirds are spread across 232 intermediate cities and periurban areas (The world bank, 2010). Also, climate change and political issues had resulted in a decrease in the number of work chances, which forced people to migrate to big cities (Werz & Conley, 2012). Therefore, the exposure's consequences in these cities have been increased. The projected rise in sea level will have significant impacts on the coastal megacities of West Africa, where 40% of the population live, because of the concentration of poor populations in potentially hazardous areas that may be especially vulnerable to such changes, other coastal and deltaic areas at risk are those located in North Africa and southern Africa (Ndaruzaniye, et al., 2010).

THE METHODOLOGY AND STUDY AREA

The study aims to assess the exposure and adaptation of coastal million-cities in Africa to SLR impacts. The study based on the indicative analysis in the first stage (exposure assessment) and deductive analysis in the second stage (adaptation assessment). The exposure assessment for selected cities is based on five parameters; population, area, density, elevation, and importance. It has been used GIS application (ArcMap 10.3) as a study tool.

Africa had passed with devastating events resulting from climate change, which changed the urban pattern to be as shown in Fig. 1. The coastal zone in Africa has become a dense pattern of big cities compared to the inland cities, where are high population densities with a concentration of heavy activities. The continent's coastline is shared between thirty-three coastal countries with more than 26,000 km long. The area that existed between the shoreline and contour line +20 above the sea is a vital and critical zone due to specific reasons as mentioned in table 1, including a dense urban network as shown in Fig. 2. This zone in Africa varies in width from a few 100 meters (e.g. Red Sea area) to more than 100 km (e.g. Niger and Nile deltas). The area that existed in this zone has vital elements; such as valuable lands, ecosystems, and assets. Some of these elements are highly sensitive (i.e. natural protected areas, heritage buildings). This zone supports significant economic activities in the coastal countries (i.e. agriculture, tourism, commerce, and industry) through coastal ecosystem services. Also, it has vital cities that considered a developmental and social core for humans and habitat for ecosystems. For instance, some of those cities are the capital of the coastal counties as shown in Fig. 3. Many other coastal cities are also important ports, which are vital sites for national and regional trade. Although their location has generated a strong economic base, they have been exposed to many hazards, especially in light of their high population growth rate. This zone also is directly exposed to SLR impacts, particularly that adjacent to the shoreline. Therefore, there is an urgent demand to protect these cities from potential risks.

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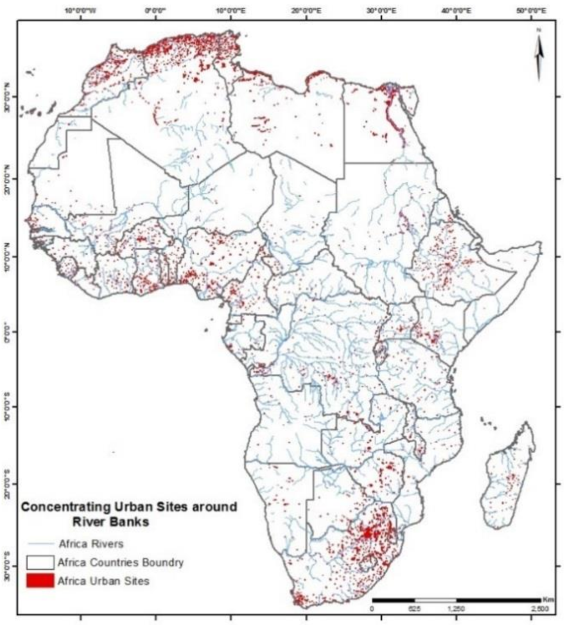
Table 1. Reasons for study's concern with the area between the shoreline and +20 m above sea level

Area	(0-5 m)	(5-10 m)	(10-15 m)	(15-20 m)	(< 20 m)
Characteristics	These areas are highly adjacent to the coast.	Many parts in this area have dunes and cliffs (coastal belts) that are prone to erosion and penetration from waves & tides.	This area is the most impacted by storm surges (exceeding 7 m), saltwater intrusion, and other extreme events.	15-20: high plateaus associated with continental shelf are prone to SLR.	> 20: this area is safer from SLR hazards.



