ADAPTING TO CLIMATE CHANGE

AND PREPARING FOR NATURAL DISASTERS

IN THE COASTAL CITIES OF NORTH AFRICA

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Summary: *The paper presents the background data concerning the expected impacts of climate change and natural disasters on the cities of North Africa, the preliminary assessment of their priority areas of vulnerability for the cities of Alexandria, Casablanca, Tunis, and for the urban development area of the Bouregreg Valley in Morocco, and the methodology for the technical work that will be carried out. This World Bank study will lead to the in-depth identification of the main challenges, as well as to the preparation of adaptation and preparedness action plans. The main priority concerns are: a) sea level rise, coastal erosion and storm surges; b) urban flooding; c) decreasing availability of water resources; d) increasing ambient temperatures; and e) risks of earthquakes and tsunamis. Main adaptation and preparedness measures will likely consist of climate-resilient urban planning, physical investments to protect or upgrade critical urban infrastructure and systems, as well as institutional preparedness and emergency plans.*

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I. INTRODUCTION

This paper presents the first results of a regional study which was initiated in September 2008, and which focuses on the challenges of adapting to climate change and preparing for natural disasters facing the coastal cities of North Africa. The study has integrated these two agendas as they widely overlap and complement each other. The objectives of the study are three-fold: ***a) to assess the vulnerability of the participating cities to the impacts of climate change and natural disasters; b) to prepare adaptation action plans which if implemented would make such cities more resilient; and c) to engage stakeholders in related decision-making***.

The study is directed and managed by the Sustainable Development Department of the Middle East and North Africa Region of the World Bank, and has received the financial support of the following Trust Funds: NTF-PSI, TFESSD, and GFDRR, which are financed by a number of bilateral development agencies. The World Bank has secured the collaboration of the following entities for the conduction of the study: a) in Egypt, the Egyptian Environmental Affairs Agency, the Alexandria Governorate, and the Arab Academy of Science, Technology and Maritime Transportation; b) in Morocco, the State Secretariat for Water and Environment, the Casablanca Governorate, and the Agency for the Development of the Bouregreg Valley; and c) in Tunisia, the Ministry of Environment and Sustainable Development.

Egis Bceom International, a consulting firm with extensive experience in North Africa, has been competitively selected in May 2009 to carry out the technical work required, and will be interacting with the national counterparts and with the technical agencies in each of the participating cities to carry out the study. Representatives of the participating cities and of the consulting firm are taking part in the 5th Urban Research Symposium. National workshops will be organized to present and validate the results of the work, and a regional workshop will be convened at the conclusion of the work to reinforce the exchanges among the participating cities and other cities in the region facing similar challenges. The study is expected to be completed by December 2010.

II. BACKGROUND

The five countries of North Africa (Morocco, Algeria, Tunisia, Libya and Egypt) had in 2005 a total population of 152m, of which 80m or 53% was urban. These numbers are projected to grow by 2030 to a total population of 209m, of which 128m, or 61%, will be urban[1]. This increase of the urban population by 48m, or 60% in 25 years is a major challenge for the countries of North Africa, one that will require extensive planning, investments, and urban governance capabilities. This process of urbanization will likely be accompanied by an increase in the concentration of urban population in the coastal zones, where there is already the highest density of economic activities, infrastructure, and trade. Already in 1995 the percentage of urban population residing in the coastal areas was varying between 30.6% in the case of Egypt, and 88.2% for Libya.

[1] Source: World Urbanization Prospects: the 2007 revision, United Nations

Table1. Percentage of the urban population of North Africa in the coastal zones, 1995

Country	Percentage
Algeria	46.9
Egypt	30.6
Libya	88.2
Morocco*	81.4
Tunisia	82

Source: « L'urbanisation en Méditerranée 1950-1995, Analyse régionale » Plan Bleu 2001
**data for Morocco was extrapolated on the basis of its Mediterranean urban population*

The cities of the region are the heart of all social, cultural and political life, and the hub of all economic activities. However, they are being increasingly impacted by climate change and its overall consequences on livability and productivity, and coastal cities are the most vulnerable cluster of urban agglomerations. Based on initial applications of statistical downscaling models, that use a combination of local meteorological data and Global Circulation Models to make projections of the local climate change impacts, preliminary climate change effects by 2030-2050 for Egypt, Tunisia and Morocco are illustrated below.

Table 2.Climate Change Effects by 2030-50 based on Downscaling Models: IPCC 4 Scenario A1B

Effects Country	Temperature (º Celsius)	Precipitation (%)	Drought (Number of days)	Runoff Range (%)
Egypt	+1.42	-14.36	0	+5 / +10
Tunisia	+1.35	-9.26	6	-2 / -5
Morocco	+1.57	-8.19	11	-10 / -20

Note: Drought is based on the maximum consecutive days of dry weather. Runoff figures are for 2041-2060

Downscaling results show that on average: temperatures will increase by +1.5º Celsius; precipitation will drop by more than -10 percent; drought will increase with a maximum number of consecutive days of dry weather of 6 days on average; and runoff will decline between -12.5 and -6 percent in Tunisia and Morocco, whereas it is expected to increase in Egypt by + 5 to +10 percent. Decreasing fresh renewable water combined with climate change impacts and demographic growth will get Egypt, Tunisia and Morocco in a state of absolute water scarcity.

