Executive summary Phase 1 Report Tunis

A pilot study within a regional framework

This study, led and financed by the World Bank, addresses **adaptation to climate change and natural disasters in the Greater Tunis urban area**. It comes within the wider framework of an evaluation of the vulnerability of North African coastal cities in the face of climate change and natural disasters. This first volume of the study constitutes the **Phase 1 report**, covering risk assessment in the current situation projected to 2030.

The study area is defined by the perimeter of the *Schéma Directeur d'Aménagement du Grand Tunis* (Greater Tunis development master plan). The analysis nonetheless focuses mainly on the Greater Tunis urban area, given that the rest of the territory considered is predominantly rural.

A city facing multiple natural hazards

Evaluation of hazards in the current situation reveals the following points.

The Tunis region is characterised by a Mediterranean climate with hot dry summers and mild and relatively wet winters. Some exceptional meteorological events serve as reminders of the **sporadic violence of the natural elements**. For instance, in September 2003, the city received 186mm of rain in 24 hours, against an annual average of around 456 mm. During the heat wave of 2003, the city experienced 59 days with maximum temperatures of over 35 ℃. During the storms of January 1981 wind speeds exceeded 140 km/h, generating waves of over 10 m.

The geological context shows that the conurbation is mostly built on quaternary formations that **favour instability of the soils** (settling, liquefaction). These formations are localised in the alluvial plains and peripheral areas, or in former sebkhas. Their thickness increases progressively to the east, where it can reach fifty metres at the edge of Lake of Tunis. These types of soil may lead to subsidence phenomena occurring. These phenomena form an **aggravating factor for seismic risk**, or even constitute in themselves a major natural risk with regard to the great changes in Tunis (up to 3cm annually in the most exposed sectors). The most sensitive areas are **on the periphery of Lake of Tunis and the Ariana and Sejoumi sebkhas**, where most urban growth has been concentrated for several decades.

The north of Tunisia is at the edge of a zone of active tectonic convergence between the European and African plates. Probabilistic assessment of the **risk of earthquake** indicates that the Tunis urban area is subject to a **moderate** risk, corresponding to an intensity of around 6 for the 50 year return period and around 7 for a 475 year return period. The resulting potential damage is qualified as low to moderate. However, given the poor geotechnical quality of Tunis' soils, **an increased degree of intensity can be considered for most of the urban area, with high potential damage for the least frequent events**. It should be borne in mind that the earthquake of December 856, in Tunis harbour, caused 45 000 deaths. The risk of damage by **tsunami** is considered to be negligible, with the different studies conducted indicating a maximum wave height of 60 cm in the Gulf of Tunis.

The study area coast, between the mouth of the Medjerda oued to the north and Slimène beach to the south, consists of, more or less extensive, sandy beaches separated by rocky points. **The coast is ever-changing with an overall trend towards erosion**. This imbalance is due mainly to a sediment deficit caused by trapping of sedimentary particles at the dams on various oueds and, in particular, the Medjerda oued to the north; to fixation or disappearance of the dunes bordered by seaside resort urban development; and to blocking of transport of sedimentary material by port facilities. The coast has generally been receding for half a century but this has never exceeded **1 m/yr on average** and has been retarded, and sometimes stopped, by the alongshore protection constructed and by the presence of rocky flats. However, the coastline can recede by as much as 10 m/yr locally. **The issue is a relatively important one**, with a built-up sea front more or less directly exposed to wave action over 16 km and some areas of natural environments that have high heritage value (beaches, cliffs, lagoons, sebkhas).

The coastal area is also subject to a **risk of submersion,** most evident during stormy periods, where the **increase in sea level can be as much as 1.13 m for a 50 year return period**. A GIS analysis, using available topographical data, shows that **such an increase in sea level would submerge part of the urbanised and industrial areas** in Basse Ville, Radès, Ezzahra and Hammam Lif Ouest. The limits of the analysis should nevertheless be recalled as the data used in the numerical terrain model were not of the same degree of accuracy throughout and were not able to identify localised features of the terrain (levees, embankments) that could protect some sectors against the flooding. Furthermore, the conditions of submersion on the edge of Lake of Tunis depend on the conditions of propagation of the storm wave via the navigation channel, propagation which could not be modelled as part of this study.