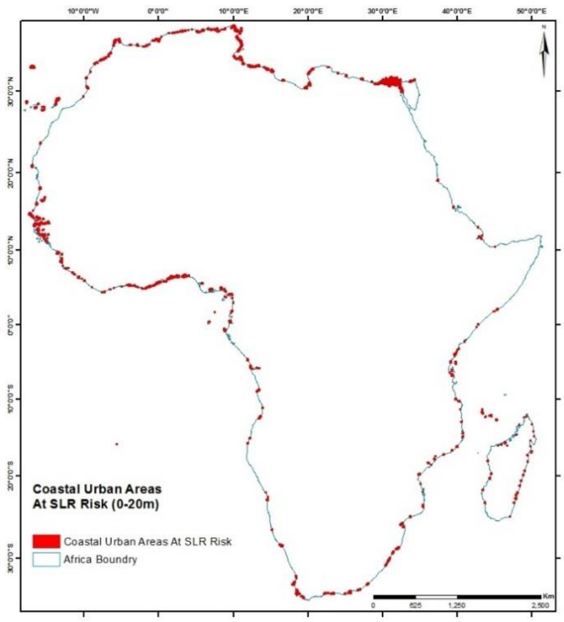


Fig. 1. The recent concentrating of urban network. Fig. 2. Coastal urban areas at SLR risk.

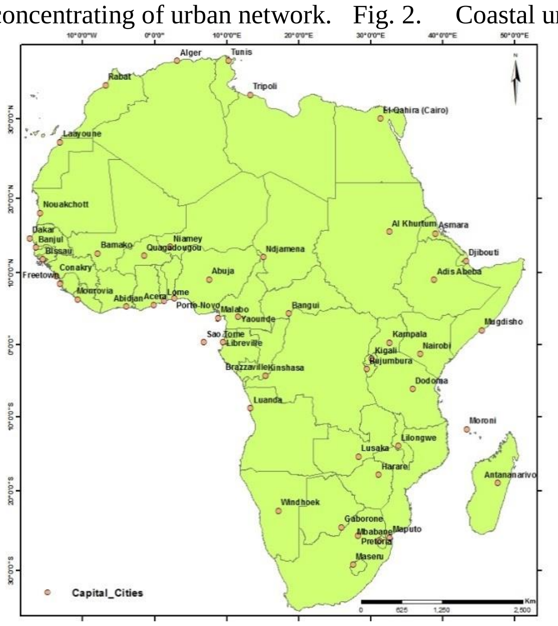


Fig. 3. Most of the capital cities are adjacent to the coast.

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EXPOSURE CLASSSES OF COASTAL MILLION-CITIES IN AFRICA TO SLR IMPACTS

Million-cities in Africa that located in the area < +20 m above the sea are highly exposed to SLR impacts, especially the adjacent margin to the sea or the ocean. The million and the most important cities that existed in < +20 m are shown in Fig. 4. Those million-cities are located in the approaching areas on the marine and riverine areas, due to variations in natural resources. The table 2 is displaying the main exposure factors of these cities; elevation, population, area, density, and importance. Accordingly, it can be classified the exposure classes of these cities to be as shown in table 3.

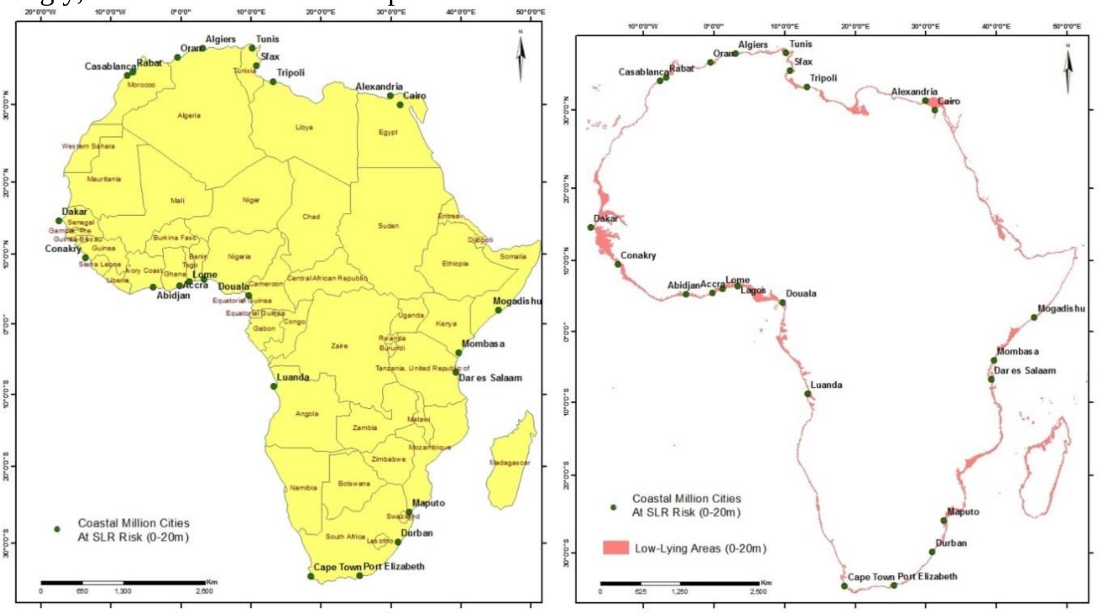

Fig. 4. Highly exposed million and most important cities in Africa to SLR impacts

