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RESEARCH ARTICLE

INTEGRATED STRATEGIES FOR ADAPTATION WITH SEA LEVEL RISE IN COASTAL CITIES AN ANALYTICAL STUDY ON SANTOS CITY, BRAZIL AND NEW-MANSOURA CITY, EGYPT

Ahmed Eltawil [1]*, Alaa Eleishy[2], AsmaaElbadrawy[3], Marcelo Nolasco[4] and Esraa Elazab[5]

[1] MSC and Lecturer assistant in Delta University, Architecture Department, Mansoura University
[2]Assistant professor, Architecture Department, Mansoura University
[3]Teacher, Architecture Department, Mansoura University
[4]Assistant Professor, Environmental Engineering, São-Paulo University
[5]Lecturar Assistant, Architecture Department, Mansoura University

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ABSTRACT

Background: Climatic changes are affecting many coastal areas in the world, which are exposed to the risk of flooding due to sea level rise and changing patterns of rainfall. Strategies regarding dealing with climatic changes impacts in coastal areas are different from one country to another; while some cities are conducting plans for protection like Santos in Brazil; there are new cities that are under construction, in flood risk coastal areas like New-Mansoura in Egypt. **Objectives**: The research aims at providing criteria for the urban planning in New-Mansoura, in order to improve its adaptation. **Methods**: The research depends on, studying the adaptation strategies, which could mitigate the effects of climatic changes and make cities more resilient and analyzing the situation in Santos as an existing coastal city which adopted some strategies for adaptation. Analyze the situation of New-Mansoura as a new coastal city with no adaptation strategies in order to conFigure the opportunities and challenges for each city and develop criteria for improving the urban planning for facing sea level rise. **Results**: The research results showed that Santos city need to adopt more connection between green and grey infrastructure; and regarding New-Mansoura adopting green infrastructure and raising the level of the city in addition to sea walls and barriers. **Conclusion**: Building new coastal cities in the circumstances of climate change is challenging, and having no adaptation plans may lead to serious problems, so precautions must be considered through the design phase and before the end of construction.

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INTRODUCTION

The climatic changes like sea level rise, global warming, shrinking ice sheets and many other changes has become a very important challenge to all countries due to its negative effects in many fields and dimensions. Sea level rise is one of the most serious impacts of climate change, which is putting the coastal cities in a high risk of flooding. The global mean sea level rose by an average of 1.6 to 1.9 mm/year over the twentieth century and it is predicted that by the end of the 21st century it will rise by 0.26 to 0.82 m (Jie Yin, 2017). This is very challenging for the coastal communities; because around 10% of the world's population live in coastal areas that are less than 10m above sea level and about 40% of the world's population live within 100km of the coast (Fact sheet: people and Ocean, 2017). Over the last two decades, floods were the most frequent global natural disaster because of the rising in sea level. By 2050; rising populations in flood-prone lands, climate change, deforestation, loss of wetlands and rising sea levels can be expected to increase the number of people vulnerable to flood disaster to 2 billion people (Lisa Guppy, 2017). So there should be new strategies and policies for designing and planning coastal urban communities and cities to make them more resilient in facing those challenges.To make cities adapt to sea level rise; there are three main strategies: protection, accommodation, and retreat (Nicholls, 2011). Some researches added attack as a fourth strategy to sea level rise (ICE, 2010). The four strategies may be identified as follows:

****Corresponding author:*** Ahmed Eltawil,
MSC, Architecture Department, Mansoura University.

- First the protection strategy, which consists of; the hard protection that aims to build physical barriers, dikes, levees, sea walls and groins to block the water, it is preferred for facilities which are hard to move and infrastructures on flat ground. And soft protection which aims at creating a buffer of vegetation or landforms of mangroves, wetlands, sand dunes, tidal flats. It is preferred for shoreline with forest and sand dunes.
- Second the accommodation strategy, which aims at upgrading the functions of the coastline while preserving locations by raising levels, drainages and alarm systems. This strategy is preferred for the sites without high ground nearby.
- Third the retreat strategy which aims at relocating and abandonment the residential and public facilities to low risk uplands.
- Forth the attack strategy, which aims at extending facilities towards water like ports, harbor, piers and land reclamation; it is preferred for facilities requiring a direct access to water (Lee, 2014).

