Chapter 19
Managing Flood Risks Using Nature-Based Solutions in Nouakchott, Mauritania

Ahmed Senhoury, Abdeljelil Niang, Bachir Diouf, and Yves-François Thomas

Abstract Whether or not exacerbated by climate change, flood risks are becoming more frequent in the capital city of Nouakchott in Mauritania. Flooding in Nouakchott is due to a combination of both natural factors and human activities. The extreme fragility of the barrier beach that protects the city from the sea, the accelerated exploitation and inadequate infrastructure built along the coast have made this barrier beach highly vulnerable to wave action, exposing the city to a high risk of flooding. Flooding is further exacerbated by rising groundwater levels in several neighborhoods of the city. Cartographic analysis of flood risk indicated that socio-economic impacts associated with floods could be high. In the case of sea water intrusion, up to 30 % of the city could be potentially submerged. This would directly affect nearly 300,000 people and entail high risks of casualties. Associated economic losses due to flooding could be as high as USD 7 billion (Senhoury, Aménagements portuaires et urbanisation accelerée des côtes basses sableuses d'Afrique de l'Ouest dans un contexte de pejoration climatique, cas du littoral de Nouakchott (Mauritanie). Thesis state, University of Dakar, April 29, 2014, 157 pp, 2014).

The following measures based on nature-based approaches are recommended to tackle flood risks in Nouakchott:

- Restore and consolidate the barrier beach through reforestation of degraded areas;
- Put in place an appropriate drainage system for rain and marine waters and a sewage sanitation system;

A. Senhoury (✉)
University of Sciences, technology and medecine, Nouakchott, Mauritania
e-mail: senhoury@hotmail.com

A. Niang
Umm Al Qura University, Makkah, Saudi Arabia

B. Diouf
Cheikh Anta Diop University, Dakar, Senegal

Yves-François Thomas
CNRS-Meudon, Paris, France

F.G. Renaud et al. (eds.), *Ecosystem-Based Disaster Risk Reduction and Adaptation in Practice*, Advances in Natural and Technological Hazards Research 42,
DOI 10.1007/978-3-319-43633-3_19

- Optimize a solution to safeguard the harbor of Nouakchott; and
- Transform wetlands created by the permanent flooding of low-lying areas in the city into urban protected areas.

Keywords Flood risks • Nouakchott • Coastal risk • Hydrodynamics • Cartographic analysis • Socio-economic impacts • Nature-based solutions

19.1 Introduction

The increasing losses and costs associated with natural hazard events in recent years have highlighted the high vulnerability of contemporary cities to disasters. Like many coastal cities across the world, Nouakchott, the capital city of Mauritania, is facing serious risks of flooding. Located behind a narrow dune belt, in area largely under sea level, this city is both exposed and vulnerable to heavy rains as well as episodic increases in the sea level (Senhoury 2000; GRESARC 2006).

The city of Nouakchott is home to one third of the country's population and the country's key economic infrastructure. Protection of the city is therefore a major concern for decision makers and residents. Protection requires detailed knowledge of the flood risks confronting the city and the identification of measures for safeguarding its vulnerable areas.

Over the last years, the amount of rainfall recorded in the city has reached approximately 100 mm, which is sufficient for stagnant waters to become a nuisance and, in several neighbourhoods of the city, a disaster. Indeed, the geological nature of the soil and high groundwater level makes soil uanble to absorb, even low, rainfall. The lack of rainwater drainage and sewage disposal system results in foul-smelling waters overflowing from septic tanks and stagnating for weeks, thereby affecting city residents' well-being and comfort and disrupting economic activities in the capital.

In addition to flood risk linked to heavy rainfall, Nouakchott is also threatened by coastal flooding due to a combination of natural factors, including the ecological fragility of the coastal dune belt and the weak difference in level and presence of *sebkha*[1] grounds, and various anthropogenic activities, namely uncontrolled urban planning, building of infrastructure on the beach, and destruction of plant cover and mining of sand dunes for construction materials.

The general objective of this paper is to characterise the vulnerability of Nouakchott to flooding linked to coastal/marine hazards as well as the accumulation of rainwater and groundwater discharge. It will then outline solutions to mitigate flood risks. Many results discussed in this paper are from a Phd Thesis supported in 2014 at the University of Dakar (Senhoury 2014).

[1] flat-bottomed depression, usually flooded, where salty soils limit the presence of vegetation.

19.1.1 Nouakchott's Geography

Located in West Africa, Mauritania lies between latitudes 15° and 27° North, covers a surface area of 1,030,700 km^2 (Senhoury 2000), and has over 650 km of coastline bordering the Atlantic Ocean. Nouakchott, the capital city, is located towards latitude 18°07 North and longitude 17° West (Fig. 19.1).

Established in 1957, Nouakchott is on the oceanic front of the Sahara, at the edge of a low and narrow coastal plain, known as the *Aftout Es Sahli*.[2] Less than 5 km away from the seafront, the city is connected to the Atlantic Ocean through a narrow sand belt and has the following geographical sea-to-inland profile:

- A relatively narrow and thinly wooded coastal belt, with an average width of 150 m and an average altitude of 6 m, which provides the city its sole protection against flooding linked to coastal hazards;
- A vast flood depression with a locally variable altitude of 1–4 m;
- Large continental dune belts.

Although a young city, Nouakchott has already experienced accelerated population growth, starting with 1800 people in 1957 and growing to almost 800,000 inhabitants, as per the last census conducted in 2013 (ONS 2013). Its spatial organisation is characterised by a radial development and by a predominantly horizontal dispersed housing. The city grew as plots of land were attributed to residents, and new subdivisions or neighbourhoods created, while previously-established subdivisions were not fully developed. This expansion was made worse by the spontaneous and uncontrolled settlement of new migrants in the city's outskirts or in pockets of the existing urban fabric on undeveloped sites. As a result, many outlying areas of the city are spreading to the sensitive and lowest areas in the coastal zone.