The urban drainage basins of the Tunis conglomeration consist of numerous small oueds and Oued Méliane, of which the outfall marks the boundary between Radès and Ezzhara. **There is a more or less severe risk of flooding in each of the basins due to a variety of factors:** inadequate or non-existent upstream drainage networks, obstacles to flow, low-lying areas downstream of drainage basins receiving rainwater from upstream and subject to effects of downstream levels (Sebkhra, sea), uncontrolled urban development causing increased run-off flows.

These factors, combined with exceptional rainfall, caused **major flooding of the city of Tunis in September 2003**. This was estimated to be a 100 year frequency even. Water levels of over 1 m were observed in certain sectors, especially in the Oueds Bardo and Gueriana basins (3 août and Enichirah estates in the town of Den Den, Manouba estate), in the Ariana basin (Essanouber estate south-east of Gammarth) and in the Mégrine area (Lac Sud). Water levels of around 50 cm were observed in numerous other sectors. **The total flooded surface area was estimated to be more than 4,500 hectares**.

Moreover **the study area is bounded to the north by Oued Mejerda**, the country's only permanent water course. Although equipped with a number of regulating dams, the oued Mejerda **is the source of frequent floods**, with most of the flooded areas being in the alluvial plain, downstream of **Jedeida**, with **more than 50,000 ha flooded by the 100 year flood**. There are, however, less risk objects than in the Tunis conglomeration, most of the flooded areas being agricultural land.

Water supply to Greater Tunis is mainly via the **Mejerda-Cap Bon canal** collecting water from the oueds in the north of Tunisia: northern coastal oueds, Sejnane and Joumine oueds and Mejerda oued. Flows in the oueds are regulated by **numerous dams** of which the oldest date from the 1950s. SONEDE, in charge of water supply and distribution, takes 13 per cent of the available resource from the canal for Greater Tunis' drinking water supply. **Abstraction and consumption are increasing steadily**, as the population increases. Critical situations for the resource are successive dry years, like those of 1987−1989 and 1993−995. **Drought management** has been introduced nationally since these successive droughts. In 1994−1995, restrictions were placed on agricultural uses, with distribution in the main conglomerations such as Tunis not being affected, although there was a **water quality problem** of increased turbidity and salt levels behind the dams.

A probable increase in natural hazard risks with climate change

Climatic projections to a horizon of 2030 were made as part of this study using **dynamic downscaling methods** from the three ENSEMBLES European project models with IPCC scenario A1B, and the Météo-France ARPEGE-Climat model with IPCC scenarios A1B, A2 and B1. These modelling results indicate that the **city of Tunis should get warmer, on an annual scale, by +1 to +1.7°C**. There is, however, a very wide margin of uncertainty associated with increased heat waves. For rainfall, **a decrease is indicated for cumulative winter and spring falls, although this is small** (-1 to -12 per cent for winter and -1 to -18 per cent for spring).

Changes in **high rainfall events** are also accompanied by **high levels of uncertainty** (lack of coherence between models or wide ranges of values). For daily extremes (maximum rainfall over, 24 hours) the sample of extreme values from the **MET_A1B** model is the one closest in its sample distribution to the values observed over the 1961−2007 period. This good correlation leads us to propose **assuming a hypothetical increase as provided by this model** (+23 per cent for a 10 year return period, +28 per cent for a 100 year return period), even though it gives results contradicting those of other models. It is also a pessimistic hypothesis which complies with the precautionary principle.

Beyond these geological (unstable natural terrain) and earthquake risks, other natural hazards will be affected by climate change.