There is another classification for those adaptation strategies as gray, green and hybrid infrastructure. Despite that the built(gray) infrastructure is more common about protecting coastlines, but some researches approved that the natural (green) infrastructure reduce the risk of flooding and erosion of coastline. In addition to, the social and economic benefits (Spalding, 2014).

There are a good opportunities to combine natural (green) and built (gray) infrastructure for designing shorelines which is known as hybrid infrastructure; which may be more cost-effective than the built infrastructure in the long-run (Ariana E. Sutton-Grier, 2015).

- Grey infrastructure are physical structures; like sea walls, dikes, levees, floodgates and breakwaters which are often made of concrete; to protect the coastline from flooding, in addition to drainage storm systems water management such as storm sewers, pipes and basins.
- Green and blue infrastructures provide multiple co-benefits where water and land come together as riparian areas, beaches, wetlands, such as recreation, psychological well-being and pollution control. Green infrastructure are represented in Healthy oyster reefs, coastal salt marshes, mangroves, coral reefs, sea grasses, sand beaches and dunes in the coast environment mainly by forests, parks, street trees, and grasslands. While the Blue infrastructures include wetlands, rivers, lakes and streams(Gómez-Baggethun E, 2013).
- The Hybrid strategy is a combination between grey and green infrastructures, application for this strategy are rain gardens, bios wales, green roofs and wetlands when combined with engineered measures. The hybrid approach provide hazard protection solutions with are cost-effective. It can reduce the dependence of grey infrastructure on urban systems and reduce its effects on the eco-system and improve the sustainability of cities. Hybrid strategies are very important in urban areas where the green strategies only may be insufficient to adapt with the rising impacts of climate change, especially if the space is limited (Nadja Kabisch, 2017).

METHODOLOGY

The methodology of this research started with studying the adaptation strategies, which could mitigate the effects of sea level rise due to climatic changes and make coastal cities more resilient. Then the analytical study, which depended on the field visits for the two cities to analyze the situation of two coastal cities in different countries with different policies and plans regarding dealing with climatic changes in coastal areas. The first city is Santos in Brazil, which had adopted some strategies for adaptation and the second city is New-Mansoura in Egypt, which is still a new city under construction. The Analytical study aims at assessing the opportunities and challenges facing each city and concluding the best practices and criteria for dealing with the coastal line; through introducing a design proposal for the threatened areas in the two cities.

Santos city, Brazil: Santos city was chosen as an example for existing coastal cities, which are facing the risk of flooding due sea level rise, and had adopted some measures for adaptation. The case of Santos will be analyzed as follows**:**

Santos city location: Santos cityis locatedin BaixadaSantista Metropolitan Area (BSMA) on the coast of Southeast Brazil; which is 65 km from the Sao Paulo which is the largest metropolitan area in Brazil, with a population of 21,090,791 (IBGE, 2015). The population of Santos city is 433,966 populations with a high concentration of people which is about 1494.26 people/ km^2. Santos city consists of two areas; first the island area with 430,000 people which is about 99 % of the population living onan area of 39.4 km^2 so the urban density is 10,636.7people /km^2;the second area is the rural area (Miller R, 2012).

Rising sea level in Brazil: Climate change in the state of Sao-Paulo will be accompanied with problems in both environmental and urban level specially the coastal areas which more vulnerable to climate change effects (Vargas, 2011). Researches indicate that, the temperature of Sao-Paulo will increase by 0.5° Cto1.0° C and an increase by 5-10% in the intensity of rain fall by 2040. In addition to that; the temperature will rise by 1.5° C to 2.0° C and 15-20% increasing in rainfall between 2041-2070.The rising in temperature will reach 2.5° Cto 3.0° C and the rainfall will increase by 25-30% between 2071-2100(Gabriela Marques Di Giulioa, 2017).The Fourth Assessment Report of the Intergovernmental Panel on Climate Change mentioned some impacts of climate change in Brazil, which includes that; the rainfall will increase and will result in increasing the intensity of flooding in the southeastern coast of Brazil, the sea level will increase and affects the coastal areas which causes a water flows in the south of Brazil, the erosion of the northeast coast will increase due to the increasing in rainfall rates(Carlos Ludeña, 2011). Over the past 30 years; the sea level in the harbor of Santos has risen by 1.2mm/year in and is expected to be increasing through the upcoming years(Alfredini P, 2015). The sea level of the coast of Santos city is predicted to rose by 18 to 30cm by 2050, which is close to the global average. In addition to that storms are expected to increase due to the climate change which will be combined with an increase in the sea level causing extreme tides and flooding of seawater(Marengo, 2015). Fig.1 shows the sea level rise expected scenarios for Santos city.