Table 2. The most exposed cities to SLR impacts

City	Elevation	Population	Area	Density	Importance
Cairo	(15-30 m)	9,500,000 (2015)	3,085 km^2	17,992 /km^2	Capital and the largest city of Egypt
Alexandria	(0-25 m)	5,172,387 (2017)	2,679 km^2	1,900/km^2	Second important and second largest city in Egypt
Tripoli	(10-80 m)	1.126,000 (2014)	400 km²	4,500/km^2	Capital and the largest city of Libya
Tunis	(2-40 m)	1,056,274 (2014)	212.63 km²	9,406.01/km^2	Capital and the largest city of Tunisia
Sfax	(0-15 m)	280,566 (2014)	56 km²	5, 010.1/km^2	Essential economic city in Tunisia
Algiers	(5-420 m)	3,415,811 (2014)	363 km²	9,400/km^2	Capital and the largest city of Algeria
Oran	(0-120 m)	852,576 (2010)	2,121 km²	9,530 /km^2	The second important in Algeria
Rabat	(0-160 m)	827,577 (2014)	118 km^2	4,896 km^2	Capital city of Morocco and its second-largest city
Casablanca	(0 -150 m)	3,359,818 (2014)	306 km^2	10,979.3/km^2	The largest city in Morocco.
Dakar	(8-30 m)	1,030,594	83 km^2	12,416.8	Capital and the largest

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		(2015)		/km^2	city of Senegal.
Conakry	(4-110 m)	1,660,973 (2014)	450 km^2	3,700/km^2	the capital and the largest city of Guinea.
Abidjan	(3-100 m)	4,980,000 (2016)	2,119 km^2	2,350.2/km^2	The economic capital of Côte d'Ivoire (20% of the population), a fourth populous city in Africa.
Accra	(5-100 m)	2,291,352 (2012)	200 km^2	11,456.8/km^2	Capital of the Republic of Ghana.
Lomé	(3-40 m)	837,437 (2010)	99.14 km^2	9,305/km^2	Capital and largest city of Togo.
Lagos	(2-50 m)	8789133 (2005)	1,171.28 km^2	11,168/km^2	The most populous and financial city in Nigeria, second most populous in Africa.
Douala	(2-20 m)	2,446,945 (2012)	210 km^2	11652/km^2	the largest city in Cameroon and its economic capital
Luanda	(4-80 m)	2,487,484 (2018)	113 km^2	22,000/km^2	Capital and largest city in Angola,
Cape Town	(0-170 m)	3,740,026 (2011)	2,499 km^2	1,496.6/km^2	Coastal city in South Africa.
Port Elizabeth	(2-70 m)	876,436 (2011)	340.78 km^2	2,571.9/km^2	One of the largest cities in South Africa;
Durban	(2-80 m)	595,061 (2011)	225.91 km^2	2,600/km^2	The third most populous in South Africa
Maputo	(5-70 m)	1,094,628 (2007)	346.77 km^2	3,200/km^2	Capital and the most populous city in Mozambique.
Dar es Salaam	(2-50 m)	4,364,541 (2012)	1,393 km^2	3,100/km^2	Capital, the most populous and economic city in Tanzania
Mombasa	(4-50 m)	1,200,000 (2016)	229.7 km^2	5,224.2/km^2	The oldest and second largest city in Kenya
Mogadishu	(4-70 m)	2,425,000 (2017)	103 km^2	23,543.7/km^2	Capital and most populous city of Somalia.

Note: Most of these mentioned elevations in the table are an average of elevations in the city, some of the coastal margins of these cities are low-lying areas that are highly exposed to SLR impacts.