19.1.2 The Climatic and Hydrodynamic Conditions

The high temperature, scarce rainfall, wind intensity and the wave regime in Nouakchott are elements that promote sediment mobility, especially on coastal dunes, and thus exacerbate coastal flood risk (Elmoustapha et al. 2007).

[2] Aftout es Sahli is a coastal lagoon, whose width varies from 3 to 7 km from the sea and the continental dunes in the east, and extends over nearly 275 km from Saint Louis (Senegal) to Nouakchott.

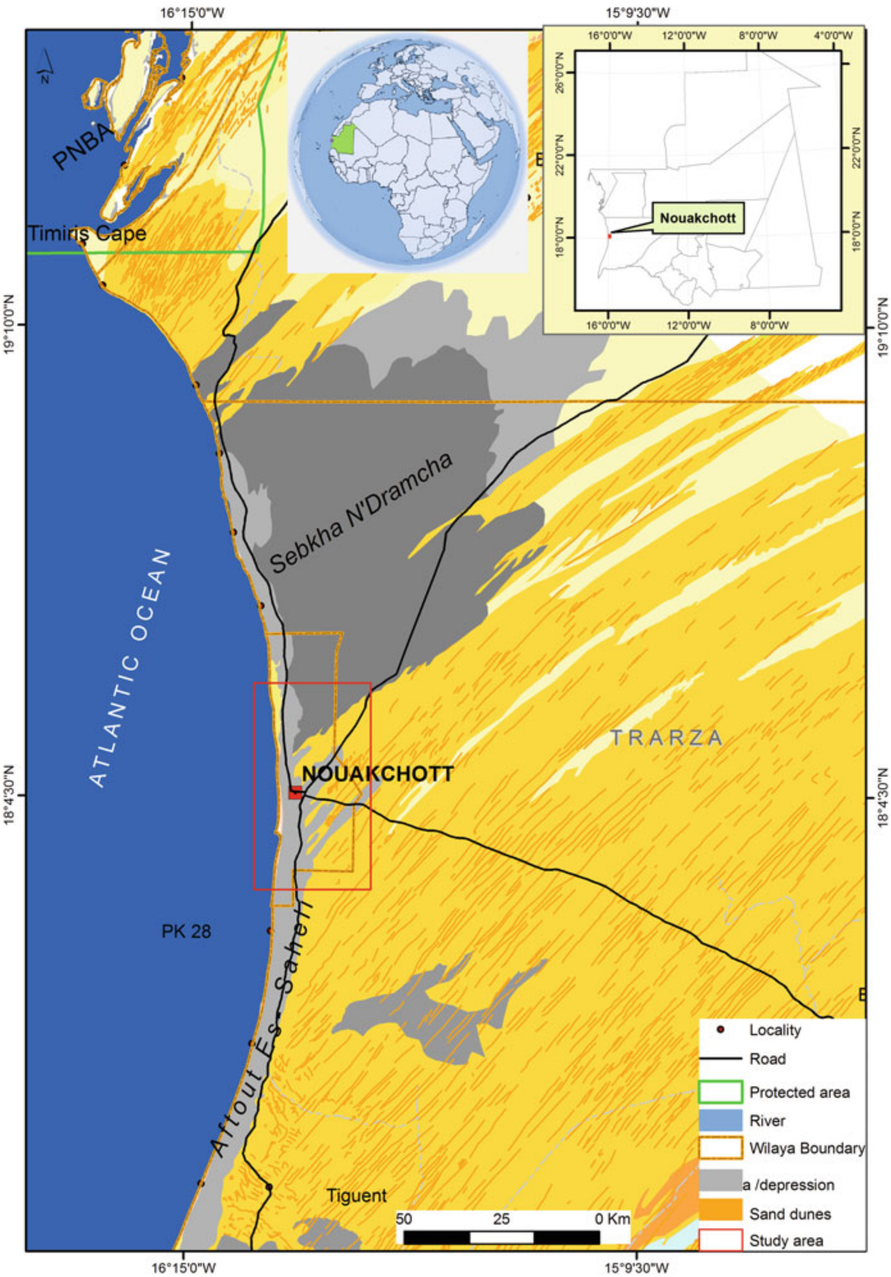

Fig. 19.1 Location of Nouakchott (Author's own figure)

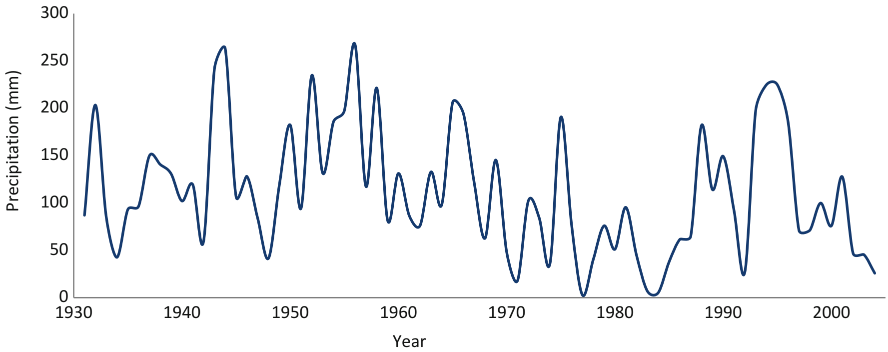

Fig. 19.2 Annual rainfall in Nouakchott between 1930 and 2004 (Data from the weather station in Nouakchott, cited in Senhoury 2014)

19.1.2.1 Average Annual Temperature

The average annual air temperature in Mauritania is between 20 and 30°C. However, temperatures above 40°C are commonly observed (Barusseau 1985). In Nouakchott, the average temperature is between 19 and 33 °C (Dubief 1963).