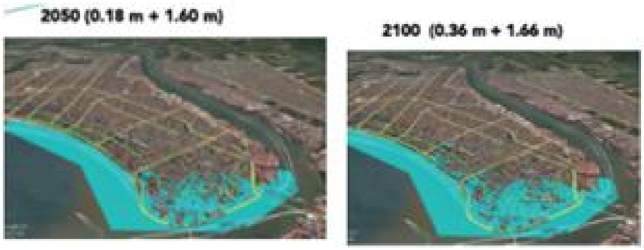

Fig.1. Impact of the sea level rise on the coast of Santos city, Brazil (Marengo, 2015)

Fig.2: Connection between sea and river to contain Flooding in Santos, Brazil (Author, 2019)

Santos urban structure: Santos is 2m above the sea level on the Atlantic coastal plain in the southeast of Brazil. Its area is 280.9 km^2 and is surrounded by hills of 650 to1200 m height above sea level. The richness of biodiversity and the extensive areas of mangroves are characterizing the surrounding area of Santos city (Master Plan 2013). Santos is divided into different zones according to the vulnerability of each zone to sea level rise. The percentage of the damage resultsdue to sea level rise and storm surge in infrastructure of the coastal areas are between; 10% to 30% in different scenarios(Young, 2016). The geomorphology and the built environment of Santos make it high vulnerable to sea level rise (Alfredini P, 2015) . The high density of the city is another coastal risk. The land use in the city is identified in nine types; the range and nature of risks and vulnerability of each area, depends on the typology and its specific condition (Young, 2016).In the front of the coastline, there are residential neighborhoods with dense commercial and residential areas, along the estuary, there is an important harbor with industrial activities where coastal marshland and mangroves exist.

Adaptation in Santos city: Santos cityis susceptible to both flooding and landslides. Floods have not caused any casualties but have resulted in traffic disruption in the city, while landslides have claimed lives and destroyed houses and infrastructure; but now the situation is better than before. Santos has a robust Strategic climate adaptation investment and institutional strengthening plan; its purpose is to identify and prioritize short, medium and long term adaptation interventions aimed at enhancing resilience to flooding and landslides in Santos. The action plan since 2012 included some strategies for adaptation, which decreased the effects of the sea level rise on the city like; Incentivize green infrastructure projects, rebuilding natural ecosystems and protecting mangroves. incorporation of projected precipitation and SLR levels into drainage system, sustainability of existing drainage systems, prioritize and enhance civil society's awareness to risk, creation of a City-Region Observatory, integrated land use planning and risk-sensitive zoning data base, improved budgetary resources and climate financing, formalized structures of cooperation with the private sector in planning and risk reduction (GHK, 2012).From the literature review and the field visit it was found that, there are some strategies that have been executed from this plan and some is still under evolution. The city has taken some measures to reduce the impacts of climatic changes like investments in alternative energy sources.

Adaptation with the sea level rise in Santos is obvious in the green infrastructures, which were adopted in the form of increasing the vegetation covers, green walls and roofs, trees on the streets, rain gardens and the preservation and restoration of mangroves. Some grey infrastructure measures have been considered like the beach nourishment for the southeast beach strip of some. Building and implementation of control gates for tides in rivers, drainage channels, pumping stations and a protection wall along the seashore and Linking canals between sea and river, as shown in Fig.2 (Intelligence, 2019). Some projects are still under construction like the project of Santos new entrance, which combines raising the entrance and the surroundings. In addition to the project of ponta da paria, which includes demolishing walls and building a portion of a submerged barrier from geobags filled with beach sand and installed 275 m offshore and contain of two linear segments with 500 meters length as shown in Fig.3; in order to contain erosion and to reduce wave strength (Santos new entry, 2019). The northeast zone also had protection project, which contain dredging, improving the pumping stations and gates system and recovering the mangroves as shown in Fig.4.