Table 3. The exposure's classes of these cities to SLR impacts

City	**Alexandria**	**Tunis**	**Sfax**	**Cairo**	**Tripoli**	**Dakar**	**Lomé**	**Lagos**	**Douala**	**Luanda**	**Mombasa**	**Mogadishu**	**Algiers**	**Oran**	**Rabat**	**Casablanca**	**Conakry**	**Abidjan**	**Accra**	**Cape Town**	**Port Elizabeth**	**Durban**	**Maputo**	**Dar es Salaam**
Exposure Level	Highly exposed			Moderate exposed										Low exposed										

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POTENTIAL SLR ADAPTATION CHANCES FOR MILLION-CITIES IN AFRICA

The natural disasters induced coastal floods, storm surges, tsunamis, droughts, forest fires, and diseases are weakening the capacity of the African coastal zone, which grew the exposure of the coastal communities to SLR threats. Moreover, low capacity in African cities is increasing due to many negative factors; such as high rate of poverty, wars, low technology, poor infrastructure, unstainable management, weak institutions, and shortage in services. The highly exposed shorelines of these cities are the low-lying margins, which deteriorated by the negative human activities. The natural sand belt and mangrove forests that protect most of the African cities against SLR impact are deteriorated due to the growth of urbanism and activities. Most of the African coastal countries are facing SLR by separate action plans at the local level associated with hard coastal engineering works, while the developed coastal countries are developing their responses against SLR impacts to sustain their coasts, especially that in the low-lying areas, via SLR adaptation policies and strategies based on many studies and field experts. Adaptation to the SLR threat is an urgent need in light of future scenarios, which may become true and worsen the situation if there is no pre-actual adaptation.

Coastal million-cities are needing to adapt to SLR and other hazards, to be more resilient in the face of different risks. Although there are significant reductions in global and national GHGs emissions recently, SLR responses may reduce these impacts rate during the coming centuries. The potential responses against SLR hazards to sustain the coastal million-cities are mitigation and adaptation, which poured in specific SLR policies and strategies. As well, other programs could be merged with them; such as programs of resilient-cities, eco-cities, green-cities, smart-cities, sustainable-cities, heat islands, disaster risk reduction, and…. Mitigation policies are a precise agenda that orientates the governmental and civil institutions to decrease the GHGs emissions rate in the atmosphere by certain legislation and codes. Adaptation is related more to actions, which is a local activity based on many procedures to protect nature or population or both from SLR.

Adaptation is a holistic process based on data (actual) and predicted variables to adjust and face the SLR changes. Because of uncertainties and complexities in this science, it depends on accurate prediction in meteorological, political, or economic aspects (i.e. scenario, models). Scenarios are identifying the hotspot areas by overlapping layers. Reducing the impacts of SLR is through many changes at the private and public levels, such as coastal defenses. The costs of anticipatory adaptation for exposed coasts are much less than the cost of autonomous adaptation during times of catastrophes. The most common strategies of adaptation are protection, accommodation, retreat, and avoid (IPCC, 2007) & (DEFRA, 2006).

Protection strategy is used to manage the shoreline by soft (e.g. nourished beaches, dunes, bio-engineering, wetland restoration) and hard (e.g. revetments, bulkheads, detached breakwaters, seawalls,) coastal engineering works. Soft works are more eco, cheap, and sustained to the environment, but they need continuous maintenance. Although the hard solutions are expensive, they are used widely between the African coastal cities due to long-term life. While soft solutions can provide a habitat for ecosystems, hard solutions can cause erosion in the adjacent unprotected shoreline.

Accommodation strategy is used to manage human activities (i.e. structures, infrastructure) through flood-resilience measures, such as emergency evacuation planning, warning systems, modification of land use, redesigning of structures, upgrade infrastructure, management practices, building codes, hazard insurance and protect risked ecosystems. For instance, raising the floor levels of properties, converting land from residential areas to open spaces, low capital investments in the risked lands, renewing of wetlands, dune rehabilitation, etc.

Retreat strategy is used to setback human activities away from the high potential existence of inundation or erosion hazards through managed and restricted plans. Also, the retreat strategy is based on cost and profit analysis, for example, if the land value is less than the protection works, the gradual retreat will be applied by the local authorities. Avoid strategy is used to do nothing in the high potential SLR risk that could be used as recreation areas or bio-swallow for surface floods.

Moreover, these SLR adaptation strategies should be used with suitable policies and developmental approaches, as shown in table 4, to protect the exposed shores from SLR hazards in light of the classification of a precise exposure assessment of coastal zones in every city. But to identify the exposure levels of urban areas, it should identify the appropriate SLR scenario and the used modeling, which should be based on a precise and actual database. Therefore, the SLR adaptation policies and strategies associated with appropriate developmental approaches should be included in an integrated framework to produce more resilient cities as shown in Fig. 5. The implementation process of this framework should be a shared process between social and governmental parts that are well-trained. Also, the framework should be updated every seven years through a reassessment process.