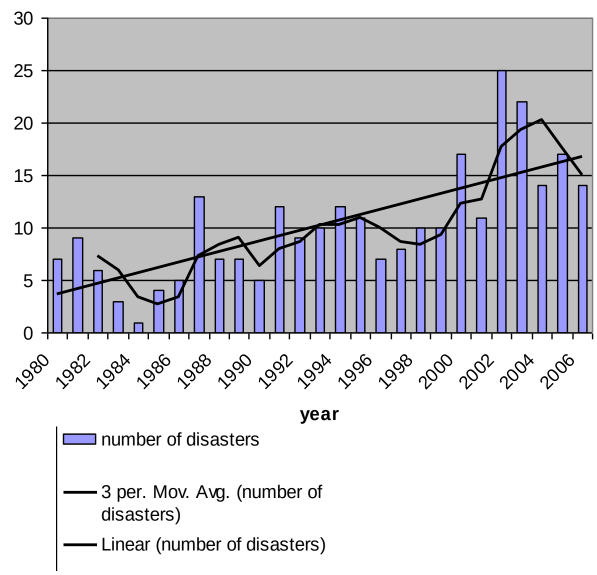
Based on the IPCC 4 linear models, sea level is expected to increase by an average of 0.10 and 0.17 meter in 2030 and 2050 respectively. A recent study based on dynamic models however suggests that global warming will cause sea levels to rise much faster than officially projected, and that an "improved estimate" of sea level rise ranges from 0.80 meter to 2.0 meter by the end of the century.[2] Middle East and North Africa will be the second developing region most affected by SLR according to a recent World Bank study[3]. According to recent estimates (Stern report) between 6 and 25 million people could be exposed to coastal flooding in North Africa under a temperature increase ranging between 1º and 3º Celsius. Some countries, such as Egypt and Tunisia, will be more severely impacted. With a possible 0.5 meter sea level rise, about 3.8 meter people would be affected in the Nile Delta (UNEP data), and the cities of Alexandria, Rosetta, Damietta and Port Said would be very severely impacted.

[2] Richard Kerr (2007). Predicting Fate of Glaciers Proves Slippery Task. Science. Website: <http://sciencenow.sciencemag.org/cgi/content/citation/2007/215/2>.
[3] The impact of sea-level rise on developing countries: a comparative analysis. WB Policy Research Working Paper 4136, February 2007.

The overall increase in temperature will result in changes in the patterns of precipitations, in increased intensity and frequency of droughts and floods, and in periodic heat waves that will have direct repercussions on urban life and on public health. Urban air quality will worsen, ground ozone formation will increase, and the urban "heat island" effect will intensify. Energy demands for air conditioning will by far surpass energy savings due to decreased heating needs, thus increasing GHG emissions from the urban areas.

Decreasing water availability and agricultural yields will likely cause a sharp acceleration of the process of urbanization, and add to the pressure that cities are already exerting on natural resources. The frequency and intensity of natural disasters directly correlated to climate change, and their impact and economic costs will also grow, also on account of the increase of population and physical investments in the urban areas. Natural disasters have significantly increased in frequency and intensity in the region during the last decade. Urban flooding episodes have taken place in many cities, causing huge damages, loss of life and of economic activities. Earthquakes of the past decade have been particularly violent in Algeria and in Morocco.

Figure 1.Number of natural disasters in the Middle East North Africa Region 1980-2006



Source: Philip Buckle, 2007: <u>Regional Stocktaking of Natural Hazard Risk and Disaster Management Capacity: Middle East and North Africa</u>, prepared for the World Bank and UN-ISDR

III. PARTICIPATING CITIES AND THEIR MAIN FEATURES

In order to address the issues of climate change adaptation and natural disaster preparedness, the study has chose the approach of working with a sample of important cities in North Africa, and with one major urban expansion project, in order to prepare vulnerabilty assessments and adaptation plans for the 2030 scenario. The cities of Alexandria, Casablanca, and Tunis are a relevant sample of the majority of the coastal cities of North Africa which will experience very significant urban growth, according to the national and regional trends described above. The selection of the Bouregreg Valley urban expansion area between the cities of Rabat and Salé in Morocco is also consistent with the emergence of a set of large-scale urban development projects and new towns which are taking shape across the region.

1. Alexandria

1.1. Urban coverage

Greater Alexandria currently spans over 23,000 ha with a land-use apportioning 45.9 percent for residential areas; 18.9 percent for industrial areas; 3 percent for public services and recreational areas; 28.8 percent for the road and transportation network, and 3 percent for military areas. Its 2006 population was estimated at 3.9 million by the national census. The current boundaries of the urban agglomeration of Alexandria comprise the following urban districts: Montazah, Eastern District, Middle District, Western District, Customs District, the new Borg El Arab; and the Marriout and El Mex lakes with the informal settlements that surround them. The urban agglomeration has historically expanded in a linear fashion, and currently reaches from the coastal village of Aboukir to the North-East to the village of El-Deir to the South-West. The city, which shows very high densities along its water-front, is built on a narrow and partially elevated coastal ridge facing the sea, behind which are located the lakes and the low-lying rural areas and wetlands, some of which are already below sea-level.