Fig.3. The submerged barrier for the southeast zone in Santos, Brazil (Santos city hall, 2019)

Fig.4: mangroves recovery for the northeast zone in Santos, Brazil (Santos city hall, 2019)

New-Mansoura city, Egypt: New-Mansoura city chosen as an example for a new city, which is under construction on the Egyptian coast; despite all of the evidences on the serious impacts of the climatic changes and sea level rise.

Location of New-Mansoura city: New-Mansoura is located in the Nile delta on the Mediterranean Sea coast in north of Egypt. New-Mansoura has a cost line of 15 km along the Mediterranean Sea with 2 km depth with an area of approximately 5300acres. It's expected that it will have a population of 680,000 people and about 158,000 residential units (New-Mansoura, 2018).

Rising sea level in Egypt: Egypt is one of the most countries in the world that are exposed to the impacts of climatic changes and rising sea level, it is predicted that the Mediterranean Sea level will rise between 0.5m and 1m during this century; as shown in Fig.5. The coastline in Egypt is about 50km wide is less than 2m above the sea level. this coastline is protected only by a 1 to10km coastal sand belt from flooding; weak parts of this sand belt is expected to be destroyed by the rise of sea level, which is necessary for the protection of the coastline and the low-lying lands (Dasgupta, 2009). The Nile delta and its coastal areas has more vulnerability to flooding due to the rise in sea level and it will be exposed to soil erosion at different areas and in different levels depending on the topographical and geological conditions of each area, in addition to the protection strategy used there (UNPD, 2011). There is many evidence of climate change and its impacts in the; Nile Delta also was hit by a Super Storm in 2010 and 2003 with over 1.2 m height and 7m waves force; which caused a flooding in the delta and its coastal cities in (Jeffress Williams, 2015).

New-Mansoura urban structure: The city adopted the grid planning where the entire city is facing the Mediterranean Sea; and the streets interact horizontally and vertically directed to the north, with two main roads parallel to the coastal line. The network of the streets and roads starts from the major road outside the city, main roads parallel to the coastline with 60m width, Service Streets, residential streets in addition to pedestrian paths. The heights of the buildings in the city are different depending on its functions; where private villas with a height of 11m, social housing with 15m height and high-rise towers with heights up to 100m. Heights of 100m lay directly in the front of the cost line.

Adaptation in New-Mansoura: From the field visit and the study of the city plans introduced by the new urban communities in Egypt, it was found that there are no strategies planned for facing the future predicted sea level rise. The coastline of the first stage of the city is still in the initial stage of construction. Fig.6shows a section for the coastline of the city showing the difference in level between beach and city which is only 1.5m and may exposes the city to the danger of flooding. Although the city is still uncompleted but evidences on flood risks are obvious; when there is a rain event the construction sites floods with water.

RESULTS AND DISCUSSION

From the analysis of the situations of the two cities through the field visits and the plans adopted in planning, it was found that the policies of each country regarding dealing with the impacts of climatic changes was reflected in the planning of each city. It was also found that; in order to adapt city planning to sea level rise there must be integration between green and grey infrastructures; there must also be integration between the planning and the environmental, economic and social aspects in the city. Policy makers, planner, architects, residents need to be aware of the consequences of dealing with coastal cities in those challenging situations. The following will show the opportunities for each city to improve its situation in regarding facing the risk of flooding:

Adaptation assessment in Santos city: In Santos's case, preparation for disaster is well advanced. Other cities can certainly learn from the experience of Santos in this regard (GHK, 2012). Santos city in Brazil provides a good example for adaptation to sea level rise in developing countries, not only on the level of planning and integration between grey and green infrastructure; but also on the level of improving long term future plans based on research studies. To improve accurate data base in addition to increasing people awareness and encouraging the private sector to invest in the adaptation plans.

Adaptation assessment in New-Mansoura: Despite most coastal cities in the world are taking measures to face the risk of sea level rise. and despite the risk of sea level rise in the Mediterranean sea and the flood risk of Nile Delta; New-Mansoura is a new city under construction in a location which is just 3 m above sea level (New-Mansoura, 2018), and no adaptation measures is considered in the planning of the city. But there is a good opportunity for adapting the city to climate change as it is still under construction and making modification in this stage is more easy and cost efficient than in the operation stage like existing cities. New-Mansoura city needs integrated strategies in the planning, in order to achieve the sustainable development goals for this new city. The city is divided into four stages for construction; the research is focusing on the first stage, which is under construction. Fig.7 shows the first stage of the city where the design proposal will be introduced and the location of the case studies by the coastline as the research will focus on the area near the coast as it is the first area that will be exposed to the flooding risk.