19.1.2.2 Rainfall

Rainfall data were obtained from the meteorological station of Nouakchott, covering the period 1930–2004. The evolution of annual precipitation over this period (Senhoury 2014) shows irregular rainfall in Nouakchott (Fig. 19.2). Rainfall variation is high, from a minimum of 5 mm recorded in 1984 to a maximum peak of 241 mm recorded in 1945.

The irregularities of precipitation observed in recent decades indicates a probable connection with climate change. This hypothesis requires further study, especially in the context of Nouakchott, where a correlation between rainfall and flood risk has been established (Senhoury 2014).

19.1.2.3 Wind Regime

Two wind regimes are active in this region: the rain-bearing Atlantic monsoon and the dry, North-Northeast trade winds linked to the Azores and Sahara region of high atmospheric pressure. Wind speeds and directions at 11 m above sea level have been continuously measured since 1975 by the Port de l'Amitié Authority (Ould Mohameden 1995). The most frequent winds are from the East-Northeast to West-Northwest sectors (81.7 % of the observations). Winds from the North-Northwest to the Northwest sectors represent 39.0 % of annual wind conditions, while winds from the North and North-Northeast sectors are present 21.0 % of the time. Wind speeds exceeding 13.9 m/s occur 1.1 % of the time, while speeds under 3.2 m/s are observed 6.3 % of the time.

19.1.2.4 Tidal Regime

Tides propagate from the north to the south along the Mauritanian coast, and are mainly semi-diurnal at Nouakchott. The tidal regime is microtidal, with ranges attaining 2 m during high spring-tide conditions (Ould Mohameden 1995).

Due to this rather small tidal range, tide-induced currents are not significant along the coast of Mauritania, which is nevertheless affected by a major oceanic circulation, the Canary current which originates from the northern Atlantic. A branch of this current veers westwards at CapeBlanc to the north of Mauritania, forming the North Equatorial current along the coasts of Mauritania and Senegal. The speed of this permanent current, orientated southward is about 0.2 m/s (Hebrard 1973).

19.1.2.5 Wave Regime

Between 1975 and 1982, wave measurements were carried out off Nouakchott wharf at a water depth of 9.5 m during a feasibility study prior to the construction of Port de l'Amitié harbour. The distribution of the mean wave heights and periods for the year 1976 has been analysed (Ould El Moustapha et al. 2007). Waves from the northwest and west-northwest are the most frequent, representing respectively 46.2 % and 23.6 % of the observations. Wave periods[3] are rather small; values smaller than 4 s and between 5 and 6 s represent 33.6 % and 38.9 %, respectively, of the observations. Periods exceed nine seconds only 15.7 % of the time. Mean wave heights are between 0.8 and 2.0 m 80 % of the time, and only rarely exceed 2.0 m. Maximum wave heights are associated with waves from the West and West-Northwest sectors.

19.1.2.6 Storm Regime

A statistical analysis of storms was performed in a previous work (Senhoury 2014) using the re-analysis method. The databases covered in this work are the data from the European Center for Medium-Range Weather Forecasts (ECMWF). The measuring point is located in the sea in front of Nouakchott (longitude: −16.75° latitude: 18.00°). These data cover the period 1957–2013. The processing of data identified 39 severe storms on the coast of Nouakchott. The results show that

[3]The time which separates two crests of successive waves.

although their frequency is not high in Nouakchott, severe storms are long in duration and last for several hundred hours.

Moreover, the frequency of these storms seems to be growing since the 1990s. The results show that storms have occurred frequently three times a year since 1990, while this rate has never exceeded two storms per year before 1990.

19.1.2.7 Nouakchott's Flood History

Several flood incidents have been recorded on the Nouakchott site, including the following key events:

- In 1950, the coastal plain of *Aftout Es Saheli* was flooded as a result of exceptional increases in the level of the Senegal River. That same year, following torrential rains, the Senegal River waters ran into the Atlantic Oean through *the Chott Boul* and the mouth located south of Saint-Louis, Senegal, and flowed as far as Nouakchott through *Aftout Es Saheli*. The floods destroyed the only neighbourhood standing in those days, which was rebuilt on the same site by the then colonial administration. Similar flooding events had been recorded in 1890 and 1932.
- On three separate occasions, in February 1987, August 1992 and December 1997, waves driven by violent storms crossed the coastal belt towards the direction of Nouakchott, causing the failure of the coastal belt in several places and moderate damages.
- Rainfalls recorded in 2013 (about 100 mm), although high but not exceptional, resulted in disastrous flooding in almost all the neighbourhoods of the city (Fig. 19.3). The disaster served as additional warning and a call for planned action with long-term solutions.
- In addition to flooding by rains, groundwater is also surfacing more frequently in several areas of the city, which exacerbates flooding episodes. Most of these affected areas are urbanized but are characterized by poor urban planning and therefore are at a higher risk of flooding.

19.2 Main Causes of the Vulnerability of Nouakchott

Nouakchott is highly exposed and vulnerable to flood risks, which are a result of a combination of underlying factors, including:

- Climate extremes, linked to climate change and climate variability (Niang 2014);
- Weakening and subsidence of the coastal dune belt due to poor urban planning and pressures from human activities (e.g. port facilities, construction of various

Fig. 19.3 Flood in Nouakchott following rains in 2013 (Source: enhaut; reproduced with permission)

buildings on public areas on the beach, construction of roads and terraces that prevent water run-off from permeating into the ground, construction of houses on wetlands, and from natural forcing (e.g. exceptional tides, waves, storms, etc.);
- Lack of a rainwater and sewage disposal system.

This section provides detailed information on the main factors that contribute to flood risks in Nouakchott.

19.2.1 Severe Climate Conditions

As extreme events become more recurrent and storms more intense, climate change appears as a likely assumption. Increased frequency of west winds clocking at more than 10 m/s, and the greater amplitude of swells, compound the threats faced by low-lying coastal areas. Flood risk is made worse with the likely rise in the average sea level.