1.2. Future urban development

UN Demographic projections for the year 2030 forecast the population of Alexandria to grow by 67% and reach 6.5m. This major growth will translate itself in the urbanization of surrounding areas, and threatens critical natural resources, such as the Marriout and El Mex lakes, which currently play a critical role in the management of drainage waters prior to their discharge into the sea. Urban renewal and residential construction is being planned in and around the village of Aboukir to the North-East; however the major direction of urban expansion will be towards the South-East, according to the Alexandria 2050 vision and to the Alex West and New Alexandria plans. The wetlands and rural areas inland of the city will likely be progressively urbanized.

2. Casablanca

2.1. Urban coverage

The geographic scope of Greater Casablanca, which spans over a 25,000 ha area includes the districts of Ain Chock Hay Hassani, Ain Sebaa-Hay Mohammedi, Ben Msik-Sidi Othmane, Casablanca-Anfa, El Fida-Derb Soltane, Mechouar Casablanca, Sidi Bernoussi-Zenata, Mohammedia, Médiouna and Nouaceur. The current population is estimated at 4.5 million. The city has grown over time around its harbor and original historical nucleus, expanding around the neighboring logistics and transport area, and now encompasses the main industrial areas of the country, Sidi Bernoussi and Mohammedia further North, as well as important service centers, financial hubs, and trade activities. Greater Casablanca is built on a low-lying coastal area, which has increased its urban density through the growth of large informal settlements as infill areas, and is well served by the national highway and by a number of major roads, as well as by the railway lines.

2.2. Future urban development

Casablanca seeks to redefine and re-position itself on the eve of its centenary and has just finalized a new Schéma Directeur d'Aménagement et d'Urbanisme (SDAU) produced by the Agence Urbaine de Casablanca with the assistance of IAURIF (Institut d'Aménagement et d'Urbanisme de la Région de l'Ile de France) covering the period 2008-2030. The residential expansion of Greater Casablanca will occur around the city with the preservation of coastal green areas, especially in the southern part of Casablanca. The SDAU key features include a reduction of urban densification and the growth of urban population in external neighborhoods, with the creation of a green belt around Casablanca and the relocation of some of the population into new urban zones, and the rehabilitation of slums. Four important urban poles devoted to service activities will be created and guided by special zone plans: the redevelopment of the Casa-Anfa old airport area, Errahma, Lahraouyine and Sidi Moumen, whereas Mohammedia will retain its role as the industrial pole of Greater Casablanca. Major infrastructure projects are planned in conjunction with the urban expansion (ports development, transport system, wastewater treatment, etc.). Greater Casablanca is expected to host a population of over 5 million by the year 2030, and the surrounding urban areas are expected to absorb the additional growth.

3. Tunis

3.1. Urban coverage

The geographic area of Greater Tunis, which spans over a 300,000 ha of which only 20,000 ha are urbanized, is subdivided into four governorates: Manouba, Ariana, Tunis and Ben Arous. The area includes a number of vast water expanses which are at or below sea-level: the North and South lakes between the city and the sea-front, which are connected to the sea, as well as the inland Ariana, Es-Sejjoumi and Sokomi "sekhbas", or very large natural drainage basins. The relevant coastal zone spans from Gammarth, north of the village of Sidi Bou Said, to Ez-Zahra south of the Oued Miliane estuary. The coastal zone includes sea-front residential neighborhoods such as Carthage, El Kram and La Goulette, but also the infrastructure of the Goulette and Rhadès ports and their logistical platforms, as well as water treatment plants, a power station, and other infrastructure. The watershed includes the Kebir-Miliane basins. The current population of Greater Tunis is estimated at 2.5 million.

3.2. Future urban development

The Schéma Directeur d'Aménagement du Territoire (SDAT) for the Greater Tunis for 2008-2021 has been in preparation for a number of years, and is finally reaching completion and approval. According to the SDAT, the residential expansion of the Greater Tunis will extend towards the west in higher altitude zones, moving the growth of the city away from the coastal low-lying areas which are more prone to seasonal flooding. On the basis of the current demographic projections, Greater Tunis would reach 3 million by 2030. In addition to the projected urban growth, however, five major urban redevelopment projects are planned in and around Tunis, greatly influencing its future urban profile, with investments from Gulf countries and an overall budget envelope estimated at around US$ 50 billion. These projects include commercial centers, financial centers, a technopolis, hotels, marinas, residences of high standing, sport clubs, leisure facilities, etc. They will be located around the Sebkah Ariana, the north coast, and the South and North lakes of Tunis, and aim at revitalizing the city and at making it a key Mediterranean metropolis for the 21st century. Because of their size and their potential of transformation of the city's structure, the possible impacts of climate change on these projects, as well as the increased demand for water and energy generated from them, raise concerns as to their sustainability.