The conditions of coastal erosion and submersion in particular will be affected by **a rise in sea level** arising indirectly from global warming, via thermal expansion of the water and melting of the polar icecaps. Based on a critical analysis of the IPCC's projections and the latest references in the literature on the subject, we assume for this study a **global rise in sea level of 20 cm by 2030**. It should be pointed out that this is a high projection, impossible to refine for Tunis in the absence of long-term mare-graphic data.

In spite of numerous projects for coastal protection, **a rise in sea level will reactivate or amplify the process of coastal erosion,** and therefore receding of the coast line. The sandy beaches still in their natural state risk **receding on average by 10 to 15 m** by 2030. In the urbanised areas, already protected by structures or along which protective works are projected (widening of beach by massive replenishment with sand then periodic maintenance, installation of structures blocking the replenishment material laterally), retreat will be slower but nonetheless inexorable. **In case of storms combined with high water levels** (assumption of values of +1.34 m NGT (levelling datum for Tunisia) corresponding to a return period of around 50 years), beach head works in urbanised areas risk **severe damage** (as in 1981), as the width of the beach is not sufficient to damp the effects of the swell as too close to the high tide line.

The sandy beaches remaining in their natural state will be totally submerged and will recede significantly. However, they should be able to partially reconstitute in periods of fine weather, and almost entirely when the beach head consists of dunes.

By 2030, **all of the coast between Kalaat Landalous and the Touring Club on the Raoued beach will be severely eroded** whereas in the present situation the coast between Hessiène oued and the southern part of the widest area of the Raoued beach—which still has a line of dunes at the beach head—was at low risk. It will also be noted that there will be **major changes of the coast between Ezzhara and Hammam Plage** (inclusive), which will be at high risk of erosion whereas at present the Ezzahara and Hammam Plage stretch of coast is classed as having a medium risk of erosion. In all, **27 km of urbanised seafront will attain a status of high risk of erosion,** against 16 km at present.

The additional area of submerged terrain in 2030 for a water level at +1.34 m NGT (return period 50 years) in relation to a water level at +1.13 m NGT in the present situation **is significant**, i.e. around 1,000 ha. From simulations run the impacted areas are mainly in the Sebkha Ariana. An **addition to the 100 year storm level** (+1.54 m NGT) **would lead to an additional increase of around 1,200 ha,** spread over the entire coast. The high levels of uncertainty of these estimations must be borne in mind, especially due to the level of detail in the relatively rudimentary numerical terrain model, and they must be considered as high hypotheses.

The conditions of flooding to 2030 in the urban parts of the Tunis conglomeration were evaluated using the modelling carried out for the 2005 BCEOM-SIRUS study, with new hypotheses on rainfall and the waterproofing of surfaces (increasing urban density). **The climate change hypothesis assumed modifies the frequency of exceptional precipitation events:** the 20-year return period rainfall in the current situation becomes the 10-year rainfall, the 100 year rainfall in the current situation is assigned a return period of 50 years in 2030. **The rate of waterproofing of ground surfaces goes from the current 31 per cent to 47 per cent in the future**. All of the flood protection projects covered in the 2005 study (flood mitigating sills, resizing of some parts of the drainage network, draining works, pumping station, etc.) are assumed to have been implemented.

When adding the influence of climate change to the effect of increased urbanisation, the situations obtained from modelling are relatively variable, as the increase in urbanisation applied is not identical for all of the drainage basins. **The effect of urbanisation is often of the same order of magnitude as that of climate change, sometimes greater for the drainage basins in which waterproofing increases greatly**. Modelling indicates major overflows from the networks and main branches, as well as overflows from the existing flood regulating basins, often inadequate for the 10-year frequency events in the current situation. The flood mitigating sills planned for remote protection in the upstream parts of the drainage basins do not overflow as they are sized for a high level of urbanisation and are adequate to absorb the impacts of climate change and limited urbanisation in these upstream areas.