19.2.2 An Artificialisation of the Coastline, Paying Little Attention to Its Fragile Balance

Natural events, however, do not solely account for the environmental deterioration of the coastline located in the vicinity of Nouakchott. Human activities that ignored the environmental dynamics of the coastline have largely contributed to disrupting a naturally fragile balance.

In this regard, the construction of the Nouakchott's port, known as *Port de l'Amitié,* in 1979, which was carried out without a prior environmental impact assessment, has strongly disturbed the hydrodynamic and sedimentary functioning of Nouakchott's coastline and the evolution of the coastal stretch. As a result, the following has been observed (Figs. 19.4 and 19.5):

- Severe siltation of the coast, north of the port, which has already caused the decommissioning of Nouakchott's wharf, and this process is threatening to spread, in the short term, to the port's basin through a detour around the far west side of the port embankment. The latter threat will remain, although current works to expand the embankment might delay the siltation process by two to three decades;
- Significant erosion south of the current port facilities, which has already prompted the adoption of safeguard measures, such as use of spurdikes and containment dikes (Fig. 19.5). This erosion is the cause of the marked destruction of the shorefront dune over several kilometres south of the port. As a result of the degradation of the coastal dune, the *Aftout Es Saheli* plain and neighbourhoods in the southern part of the city have become more prone to sea water incursions.

The constructed protection measures do not always have positive effects. Indeed, these protection measures were constructed in an *ad hoc* basis, and their negative environmental impacts have seldom been considered.

Moreover, while the *Port de l'Amitié* is by far the primary cause of the negative evolution of Nouakchott's coastline, other anthropogenic activities have also contributed significantly to undermining the coastal system, namely:

(a) **Sand removal** from the coastal dune for construction purposes is one of the main causes of weakening the coastal dune, and is at the root of the breaches seen, from which *Aftout Es Sahli* has suffered sea flooding on several occasions. Sand removal is now fully prohibited.
(b) **The construction of buildings on the coastal dune**, where in 2005 there were already five hotels and several industrial and/or trading infrastructures (factories, fish market, etc.), has also weakened this coastal dune. Built infrastructure exert pressure on and weaken the dune belt, the only form of protection against coastal flooding in some areas of the city.

Fig. 19.4 Aerial view of the site of Nouakchott's port in 1980 (Reference : 80_Mau_42_155 IGN France, reproduced with permission)

(c) **Recreational activities**, such as frequent and unregulated car stunts (a recreational, sporting activity), destroy pioneer plants, prevent the types of sediment accumulation that develop with these plants, flatten dune ridges and make it impossible to seal breaches along the dune belt. This motorised traffic is exacerbated by the anarchical trampling of spectators that come in increasing numbers to watch the car stunts.

(d) **Uncontrolled grazing by animals which consume dune vegetation and the use of dune vegetation as firewood by some households**. This vegetation, which is supposed to fix the sand dunes in place, has already been degraded by drought in the past decades.

Fig. 19.5 Aerial view of Nouakchott's port in 1991 (Reference 1991_Mau_12_150 IGN France, reproduced with permission)

19.2.3 A Brackish Water Table with Continuously Rising Water Levels

A large part of Nouakchott was built in a low-lying area whose altitude is lower than the sea level. In many parts of the city, the water table is surfacing and its level is directly related to that of the ocean. In addition to being a receptacle for marine and rain waters, the water table may threaten the city of Nouakchott in case of outcropping and degrades habitat conditions, even without flooding episodes.

Since the commissioning of Nouakchott's system of safe water supply from the Senegal River (*Aftout Es Sahli* project), water distribution in the capital city has increased from 60,000 m^3 to 170,000 m^3 daily and may reach 226,000 m^3 daily in 2030 (MHET 2014). This significant increase has taken place without an appropriate system for sanitation and wastewater treatment. Hence, a network of individual septic tanks and cesspools partly contributes to the refilling of the water table. According to current estimates, 90 % of waste waters and discharge flow directly into the water table.

When the water table is high, even a small amount of rainfall cannot infiltrate into the already saturated *sebkha* ground, which results in flooding. In addition to the flood risk, people directly exposed to polluted waters face other health risks. The rapid development of housing projects in floodprone, low-lying areas has only exacerbated these risks.

In this regard, it is crucial to take into account the functioning of the water table, when considering global sea level rise, climate extremes, the coastal regimes (tides, waves, etc), rainfall and wastewater linked to accelerated urbanization.

19.3 Review of Nouakchott Flood Risks

The topographic survey of Nouakchott completed in 2006 by the GRESARC research group (GRESARC 2006) was used to map out flood-prone areas in the city. The study showed that about one third of the city's urbanised areas are located at extremely low topographic levels, and hence prone to flooding.

Simulations have been conducted (Fig. 19.6) to help understand the extent of flooding in Nouakchott, for instance in case of several large breaches in the dune belt following a strong storm, or in the case of rising groundwater levels together with heavy rainfall. To develop this map, it was mainly assumed that the extreme sea level reaches between 1.0 and 1.4 m, or that the height of rainwater that puddles are not absorbed into the ground due to watertable saturation is approximately the same values.

Based on the study, the inhabited areas in the city most prone to flooding are essentially:

- The western part of the *Tevragh Zeina* urbanised area;
- Almost all the inhabited areas of the *Sebkha* and *El Mina-nord* neighbourhoods;
- The majority of homes in *Riyad*.

The eastern end of the *Téyaret* and *Ksar* neighbourhoods as well as the central and north-central part of *Dar Naïm* are equally located at a point below the extreme sea level of 1 m, but are separated from the sea by higher, elevated zones. These areas are less exposed to risks of coastal flooding. However, these disctricts are also particularly vulnerable to inland flooding triggered by heavy rains.