The strategy adopted by this proposal depends on integration between green and gray infrastructure; through using what is called hybrid infrastructure. The case study is divided into four main zones, the first is the housing zone, the second is the street zone, the third is the pedestrian path zone and the fourth is the beach zone; as shown in Fig.8. For the housing zone, green infrastructure is used to adapt with water floods. Green roofs are used to absorb rainwater and rain gardens to seep storm water into the ground and the excessive water to the city storm drain. In addition to, using bio-swales to collect, absorb, and filter the floodwater from street and houses into the ground before it goes to the city storm drains; it is also designed with crossing points to help people to cross it. All paths and parking spaces are made of purpose pavement materials. A storm water system is used to collect the rainwater from the roofs of the buildings into the ground, and then to the city storm drain. For the street zone, a soft protection strategy is proposed through using porous asphalt, which can absorb the storm water and all the slopes of the streets are directed towards the planted bio swales to catch the storm water and filter it slowly into the ground.

Fig.5: Nile Delta map and the excepted situations in the case of rising sea level 0.5m and 1m (Elsharkawy H., 2009).

Fig.6: Section of the city showing the level between beach and city in New-Mansoura, Egypt (Author, 2019)

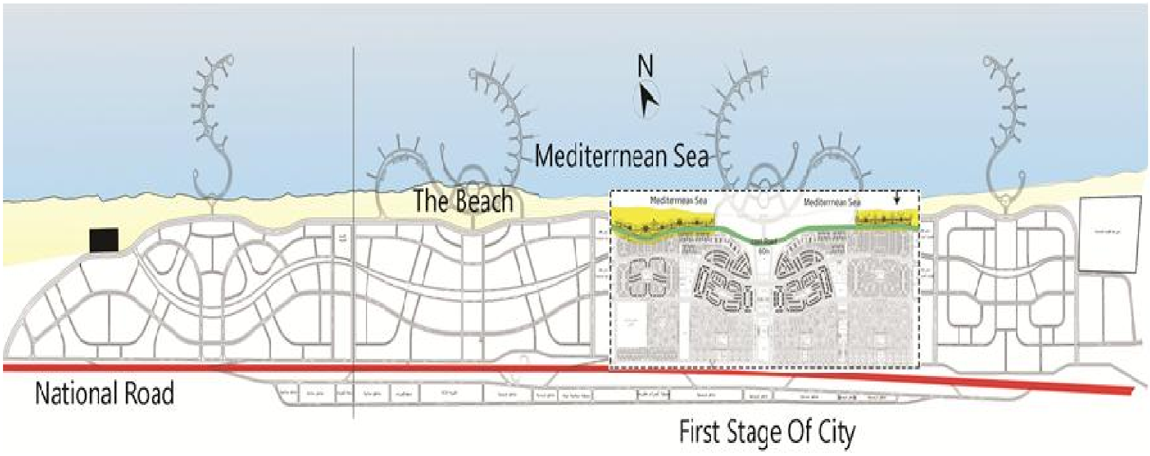

Fig.7: First stage of the New-Mansoura city (Author,2019)

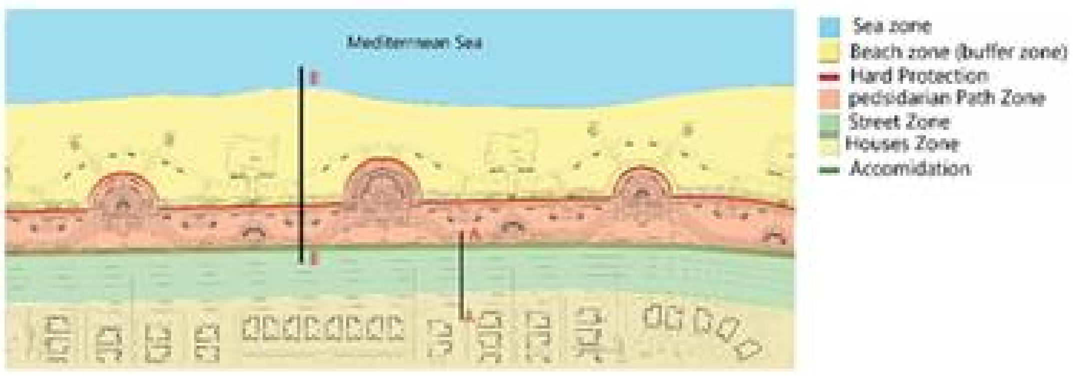

Fig.8: Case study zones in New-Mansoura city (Author, 2019)