Compared to the current situation, the situations modelled for 100 year floods for 2030 indicate **worsening of the flooding conditions for the Ariana-Soukra-Marsa basins, for the lower town and, in general, for all of the drainage basins that currently have a 10-year level of protection and for which no development to provide a higher level is planned**. For the Guereb-Roriche basin, the planned works would ensure an important reduction of flood prone areas in the lower parts (about 43%). For the Bardo-Gueriana basin, severe worsening is obtained in relation to the situation with development works with, however, an improvement in relation to the current situation without works (40 per cent reduction in flood prone areas in relation to current situation). The development work planned to reduce the level in the Sedjoumi

sebkra limits flooding of the areas at the periphery of the sebkra and lower part of the Bardo-Gueriana basin.

By 2030, if the **water resource** is not modified, the pressure of population growth alone will push **abstraction by SONEDE from the Mejerda-Cap Bon canal from 13 per cent to 20 per cent, or even 32 per cent, with the major urban development projects planned for that horizon**. With hypotheses assuming **a reduction in the resource** (silting of dams, climate change) **of around 15 per cent** these values go respectively to 23 per cent and 37 per cent. **The major projects account for around 37 per cent of water requirements at the 2030 horizon**. These additional needs will probably require calling on other resources so as not to excessively penalise agriculture or other northern Tunisian cities.

Appearance of new vulnerabilities by 2030

Moderate population growth (around 750 000 more people) is projected to 2030, giving Greater Tunis a population close to 3 million.

Current urbanisation in the conglomeration shows 'interstitial voids' within the urban patch. The gross habitation density is therefore relatively low over the urbanised area, the greater part of the area being occupied by two storey buildings. **The present urban fabric therefore has the potential to accommodate the additional population**.

However, an analysis of current trends indicated **continuous low-density extension of the city** by building (regulated or not) of new housing, the urban patch tending to extend beyond the natural limits of the site (Tunis basin) with construction on the hillsides and in the flood prone areas on the edges of the oueds and sebkhas.

This form of urban expansion is a **symptom of a high demand for housing.** However, demand is no longer driven by the acute quantitative and qualitative crisis of the era of rural migration (shanty towns) nor by a mass movement towards middle class housing. The available data point rather to a 'suburbanisation' of the middle classes, especially in the areas between Lake of Tunis and the Ariana sebkha, which will probably be ongoing at the study horizon.

The 'lower' classes will mainly remain in the denser western and south-western quarters of the capital but, with the expected improvement in the built fabric, population densities should reduce and precarious forms of housing gradually disappear. At the same time, the quarters of the hyper centre (medina, European city) will lose some of their (residential) density due to development of the services sector.

By 2030, theses central functions will extend to a much wider area than at present, occupying, by extension of the hyper centre, the southern banks of Lake of Tunis as well as more distant areas (Port Financier, etc.). It is assumed that the **'major projects'** contributing to this dispersion of tertiary functions will be completed by 2030. It is also assumed that the polycentrality (planned in the *Schéma Directeur d'Aménagement* − development master plan) will be, partially, achieved.

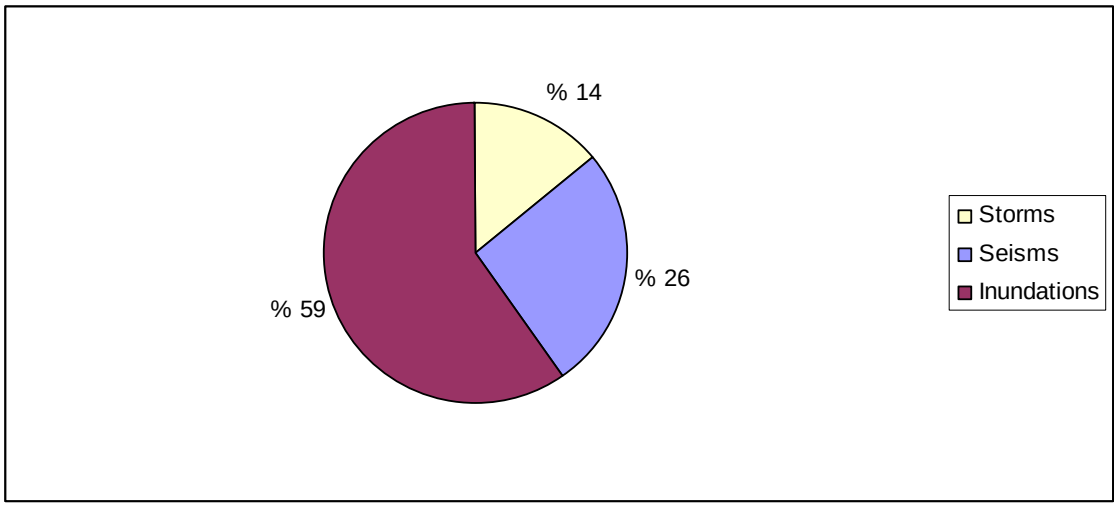
In terms of vulnerabilities, the cumulative result of these changes seems to be a **reduction of the exposure of the poorer populations** (precarious living conditions), counter-balanced by the **appearance of new urban patches** (major projects) on sites relatively exposed to climatic risks (Lake of Tunis, shoreline) and by **expansion of informal settlements disregarding natural hazards**.