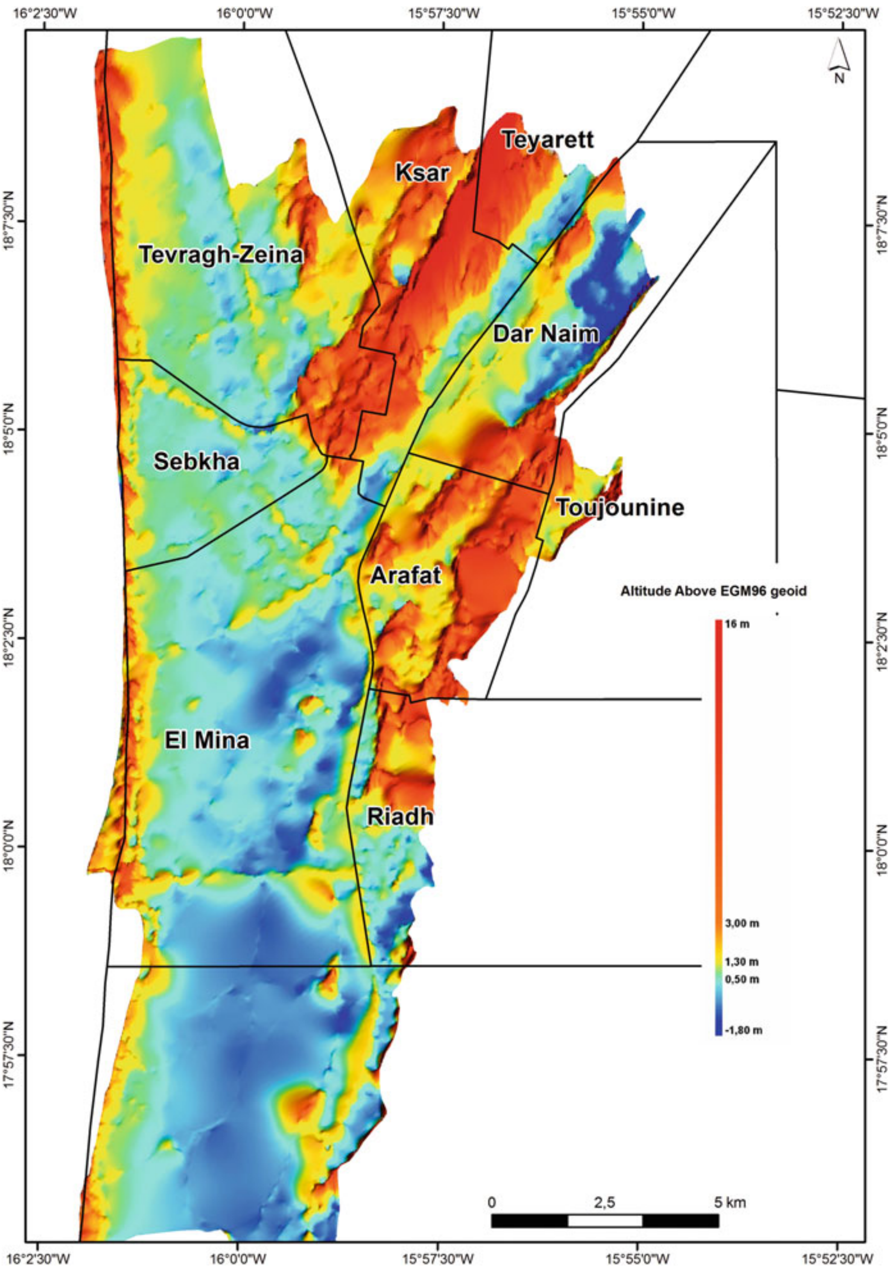

Fig. 19.6 Nouakchott topographic levels map (Author's own figure)

19.4 Assessment of the Socio-economic Impacts of Possible Flood Incidents

The socio-economic impact assessment of possibe flood incidents at Nouakchott was undertaken in 2014 by Senhoury (2014). This assessment was based on the study of flood-exposed areas and available data of the population and infrastructrure distribution. A Geographic Information System (GIS) was used which included the mapping of land-use in Nouakchott, the topography made by GRESARC in 2006 and the National Statistics Office's (ONS) statistics on population distribution. Using the ArcGis software to operate the GIS system helped to calculate flood risk areas, the length of tarred (cemented) roads, and the number of threatened socio-economic infrastructures.

The findings presented in this paper are those of a scenario whereby the extreme sea level is 1.4 m. The inundation considered in this regard supposes that one of the following events could occur:

– Appearance of several large breaches associated with a storm whose duration makes it possible for a significant amount of seawater to spill over;
– Rise in the level of Nouakchott's brackish water table to reach the extreme sea level, with possible significant rainfalls.

The flood map of Nouakchott indicating flood-prone areas, buildings and infrastructures impacted under this scenario is provided in Fig. 19.7.

The flood-prone population of Nouakchott was determined based on the size of the population residing in the city in 2011, estimated at 727,000 inhabitants. The calculations show that 38 % of the population face flood risks, representing 273,000 people that will have to be displaced in the event of flooding by sea. The bulk of potentially-affected population live in low-income neighborhoods of Nouakchott and are predominantly poor.

Calculations made with the ArcGis also determined for each commune of Nouakchott the size of flooded areas together with their economic values, based on 2005 data on the extent of urbanization. Results showed that an area of more than 10,400 hectares, including 8200 urbanised hectares, is likely to be submerged, i.e. about 30 % of the city. Risks in terms of human losses are considerable, especially when people are not informed nor trained in disaster management. The civil protection departments do not seem to have the means to handle flooding incidents of such a magnitude (MPEM 2005).