4. Bouregreg Valley

4.1. Future urban development

The project is aimed at the development of the vast valley that separates Rabat from Sale, over an area of about 60 Km2, located at the estuary of the river and inland from there. The valley is mostly agricultural and sparsely populated despite its strategic location, on account of its historically flood-prone nature. The project is sequenced into six steps, or "sequences". The first two, grouped under Phase I, are expected to be completed by 2010. They include: a) major infrastructure works that would be publicly financed: drainage, flood control, environmental cleaning, tourism development including a new marina, land development near the estuary, and major urban transport developments. The cost of these works is estimated at over US$ 700 million and b) private development of a commercial, residential, tourism, and cultural zone of about 1.2 Km2 under a joint venture agreement with Dubai International Properties. The subsequent sequences include further development of the valley upstream over the long term, for which a master plan is in place, awaiting more detailed land-use and urban development plans to take shape. Investments under phase I are focused on port and maritime infrastructure (already completed), as well as a new bridge between Rabat and Sale, major road infrastructure construction (including a tunnel) and related urban design works, and the creation of a tramway linve between Rabat and Sale.

IV. IDENTIFICATION OF MAIN VULNERABILITIES

1. Preliminary vulnerability assessment

A preliminary assessment of the characteristics and vulnerability of the four urban locations was carried out by the World Bank team in conjunction with the relevant national and local authorities, between September and November 2008. This preliminary assessment helped determine a matrix of five main vulnerability areas combining present and future climate change impacts and natural disaster risks, which are prevailing in the four urban locations. The importance of each vulnerability varies from one urban location to another, and its ranking is indicative of such priorities in the four urban contexts. The highest apparent vulnerability or risk is indicated with a 1, and the lowest with a 5.

Table 2.Vulnerabilities to Climate Change Impacts and Natural Disasters

	Egypt	Tunisia	Morocco	
Vulnerability Ranking	**Alexandria**	**Tunis**	**Casablanca**	**Bouregreg**
Sea Level Rise, Coastal Erosion and Storm Surges	1	1	2	1
Urban Flooding	2	2	1	2
Availability of water resources	4	4	3	3
Increasing ambient temperatures	3	5	4	4
Risks of earthquakes and tsunamis	5	3	5	5

2. Sea-level rise, coastal erosion and storm surges

Sea level rise is occurring in all four urban locations, and tangible signs of its impacts are evident, although measurements are limited. Its effects are compounded by the ones of storm surges and of coastal erosion, which have also increased in intensity, along the Atlantic as well as the Mediterranean coasts. Current knowledge of the three phenomena is insufficient to apportion their respective responsibilities for the impacts, which are recognized by maritime and urban authorities, but are also detected by citizens and non-experts alike: loss of beaches, coastal neighborhoods threatened by sea-waters, key urban infrastructure at risk, port structures and coastal roads overwhelmed at times by storm surges. Coastal erosion is also compounded by the increased intensities of currents and wind, by the reduced runoff of sediments from coastal rivers due to the increasing number of upstream dams, and by unregulated coastal sand extraction.

3. Urban flooding

Urban flooding is a major vulnerability which has manifested itself with increasing intensity in the past decade, with similar changes in the urban locations of the seasonal patterns of precipitations, causing short and very intense episodes of rainfall which overwhelm the existing drainage systems. The areas hit the worst have been the low-lying informal neighborhoods in the proximity of the natural lakes around Alexandria and Tunis, as well as the industrial area of Mohammedia in Greater Casablanca. In addition to the new magnitude of precipitation episodes, all cities have been experiencing in the past decades: a) an unplanned urbanization with building encroachment on flood-prone and drainage areas; b) insufficient works to manage watershed upstream runoff; and c) poorly calibrated drainage systems. Moreover, the combination of storm surges and urban flooding is another important dimension that has been repeatedly observed, whereby the simultaneity of the occurrence of heavy rains and storm surges increases the likelihood of coastal urban flooding, as the outflow of drainage water into the sea is impeded by the force of the waves.

4. Decreasing availability of water resources

The projected decrease of precipitations in the three countries will affect the amount of runoff from the watersheds or rivers that are currently providing water supplies to the urban areas. This decrease in the availability of the resource is accompanied by a steep increase in water urban demand, due to expanding urban populations, economic activities, and increasing consumption patterns generated by economic growth. In Egypt, the Mahmoudia canal provides water to the city of Alexandria. However, the Nile river basin climate change models project a sharp decrease of the Nile flow that will likely diminish Alexandria's water supply share in the future. The Oum Er-Rbia and the Bouregreg watersheds provide water to the cities of Casablanca, Rabat and Salé and consequently to the Bouregreg Valley urban expansion area and both river basins will face a reduction of runoff in the future. As for the Greater Tunis, the Kebir-Miliane river basin will also suffer from a reduction of runoff that should affect the quantity of water supplied. Underground water extraction for agricultural purposes (e.g. in the Casablanca area) has contributed to the salinization of the water table, and the quality of the aquifer will deteriorate with time due to the intensification of coastal water pumping and to sea-water intrusion in the water tables. In the face of water scarcity, various policy options are being pursued, ranging from programs to reduce water leakages (Casablanca), to programs to promote the agricultural re-use of waste-water (Tunis), to future desalination options.