Table 4. The developmental approaches and related SLR adaptation policies

Approach	Principle	Objectives	Policies
Caution/limited Development	Lose (human uses) - win (nature)	• Preserving nature and neglecting human needs. • Employ softer, greener shoreline treatments where appropriate.	• Avoid new development in potential risk areas. • Retreat/ setback any activity that increases the exposure. • Dominant uses are agriculture, wetland, and open space. Heavy structures are restricted. Property acquisition and conservation programs are focused on this area. • Shoreline protection with soft armoring. • Risked buildings are gradually moved out and replaced with natural protection and open space. This can be applied by downzoning to low density. • Encouraging the light industries (handcraft works, fisher industries, ...).
Balanced Development	Win (nature) - win (human uses)	Sustaining the nature and filling the needs of human	• Increasing resilience of highly exposed areas (technological, institutional, human capital, risk reduction, information management). • Improving flexibility of highly exposed natural systems (mitigation, rehabilitation, ...). • Increased social awareness and preparedness. • Zones accommodation of structure (codes for elevation, footprint) • Limited urbanization is surrounded by open areas.
Intense Development	Lose (nature) - win (human uses)	Filling the needs of humans and depleting the natural resources.	• Increasing infrastructure and long-term investments. • Dense urbanization (residential, industrial, commercial, and tourism building) and infrastructure. • Intensive shoreline protection.

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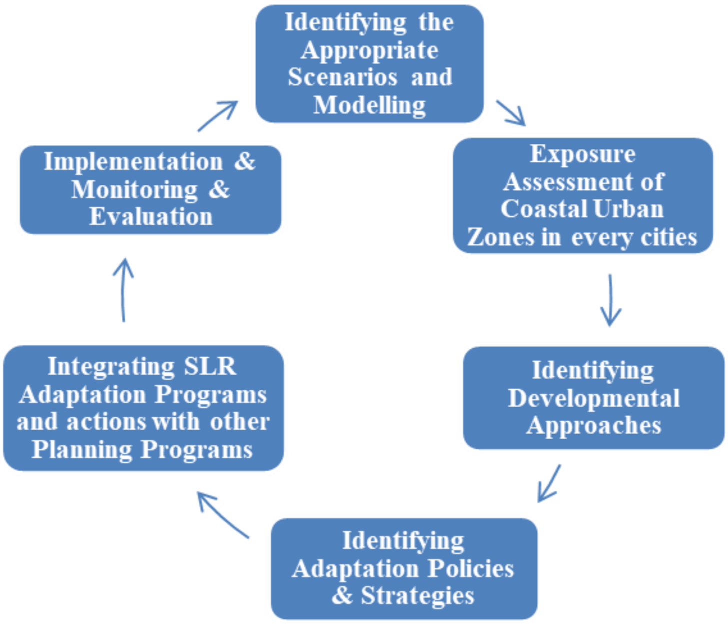

Fig. 5. An integrated framework to be more resilient cities

CONCLUSION

Because of climate change impacts that faced the African lands, the urban pattern has concentrated towards the coasts. The area that existed between the shoreline and contour line +20 above the sea is a vital and critical zone, which has a dense urban network. African big cities that have about a third of the population are suffering from many social diseases, such as poverty, conflicts, and slums. Besides that, they face many serious environmental threats, SLR is one of the most destructive hazards, especially that close to the shoreline with high density (twenty-four cities). While the coastal million-cities are representing a vital social and economic role in their countries, they are highly exposed to SLR impacts, especially the adjacent margin to the sea or the ocean.

The strategic spatial planning of these cities should have a group of selected SR adaptation strategies that are appropriate to the circumstances of every city. The exposure analysis is an essential base to set an integrated framework to support their resilience against SLR impacts Furthermore, proactive adaptation is more economical and more effective than reactive adaptation. Accommodation strategy is very urgent to redesign the building and the infrastructure to adapt to the raised SLR rate by the precise supervision of local authorities. A protection strategy is required for high-density areas, the hard works could be used in front of severe waves, while softworks could be used in high tides or weak waves that create wide and eco-beaches. Avoid strategy or do nothing is an appropriate strategy for the highly exposed open spaces. Retreat strategy could be used when the cost of protection is higher than the value of the assets. All of the adaptation works are shared between the social and governmental parts. The developers and designers are well trained and aware of all changes. Moreover, it should be a frequent reassessment of SLR hazards every seven years to be updated with changes.

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