By assuming that unit costs of housing are close to market prices, and depending on whether homes are located in higher- or low-income areas, the material values of threatened areas are estimated at a cost of more than USD 7 billion. With regard to tarred roads, the simulation area covered a network of 371 km in 2005. In the event of coastal flooding, 189 km would be destroyed, representing a value of USD 31 million. Other critical infrastructures, including schools, hospitals, mosques and markets, that provide key social services would also be threatened. Table 19.1 shows the number of basic infrastructures under threat in case of flooding at 1.4 m.

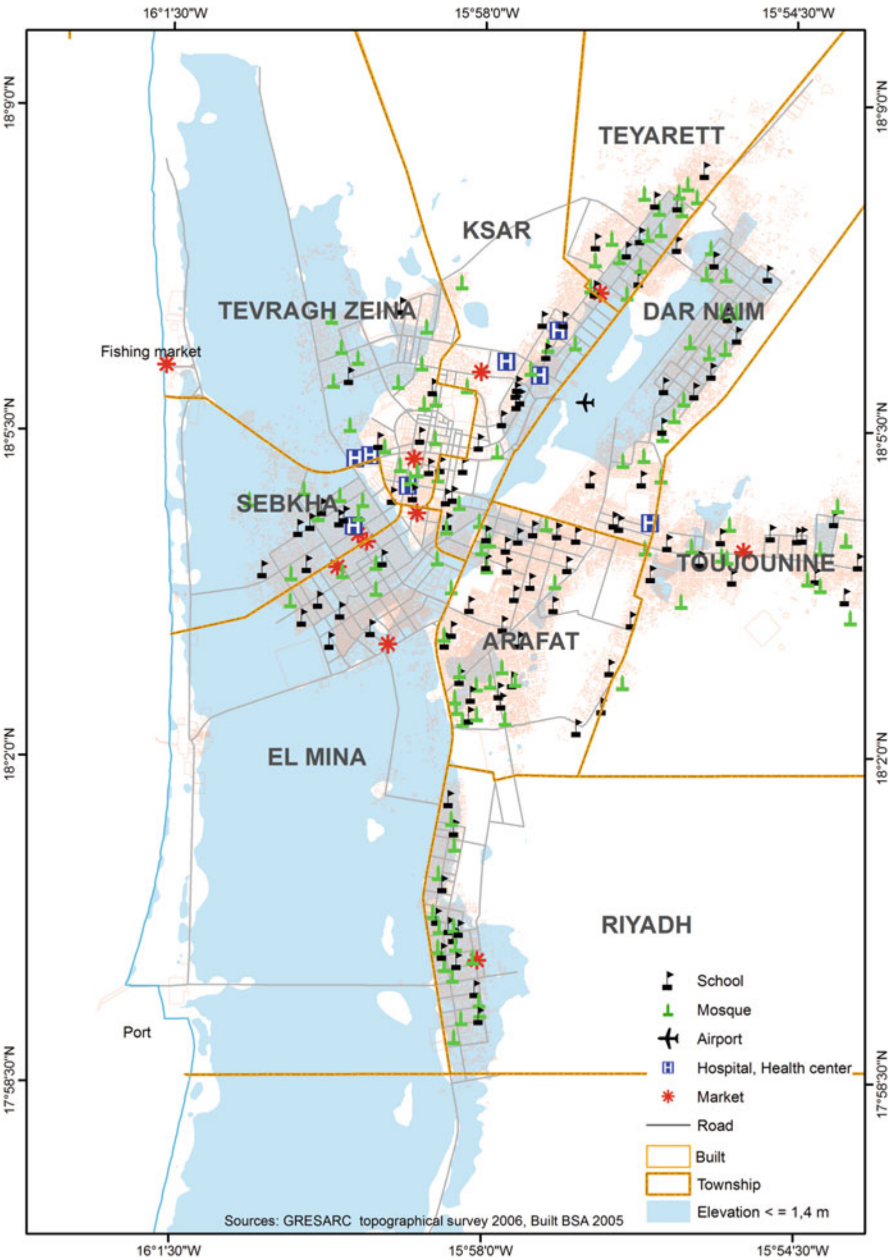

Fig. 19.7 Submersion map of Nouakchott for an extreme sea level equivalent to 1.4 m (Senhoury 2014, reproduced with permission)

Table 19.1 Threatened basic infrastructures (Senhoury 2014)

Type of infrastructure/ service	Total number of infrastructures existing in Nouakchott in 2005	Number of threatened infrastructures
Schools	107	45
Public hospitals	8	2
Mosques	112	60
Markets	11	6

It should be noted that strategic economic infrastructures are also threatened by flooding. Because of the limited information on the economic values of such infrastructures, only a limited indicative list of key threatened properties comprises:

- Part of Nouakchott's airport;
- Nouakchott's port;
- Nouakchott's wharf; fish market; and
- Two important cement factories

19.5 Proposed Corrective and Adaptive Measures

Given the flood risks facing the city of Nouakchott and the scope of their environmental and socio-economic impacts, mitigation and/or adaptation measures are required. These must include both preventive and corrective measures.

19.5.1 Preventive Measures

The preventive actions proposed consist of adopting flood-sensitive land-use measures and regularly monitoring the current evolution of the coastline, as follows:

– Develop and implement urban town planning maps and schemes that firmly prohibit construction works in areas likely to be submerged or flooded, i.e. low-lying areas of Sebkha (with an altitude between −1 and +1 m), the ridge of the dune belt and along the beach between the dune and the coastline;
– Stop any activities that threaten the coastal dune belt; it is urgent to maintain the prohibition of sand removal for construction purposes, provide options for sand collection, control car traffic along the fragile segments of the coastal belt and prohibit animal grazing on the plant cover that holds the dune belt intact;
– Put in place an early warning system, which could trigger an immediate response to a potential disaster or a serious anthropogenic stress. This system would ensure monitoring of weather, and its hydrodynamic consequences as well as the morphological monitoring of the beach and dune belt. The system would also help monitor the expected increase of the groundwater level in relation to climate drivers (sea level, rains, etc.).