The most vulnerable urban sector is clearly the "**Basse Ville**" (low city), located between the Tunis port and the Medina, which will remain a dense urban pole in 2030, while affected in the meantime by growing risks of flooding, marine submersion and geological instability.

Non-negligible climate change cost

A **first approximation** of the cost of natural disasters and climate change up to 2030 indicates a cost of around **140 MDT**, in annual average costs expressed in constant current DT. This represents **between 49 and 57 DT/person/year** (depending on whether the ratio is carried out with the current population or that of 2030), i.e. **0.77% of the GDP of Greater Tunis, or 0.29% of the GDP of 2030**.

These annual costs are divided up, as shown below, in terms of the hazards considered:



Not expressed on an annual basis, but rather on the scale of the period considered, the **current net value of the disasters considered for the period 2010-2030 is roughly 1.5 billion DT**, in constant 2010 terms, which also represents **approx. 8% of the Tunis GDP** (current).

Indirect costs account for 40% of total costs. This is mainly attributable to the methodological choices made. Moreover, the **proportion that is attributed to climate change may be estimated to be around one fifth of the total cost (21%)**, mainly in connection with the flooding. We should note that, with regard to the climate change hypotheses considered, this value should be considered as being a maximum value.

Climate change is likely to worsen sanitary conditions (malnutrition, diarrheal diseases, malaria, etc.). **Annual average health costs for the year 2030 are estimated to be 30.6 MDT, which represents between 6 and 16 basis points of the Greater Tunis GDP** depending on whether we consider the GDP of 2010 or 2030. Health questions therefore have a significant impact on the overall mix of costs of the various risks considered in this study.

We should highlight the exploratory character of this economic evaluation, the results of which can only be interpreted within the considered hypotheses.

A perfectible institutional context

Prevention and management of natural disasters in Tunisia involves a number of organisations, with the ***Office National de la Protection Civile*** (national office for civil protection) at the core of the system. The overall structure and approach have hardly changed **between 1991 and the present day.** The disasters that have occurred over the past 30 years have therefore hardly influenced the regulatory and institutional framework. This is, no doubt, linked to the fact that Tunisia was 'relatively' spared during this period, and the public authorities did not deem it useful to make major changes to the current organisation, which has several faults that were highlighted during the 2003 floods.

The system as it was designed and established by Law No. 93-121, then further specified in the decrees governing its implementation, **only partially covers risk prevention,** and remains focused on 'response', viewed as all of the emergency actions that can be taken to deal with an event. The **lack of cartographic information and of geographical databases** remains one of the main weak points for progress in this area.

The **other perfectible points in the system** appear to be: absence of local competence, especially at the municipal level, in the areas of natural risk management and adaptation to climate change; certain regulatory inadequacies, such as the absence of texts specific to the different types of risk; some overlapping of competences, between ministries and public bodies with sectoral technical skills (particularly ONAS, ANPE, ONPC); and organisation of the information chain.