Fig. 9. Section A-A in the proposed design for housing zone and street zone in New-Mansoura city (Author, 2019)

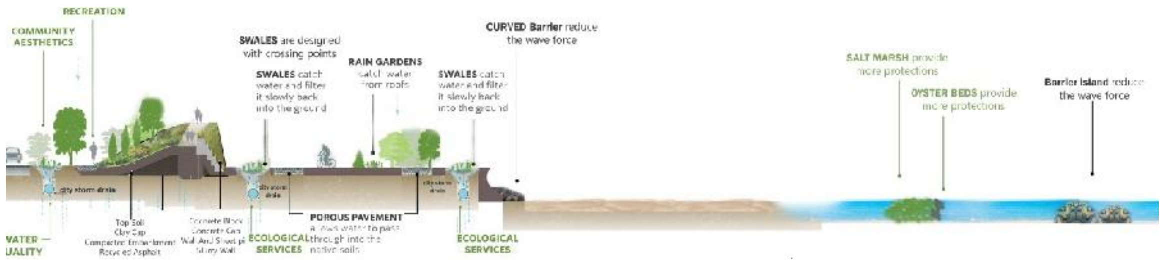

Fig.10. Section B-B in the proposed design for pedestrian path zone and the beach zone (Author, 2019)

Also porous pavement sidewalks will be used, as shown in section A-A in Fig.9. For pedestrian path zone, some strategies are proposed. First, is using accommodation to raise the level of this path to compensate the low level of the city, that is difficult to raise it now, this structure of the pedestrian path will consist of a green organic sheer wall from the side of the street and steps from the side of the beach to create an area for activity.

The structure also ends with a sidewalk with pervious pavement and a planted grass swales near the street to collect, absorb and filter the water from the sloped wall. Second, a rain garden is designed to collect and absorb the stormwater. In addition to; adding planted bio-swales, pervious pavements, sidewalks and bike lanes. Designing wetlands and parks is also proposed to accommodate temporary inundation and to function as green buffers for the coastal areas of the city.

For the beach zone, the research propose a hard protection strategy, where a curved barrier with rocks is used to reduce the water flood to the coast line, as the literature review showed that it is the most effective kind of barriers for this function. In addition to using another buffer of sloped sandy beach will be used, which could work as a first defense line of the flooding seawater. Also; using island barriers in the sea is proposed to break and reduce the sea waves, in addition to salt marshes and oyster beds to provide more protection from water flooding. As shown in section B-B in Fig.10. This proposal for the city of New-Mansoura mainly focused on the accommodation, gray and green strategies in order to maintain the coastlines. All of the proposed strategies should be integrated in order to work together for achieving the optimal efficiency, reducing the risks of sea level rise and converting the city into a sponge city.

Conclusion

The research considered the climatic changes impacts related to sea level rise as a major aspect affecting the sustainable development of the future of many coastal cities in the world. It was found that the adaptation strategies in the planning of coastal cities are very necessary to face the risk of sea level rise in addition to considering the social, economic and environmental aspects in an integrated way with the urban planning strategies in order to achieve the optimal efficiency for the adaptation in coastal cities. When planning new cities choosing the location is the most important aspect as it affects the future of the city on all levels, the criteria for choosing the location must consider the climate current situation and the future changes predicted in order to make the best decisions. Choosing a new city location by the coast in those days are considered to be very challenging, but there is one advantage that it is better to adopt adaptation strategies to sea level risesince the planning, design and construction stages of the city as this will be more easy and coast efficient than dealing with a city which is already operated from many years. It is very necessary for all coastal cities through the whole world especially in developing countries to consider climatic changes studies in order to obtain a data base for predicting the situation of the climatic changes in the future; and be able to improve an efficient adaptation plans. Awareness among people, policy makers, urban planners and architects about climatic changes impacts is a major aspect for the future of coastal cities especially in developing countries.

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