19.5.2 Corrective Measures

The proposed corrective measures are based on previous studies (IRC-Consultant 2008; Senhoury 2014). They aim to mitigate flood risks through the optimum utilization, when possible, of available natural resources. The choice of nature-based approaches is dictated by two reasons. They help to correct the current malfunctioning of the coast of Nouakchott and improves the protection of its ecosystems and ecosystem services that contribute to flood risk reduction. Moreover, the engineering approaches have a relatively high cost. To this end, the following measures are recommended:

(a) Establishing a drainage and water treatment system

In order to reduce flood risks in the city because of both the rainy season and groundwater discharge, it is recommended to accelerate the establishment of a drainage system for sewage and excess run-off by building a wastewater collection network and a treatment station. The treated wastewater can be utilized for gardening and reforestation of the coastal dune. This will help to collect and redirect waters collected and promote its rational and sustainable use in order to reduce overexploitation of potable water in an arid city.

The Governments of China and Mauritania have signed in December 2014 an agreement for the provision of USD 32 million to construct a sanitation system in Nouakchott. The planned project includes the construction of modern rainwater and wastewater drainage networks. Feasibility studies suggest building two separate drainage systems, i.e. a rainwater network and a wastewater network. The proposed drainage system should take into account basic data on wastewater production in Nouakchott, currently estimated at 82,000 m^3 and the assumption of erratic rainfall varying from 5 to 241 mm.

(b) Reinforcement of the coastal dune

Low-lying areas are found in Nouakchott's coastal dune belt, which make these areas particularly susceptible to breaches and seawater intrusion. A priority action to protect the city from coastal flooding should therefore consist in plugging (i.e. repairing) the breaches and, more generally, in reinforcing the dune belt.

The optimal functioning of the coastal belt does not require that it remains strictly stable in its current position but that controls are undertaken for the structure to play its role with some degree of mobility.

According to IRC-Consultant's 2008 estimates, the optimal height required for the reinforcement of the coastal dune should be at least 6 m above the sea level (IRC-Consultant 2008). Needless to say, the most effective belts are those with a large width. From the outset, a width/height ratio of 20 seems to be appropriate, representing a minimal width of 120 m and a minimal height of 6 m.

Two complementary techniques for reinforcing Nouakchott's coastal dune area are recommended, i.e. mechanical techniques and biological techniques. In the context of Nouakchott, these techniques complement each other and offer the advantage of incurring minimal environmental impacts.

Fig. 19.8 Experience of sand dune stabilisation using Typha australis stalks on the dune between the “Plage des pêcheurs (Fishermen’s Beach)” and the wharf (Author’s own figure)

Across the entire dune area facing the city, north of the port facilities, the dune belt is where major sand movement takes place. Setting up shelterbelts to protect dunes may result in the quick accretion of the dune. The mechanical technique of using windbreak hedges could therefore be effective in this case. For socio-economic and ecological reasons, it is preferable to use windbreak hedges made of local plant materials, because they are low cost and accessible. Indeed, these locally-developed techniques have been proven to be efficient in several areas of the coastal dune, based on pilot projects. The most replicable example is from a pilot study conducted in 2005 which used the stalks of an invasive plant species known as *Typha australis* to build windbreaks or shelterbelts on dunes (Fig. 19.8). This invasive plant is a threat to the ecosystem of the Senegal River, south of Mauritania; hence, using the stalks of this species to make shelterbelts is one way of eliminating it.

The mechanical reinforcement of the dune belt contributes to the development of natural vegetation. It would be interesting, however, to supplement it with biological measures that support re-vegetation, which are in turn conducive to the accumulation of sand and its mobility reduction. When a satisfactory profile is achieved, certain plant species must be introduced in the dune, primarily in the rear portion. It is recommended to choose local bushy species, particularly *Nitraria retusa, Calotropis and Tamarix,* as they are quite adapted and highly resistant to dryness. Planting should take place in the area located between the *Port de l’Amitié* and the *Plage des Pêcheurs*, stretching 12 km long. The size of the back dune to be planted is estimated at 240 hectares (200 m wide), with a density of 200 seedlings per hectare, representing a total of 48,000 seedlings (MPEM 2005). Treated areas must be protected by a perimeter fence to ensure constant care and surveillance.

(c) Preservation of Nouakchott's port

The alarming deterioration of the coastline induced by the construction of Nouakchott's port facilities is considerable, which as a result has become the cause of major flood risks for the city. Consequently, optimal solutions should be found to manage the coastline's evolution that allows both the preservatin of the *Port de l'Amitié* and erosion reduction in its southern part.

This is why digital simulations on various options for the development of the *Port de l'Amitié* were conducted in the framework of a partnership with the GRESARC research group of the University of Caen on behalf of the consultancy firm IRC-Consultant (IRC-Consultant 2008). The UNIBEST model (Delft Hydraulics 1994) was used to make these simulations.

The results show that for the port of Nouakchott, the restoration of the sedimentary transit through by-passing seems to be an ideal solution in terms of sediment balance. The by-passing is a system which allows to restore artificially the sediment movement along a coast (by pumping or transportation in trucks). This solution has double effects. It would avoid siltation in the port by reducing accretion in the northern part and, at the same time, help to replenish the beach located south of the port. Yet, this solution appears costly owing to the significant amount of sediments for which an artificial transit is required given the intensive drift along the littoral.

(d) Creation of protected urban areas in Nouakchott

This adaptation measure is about transforming wetlands created by the permanent flooding of low-lying areas in the city into urban protected areas and using them for recreation such as bird watching as well as for excess water retention. A pilot project of this nature is under consideration in the centre of Nouakchott. In 2014, the Commune of Tevragh Zeina proposed this pilot action and is actively seeking support from national and international partners (Commune de Tevragh Zeina 2014).