Vulnerabilities and Risks in Tunis - Synthesis Table

Hazard	Time Horizon	Urban Sensitive Components	Risk			
			Type (casualties excluded)	Location	Intensity	Level
Ground instability/ seismicity	2010	Depends on the type of construction and the population density: medina-type urban fabric and dense working-class districts.	Risk of structural damage and collapses in the case of an earthquake.	Categories M1 and R1 in Figure 75 (the current urban fabric).	Intensity roughly VII MSK for a return period of 50 years. No damage for events with a frequency of 20 years, moderate damage for an exceptional event (15 to 20% of loss in property value). Aggravating factor: high subsidence phenomenon in the Lower City and, to a lesser extent, the Port of Radès.	Medium
	2030	Same components, but a much more reduced surface area due to the reduction in the density of residences and insecure housing (-57% for fabric R1).		Categories M1 and R1 in Figure 95 (the urban fabric for the year 2030).	Same type of damage. High subsidence on the edge of the Southern Lake, in sectors exposed to urbanisation, but it is assumed that these projects will take the risks into account (no damage).	High
Marine submersion / tsunami	2010	Natural coastline outside of the conurbation and dense urban areas along the seafront and the Tunis lake shores.	Structural damage to buildings situated at the front (erosion); submersion of low areas.	See Figure 79 (submersion)	Approx. 4,500 ha exposed to a risk of submersion for a storm with a frequency of 50 years over the entire Tunis region coastline. Risk of tsunami considered to be negligible.	Medium
	2030	Same components, but increasing urbanisation along the seafront and lake shores, and reduction in natural areas.		See Figure 98 (submersion)	Approx. 5,500 ha exposed to a risk of submersion for a storm with a frequency of 50 years (+22%).	High
Coastal erosion	2010	Natural coastline outside of the conurbation and dense urban areas along the seafront and the Tunis lake shores.	Beaches disappearing and structural damage to buildings situated at the front.	See Figure38	Built-up sea front exposed to erosion over a distance of 16km of linear coastline.	High
	2030	Same components, but increasing urbanisation along the seafront and lake shores, and reduction in natural areas.		See Figure 64	Built-up sea front exposed to marine erosion over a distance of 27km of linear coastline (+70%).	Very high
Flooding	2010	Dense residential districts: medina, pre-war historical centre (Lower City, Ariana), working-class districts with insecure housing (e.g. the Bardo-Mannouba sector).	Flooding of ground floors (damage to buildings).	See Figure 80 for overall view and Figure 81 to Figure 87 for detailed views.	Approx. 4,500 ha of land flooded by the 100-year flood in an urban area. Water levels exceeding 1m in the basins of the Oueds Bardo and Gueriana, the Ariana and in the Mégrine area.	High
	2030	Same components, but on reduced surface areas due to the “dedensification” of the urban fabric (in particular, in Bardo-Mannouba and Ariana). Appearance of new districts exposed to risks, less dense and a lot more spread out (especially the Ben Arous – Ezzahra sectors, and around the Sebkha Ariana).		See Figure 99 for overall view and Figure 81 to Figure 87 for detailed views.	Despite the projected protection structures, slight increase in flooded surface areas during the 100-year flood, especially west of the Sebkha Ariana (+31%) and the Lower City (+23%). In the absence of projected structures, the flooded surface areas could increase by 30 to 40% due to urbanisation (increase in waterproofing), excluding the effect of climate change.	Very high
Drought	2010	Population and economic activities (water needs).	Water shortage.	Cannot be mapped.	In an average year, intake of only 10 to 15% of the resource available from the Medjerda – Cap Bon canal to supply drinking water to Greater Tunis. In a dry year, water restrictions for agriculture (-30%) and reduction in water quality.	Low
	2030	Same components, but increase in needs (+153% for drinking water) between now and the year 2030.			Intake of approx. 37% of the available resource. Major urban planning projects alone represent 37% of the water needs. In a dry year, multiplication of conflicts concerning use, to the detriment of agriculture.	Medium