5. Increasing ambient temperature

In a range of increases which will need to be ascertained with strong approximation, ambient air temperatures will rise considerably in all four urban locations considered, with a variety of negative consequences. Higher ambient temperatures will worsen air quality in the cities, where PM, NOx, SOx, CO, ground O_3 and VOC criteria pollutant thresholds are already significantly exceeding WHO's standards. Air pollution from fixed and mobile sources is already a critical issue, especially in Casablanca and Alexandria, while Tunis has implemented considerable improvements. Climate change induced higher temperatures will thus create a supplemental incentive to initiate air quality management programs. Increased ambient temperatures will also exacerbate the intensity of the heat-island effect in the urban areas under consideration. The differential of ambient temperature between the built-up areas of the agglomerations and the neighboring rural areas, which can already reach 3 to 4 C, is likely to increase, and the resulting higher temperatures in the city centers could become difficult to bear. Impacts on energy consumption for air conditioning would be significant. Heat waves, as those experienced in some European cities in 2003, could have large impacts on human health, causing a worsening of morbidity and mortality in the face of insufficient public health systems.

6. Risks of earthquakes and tsunamis

All four cities are located in earthquake-prone areas with Tunis being probably the one most at risk of sustaining a major earthquake, whereas Casablanca, Alexandria and the Bouregreg Valley have already faced flooding and destruction due to tsunamis in the past centuries. Early warning systems to predict earthquakes and possibly tsunamis are being put in place on the Egyptian and Moroccan coasts by the UNESCO in conjunction with the UN's *Intergovernmental Oceanographic Commission Coordination Group for the Tsunami Early Warning and Mitigation System in the North Eastern Atlantic, the Mediterranean and Connected Seas* » (ICG/NEAMTWS). A mild tsunami has occurred in 1969 along the Atlantic west coast, which affected Casablanca. Incidentally, the Danish Hydraulic Institute has simulated the impact of the major 1775 tsunami which destroyed the city of Lisbon, if it were to occur today, to determine the necessary elevation of a potential nuclear power plant to be built in Safi (Morocco): a 10 meter elevation was suggested to tsunami-proof the nuclear installations.

V. VULNERABILITY ASSESSMENTS

What is described hereunder are the key components of the technical work to be carried out by the consultants in each of the four urban locations in order to produce the urban vulnerability assessments and the related ***urban vulnerability maps***, which will be the main outputs of the first phase of the study. They are presented for the purpose of sharing the methodological approach being followed in this research work.

a) Providing updated and exhaustive scientific assessments of future climate change and sea-level rise, and probabilistic risk assessment of natural disasters:

Downscaling of global circulation models will be performed for the four cities and their upstream watershed basins based on urban, watershed, and geographic area specific meteorological data. The UN IPCC 4 three-emission scenarios (B1, A1B and A1FI) with three climate models (CSIRO, ECHAM4 and HadCM3) will be used for the simulations, in conjunction with appropriate downscaling methods (such as the Statistical Downscaling Simulation Model and others) to derive the following projections up to the 2030 scenario: spatial and temporal distribution of precipitation ranges; projected temperature change ranges; projected reduction in runoff ranges; and droughts expressed in terms of the maximum consecutive days of dry weather ranges. All simulations should conform to the 95 percent confidence level and the narrowest possible confidence interval (interval that would optimize the results robustness) as well as derive the frequency of temporal peaks vis-à-vis the mean by 2030. Moreover, weighting scales will be applied to reduce the uncertainty between spring and annual precipitations. All the results will be confronted with an average baseline derived from past meteorological data including the most recent years.

Sea-level rise IPCC 4 projections are drawing significant criticism given that the IPCC 4 only used linear models to predict the SLR whereas a number of recent scientific publications are using dynamic models which indicate the likelihood of significantly higher increases in SLR by the mid-century or sooner. There is a critical need to assess the validity of the more recent approaches, and to narrow the uncertainty as to the projected SLR for the four urban locations, as a key input towards understanding their vulnerability and for the design of remedial actions. Two tasks will be performed: (i) compiling (as far as possibly for the past) SLR historical data series for each urban location (former colonial powers could possibly have data series before the first half of the 20th century in the case of Morocco and Tunisia) or by country proxies (closest countries with data such as Spain, Portugal, France, Italy, Cyprus, etc.) to derive a historical trend of the SLR; and (ii) performing a qualitative review of all the SLR linear and dynamic literature to produce a meta-analysis that will help predict more robust and reliable Eastern Atlantic and Mediterranean level rise scenarios based on the IPCC 4 six-emission scenarios by 2030, as well as other more recent scientific studies in the relevant literature.