The idea of this project is to harness an urban wetland created at the centre of the city, where several incidents of flooding caused by rainwaters or groundwater discharge have occurred. Indeed, surface sealing combined with increased construction and waterlogging have exacerbated rainwater stagnation in the lowest points of the city. These ponds, whose numbers grow year after year, fill with water during the rainy season and remain water-logged for an increasingly longer period, often throughout the year. A number of these urban wetlands, such as the site located in the *Ambassadeurs* neighbourhood in the centre of Nouakchott, has become home to specific vegetation and is increasingly visited by water birds (with more than 65 identified species). The site has become a real biodiversity hotspot in town.

The establishment of a protected urban area on that location boils down to enclosing and developing the site into an area for flood mitigation, birdwatching, recreational activities and promoting environmental education Such pilot projects should be duplicated and implemented in other parts of the city.

19.6 Conclusion

The city of Nouakchott provides a case study to understand the risks of flooding in coastal cities and the drivers of these risks (see also van Wesenbeeck et. al., Chap. 8; Nehren et. al., Chap. 18; David et. al., Chap. 20). The review has highlighted that Nouakchott remains vulnerable to serious flood risks of different origins, such as coastal flooding, rainfall accumulation and groundwater discharge. This vulnerability is the result of a marked deterioration of the environment within and outside the city. In fact, more than natural hazards that threaten the city (i.e. sea level rise, increased storm frequency, etc.), coastal degradation linked to unsustainable human activities have been instrumental in disrupting a fragile ecological balance and resulting in increased disaster risk to city dwellers.

Several contributing factors to the risks of flooding in Nouakchott have been considered, inluding natural factors (fragility of the coastal dune belt, topographic low of some areas) and various anthropogenic activities (uncontrolled urban planning, construction of infrastructures, destruction of plant cover and removal of construction materials from the coastal dune). This is compounded by the lack of a run-off drainage and sewage disposal system, particularly as groundwater tables are no longer capable of absorbing excess runoff, which increases flood risks for Nouakchott.

The digital terrain model, developed for mapping floods risks in Nouakchott, was used to highlight areas with topographic levels lower than the average sea level. Findings from the cartographic review of these risks suggest that with or without climate change, Nouakchott still remains subject to risks of flooding, if not major submergence. In the event of seawater intrusion, nearly 30 % of the city would be submerged to an extent far beyond recurrent floodings caused by rainwaters. Port and airport facilities, almost 200 km of tarred roads and many public infrastructures, such as health centres, universities and schools, would be affected. Under such circumstances, economic losses might reach the equivalent of US$ 7 billion.

In order to mitigate risks identified and/or adapt the coastline to the corresponding flood risks, there is a need to consider both preventive and corrective solutions. Corrective measures recommended are largely based on ecological approaches, either through optimising local natural resources (treatment and re-use of wastewaters and rainwaters for gardening) or implementing soft mechanical and biological techniques (revegetation-based reinforcement of the coastal dune).

References

Barusseau JP (1985) Evolution de la ligne de rivage en République Islamique de Mauritanie. UNESCO, Division of Marine Sciences – Marine Sedimentology Laboratory, University of Perpignan, Study reports, février 1985, 104 pp

Commune de Tevragh Zeina (2014) Projet Nature à Tevragh Zeina. Press release, 4 pp

Delft Hydraulics (1994) Unibest, a software suite for simulation of sediment transport processes and related morphodynamics of beaches profiles and coastline evolution. Theoretical reference document. H 454, octobre 1994, 40 pp

Dubief J (1963) Le climat du Sahara. Memory Occasional Papers, Inst. Rech. Sah., Université Alger.T.1, 312 pp

Elmoustapha AO, Levoy F, Monfort O, Koutitonsky VG (2007) A numerical forecast of shoreline evolution after harbour construction in Nouakchott, Mauritania. J Coast Res 23(6):1409–1417

GRESARC (2006) Cartographie des risques littoraux de Nouakchott. Study report. MPEM & UICN. 63 pp

Hebrard L (1973) Contribution à l'étude géologique du quaternaire du littoral mauritanien entre Nouakchott et Nouadhibou. Participation à l'étude des désertifications du Sahara. Thesis, University of Lyon, 483 pp

IRC-Consultant (2008) Revue de l'état des risques d'inondation de la ville de Nouakchott. Preliminary report, Volume 1: main report. Department of Environment, Mauritania, 64 pp

MHET (2014) Réactualisation de l'Etude du Plan Directeur de l'assaisnissement de la ville de Nouakchott. Study report, version draft.Ministry of water, energy and TICs, Mauritania, 83 pp

MPEM (2005) Rapport sur les risques d'inondation de la ville de Nouakchott. Study report, 30 pp

Niang AJ (2014) Resilience against climate change: case of Nouakchott City. Geo-Eco-Trop 38 (1):155–168

ONS (2013) Etat d'avancement des activités du Recensement Général de la Population et de l'Habitat 2013. Study report, 10 pp

Ould Mohameden A (1995) Aménagement et évolution du littoral, Apports de la télédétection et de la modélisation mathématique: cas du port de Nouakchott. Nice, France: University of Nice, PhD thesis, 149 pp

Senhoury A (2000) Influence d'un ouvrage portuaire sur l'équilibre d'un littoral soumis à un fort transit sédimentaire, l'exemple du port de Nouakchott (Mauritanie). Thesis, University of Caen, Basse-Normandie, December 15, 2000, 162 pp

Senhoury A (2014) Aménagements portuaires et urbanisation accelerée des côtes basses sableuses d'Afrique de l'Ouest dans un contexte de pejoration climatique, cas du littoral de Nouakchott (Mauritanie). Thesis state, University of Dakar, April 29, 2014, 157 pp