Historical series of relevant natural disasters will be compiled for the entire three countries and a probabilistic risk assessment will be performed to determine future spatial area vulnerability for the four urban locations. Data to be compiled include intensity and frequency scales and impact based on 1950 onward historical disaster events: (i) earthquakes historical series; (ii) tsunami risks should be compiled based on historical events that affected the coastal locations (e.g., event that caused a 100 feet high tsunami in Alexandria in 365 AD; Portugal 1775 AD, and 1969 AD that affected Morocco's Atlantic coast), and on geological assessments (thousands of years) that will help determine the quiescence scale periods of the tsunamigenic risk for the four coastal urban locations; (iii) droughts and flash floods to be compiled for the watersheds relevant to each urban location; (v) storm surges to be compiled for each urban location's coastal zone; and (vi) heat waves and manifestation of heat island effect within the urban locations over time. Data collected on historical series of natural disasters will be utilized to carry out probabilistic risk assessment for the four urban locations and specific parts thereof, indicating via GIS layers the degree of risk of each sub-area, with sequential scenarios up to 2030 and beyond.

b) Conducting an in-depth analysis of the geological, topographical, hydrological, and environmental nature of the four sites:

Subsoil, soil and topographic analysis covering the coastal zones of the urban locations, the urban space and territorial waters (12 nautical miles) will include underlying rock types, surface material and geological structures (faults, thrusts, etc.), and will be mapped via GIS as layers. Soil type and characteristics, porosity and permeability should also be mapped. The latest available sonar-based bathymetric data will be used to map the coastal seabed. Moreover, the topographic analysis must include slope form, landform and terrain analysis and specific landform types, and will be mapped via the GIS. A topographic contour map of the urban locations with at least 2-meter contour intervals will be developed. The perimeter boundary survey coordinates shall be mapped together with the 2-meter topographic contours.

Boundary analysis will cover through satellite imagery the evolution of the coastline due to coastal erosion, which is occurring along all the coasts under the study. This analysis will include coastal stretches where coastal defenses have already been built to gauge the results. The historical land subsidence data (e.g. magnitude of ground subsidence and its spatial distribution) will be derived by the acquisition of satellite, aero or topographic photos (Russian databases, Western military declassified databases, research center databases, etc.) dating back to the 1960s, 1970s, 1980s and 1990s, and compare them with the most recent satellite imagery of the coasts under study. A number of steps will need to be undertaken to process the baseline images in order to reduce the interpretation uncertainties: geo-referencing, ortho-rectification, radiometry, fixed comparison structures, etc. Historic data collected will be utilized to identify on-going trends of coastal erosion and land subsidence, and projections for the future manifestation of these phenomena will be developed up to the 2030 scenario.

A number of sea and ocean circulation models exist for the coastal zones under review. Moreover, historical storm level data (e.g. date, central pressure, wind speed, trajectory), and storm surge (e.g. maximum heights and the time series of sea level during the storm surge events along the coastlines of the target urban locations) collected will be used to determine the likelihood of future storm surges by linking sea and ocean circulation models, storm surge models and downscaled global circulation models to simulate the likely occurrence and magnitude of storm surges up to the 2030 scenario.

The watershed basins relevant to the four urban locations have all been studied using fairly sophisticated hydrologic models. However, it is expected that climate changes will have significant impacts on the hydrologic regime and its extremes. A first step will consist of collecting historical flood data (e.g. maximum heights and the time series of river water elevation during the flood events at several points along the river and channels; historical record of flooded urban areas, especially those under known extreme events; and extent of damage in terms of lives and livelihoods affected). The watershed hydrological modeling is meant to identify critical historical hydrologic exposures that may lead to local failures of existing water resource systems in terms of floods and droughts. Therefore, basin hydrologic model results will need to be linked with future climate scenarios generated by the downscaled global circulation models. This will help assess the potential impact of a changed climate on the frequency and intensity of hydrologic extremes on the coastal population, urban areas and assets (potential flooding areas), coastal assets, coastal sedimentation and water runoff. Similarly, the SLR meta-analysis will be used to determine the salinization of the water tables along the coasts based on the projected water extraction scenarios among competing users: urban, industrial and agricultural. All such projections will be geo-referenced with appropriate GIS layers.

A similar exercise will be carried out for the assessment of the vulnerability of other natural resources in the urban locations and the related coastal zones: natural vegetation (wetlands in particular), urban green areas and parks, wildlife, agricultural areas, and fisheries. The past evolution of these natural resources in the locations will be ascertained and correlated where possible with the changes to local weather patterns, land use and economic activities that have impacted the areas. The current baseline will be determined and spatialized with appropriate GIS layers. Impacts of the climate changes determined in the previously listed assessments on these natural resources will be projected and simulated up to the 2030 scenario.

c) Assessing the current urban coverage and the vulnerability of the urban infrastructure assets present on the sites:

Based on GIS layers derived from satellite imagery, existing urban maps and other sources, the current urban coverage and extension for each location will be determined, including all infrastructure, land use, assets and landmarks. All major underground structures and overhead utility systems, ports, logistics platforms, municipal plants, industries, tourism complexes, roads and public spaces, residential areas including squatter settlements will be identified and mapped, as well as water well areas and major water supply lines, drainage channels and culverts, sewerage, drainage, gas, telephone and electrical lines, and any other relevant urban infrastructure.

d) Projecting the growth of the urban agglomerations at the 2030 scenario based on the current demographic and urbanization trends, on the master plans and development plans:

The Consultant shall analyze the current demographic and urbanization trends to predict the growth of the urban agglomerations up to the 2030 scenario, and will make use of all statistical data available, of past growth patterns, and of an updated understanding of real-estate pressures, main infrastructure developments, housing needs and other trends to predict with a reasonable amount of certainty the urban coverage of the four locations at the 2030 scenario. The likely acceleration of urbanization due to climate change and deteriorating productive and living conditions in the rural areas, in particular where rain-fed agriculture is prevailing shall be taken into account. The review will include the analysis of the urban master plans and urban development plans that have been prepared in all locations, with the caveat that some of the projected urban growth might not occur as planned, and might in fact occur elsewhere and in other forms that those predicted. With the exception of Tunis, where illegal construction practices have been practically eradicated, informal settlements and slums have proliferated in Alexandria and Casablanca, and unregulated construction is still occurring. The resulting GIS layers would predict therefore the likely urban coverage and contour of the urban agglomerations up to the 2030 scenario.

e) Constructing multi-layered GIS urban vulnerability maps based on the previous tasks:

The urban vulnerability maps will result from the interpretation of the overlap between the projected impacts of climate change and risks of natural disasters drawn from tasks a) and b) above, with the assessment of the current and future urban coverage and urban assets drawn from tasks c) and d) above. The urban vulnerability maps will hence indicate the relevance of each of the five major areas (SLR, coastal erosion and storm surges; urban flooding; availability of water resources; increasing air temperatures; and risks of earthquakes and tsunamis) for the current urban coverage and for the future urban coverage up to the 2030 scenario. Moreover, a cross vulnerability assessment (iteration of all the combinations of the five vulnerability areas) will be performed to simulate the occurrence of 2 or more simultaneous events (e.g., storm surge and flooding) and the synergistic impacts of the climate changes and natural disaster risks. In addition to classifying the existing urban areas according to their degree of vulnerability, present and future, the Consultant will also identify hot-spots, i.e. critical pieces of urban infrastructure, municipal systems, or locations, considered particularly vulnerable because of their exposure or of the complexity of their functioning and their role in the economy of the urban agglomerations.

f) Evaluating the socio-economic costs of the impacts of climate change and natural disaster risks in the four urban locations:

The urban vulnerability maps and their assessments will be accompanied by an evaluation of the socio-economic costs of the impacts of climate change and natural disaster risks stemming from the assessment of current and future urban coverage and consistency of the urban assets that would be impacted under the different vulnerability scenarios, and up to 2030. This will imply economic assumptions as to the value of the built environment, urban infrastructure, economic assets and activities that would be impacted, as well as of the natural, cultural and social assets. While the valuation of existing assets of the current urban coverage can be carried out quite accurately, assumptions will be needed as to the consistency and value of the assets of the urban growth which is expected to still take place up to the 2030 scenario. Estimates will also be provided as to the additional human burden of morbidity and mortality which would be induced by increased ambient temperatures and its effects, and by natural disaster events as predicted.

g) Assessing the roles and activities of national and local institutions in the urban planning, infrastructure provision and disaster preparedness relevant to the four urban locations:

The Vulnerability Assessments to Climate Change and Natural Disasters will include an assessment of the roles and activities of national and local institutions that are currently responsible for the urban planning, provision of urban infrastructure and services, and for disaster preparedness in the four urban locations. The assessment will extend to watershed management as it is relevant to the provision of water supply to the urban areas. The purposes of such assessment will be to: a) establish the boundaries of their competencies, and identify any possible overlaps or gaps; b) identify the role that such entities will likely play in guiding and monitoring the urban development which is expected to occur in the four urban locations up to 2030; and c) gauge their responsiveness and capacity to integrate climate change considerations and natural disaster preparedness in the management of the urban locations under their purview.

In particular, this assessment will provide a clear picture of current urban risk mapping, if any, of the level of public information and awareness of the risks, of the existence of emergency response plans (ORSEC plans and others), of the organizational and logistical capability of responsible institutions to install early warning system and to carry out emergency prevention and emergency rescue and evacuation operations in case of natural disasters. Their performance during all recent catastrophic events (e.g. urban flooding) should be analyzed to determine the level of response effectiveness and of coordination among relevant agencies.

VI. ADAPTATION AND PREPAREDNESS ACTION PLANS

On the basis of the detailed vulnerability assessments, the consultants will develop during the second phase of the work specific ***adaptation and preparedness action plans***, which will have the purpose of providing national and local stakeholders with robust strategies to address the priority areas, and to incorporate the related investments in their future public investments programming. The key components of such adaptation and preparedness action plans will be the following:

a) Urban planning recommendations aiming at minimizing the vulnerabilities identified:

The Consultant shall develop specific recommendations in terms of land-use and urban planning that would facilitate the adaptation of the urban locations to the changing climate and increase their resilience to natural disasters. Such recommendations would refer to the existing urban coverage and to the projected urban development up to the 2030 scenario. For the existing urban coverage the recommendations will be based on the assessed vulnerabilities of the various parts of the urban locations, and will indicate what zoning regulations and what land-uses should be adopted, to avoid further investments of urban redevelopment projects in areas which are considered particularly vulnerable. The Consultant will indicate which areas, if any, will require "managed retreat", especially in view of sea-level rise projections, and identify areas that could be subject to further planting of urban vegetation to better cope with increasing temperatures.

For future urban development, the recommendations will indicate the various degrees of vulnerabilities of the areas to be urbanized, which ones if any should be avoided, and develop on such basis spatial layouts to be overlaid to the master plans and urban development plans that have been produced, as well as to the Consultant's own projections of urban growth as developed under Phase I. Recommendations will include designation of areas for natural dispersion of drainage and all other natural reserves and protection areas that should be integrated into future urban planning and urban development in view of increasing the adaptation of the urban locations to climate change and their resilience to natural disaster risks.

b) Recommendations concerning the physical investments that will be required to protect or upgrade the urban infrastructure assets and systems in order to adapt:

The Consultant shall develop specific recommendations concerning the protection or upgrade of the existing infrastructure, built environment, and urban systems to increase their adaptation to climate change and their resilience to natural disaster risks. The main areas of focus will be coastal marine defenses, key urban infrastructure hot-spots, water supply and drainage systems, and buildings.

<u>Coastal marine defenses</u>: based on the review of existing sea-defenses, those under construction and planned in the four urban locations, the Action Plan will offer recommendations for further consolidation or construction of soft or hard sea-walls, embankment dikes, and other structures or interventions (such as beach nourishment) amenable to increase the protection of the urban coastline against sea-level rise, coastal erosion and storm surges.

<u>Key urban infrastructure hot-spots</u>: for each of the hot-spots that the vulnerability assessment will have identified, the Action Plan will recommend adaptation scenarios that may include managed retreat (for instance in areas that are particularly earthquake-prone) as well as the hardening and strengthening of the infrastructure, such as commercial ports, logistics platforms, waste-water treatment plants, power-plants, and other critical infrastructure.

<u>Water supply and drainage systems</u>: given the likely decrease in fresh water availability from watersheds and the likely intrusion of salt-water in the water-tables, the Action Plan will make recommendations for greater water efficiency, possible waste-water re-use, access to alternative water sources, reduction of water losses, desalination alternatives, and changes in the use of water in industrial processes and agricultural practices in and around the four urban locations.

The Consultant will also review the effectiveness of the current drainage systems and recommend upgrades and extensions to cater for the envisaged precipitation patterns.

Buildings: In view of the increasing ambient temperatures, the Action Plan will recommend measures to retrofit and protect the existing built environment (primarily residential properties and public facilities such as schools, health-care structures, other public buildings), as well as to better design future buildings and facilities to make them more resilient to the climate, via better insulation materials, appropriate design, and the incorporation of energy efficient technologies.

c) Recommendations concerning the institutional preparedness and emergency plans for the urban locations in view of the climate change impacts and disaster risks:

Based on the assessment carried out in the First Phase under task g), the Consultant shall recommend measures to improve the preparedness of the local and national institutions in charge of urban planning, provision of urban infrastructure and services, watershed management and for disaster preparedness in terms of their ability to incorporate adaptation to climate change and resilience to natural disaster risks. The recommendations shall include organizational measures, such as the creation of more systemic linkages with the national bodies responsible for monitoring climate and natural disaster risks, as well as technical, financial and logistical ones, especially for those institutions in charge of emergency preparedness and response. The Consultant shall equally recommend the set-up of early warning systems, and the public information, education and communication campaigns to be carried out at local level so as to increase the preparedness of the population. New coordination mechanisms and emergency plans may be required and should be recommended where appropriate.

e) Economic valuation of the recommended remedial adaptation actions against the costs of the impacts of climate change and natural disasters, if unchecked:

The Consultant shall rank the remedial actions recommended in the areas of urban planning, infrastructure, and institutional preparedness in terms of their importance and of their urgency, and shall conduct an economic valuation of the remedial actions estimating the costs of their implementation and comparing them with the value of the projected losses due to the impacts of climate change and natural disasters, if unchecked, that will have been developed under Phase I. the Consultant shall develop in the Action Plan a number of remedial scenarios and related preliminary investment plans, which will address the priority areas of vulnerability as well as their potential synergies. In addition to the economic valuation of the remedial actions, the Consultant shall indicate the primary and secondary institutional responsibilities for their implementation, and the preferred sequencing of their implementation. Simulations will be carried out up to 2030 to show the varying degrees of vulnerability of the urban locations with and without the implementation of the remedial actions.