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ORIGINAL

Hydraulic modeling of Sebou tributaries for flood prevention in the el Gharb plain - Morocco

Modelización hidráulica de los afluentes del Sebou para la prevención de inundaciones en la llanura de el Gharb - Marruecos

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ABSTRACT

Flooding is one of the most unpredictable natural hazards. In Morocco, the El Gharb plain is the most affected. The Rharb basin receives between 500 and 600mm of precipitation and includes 30 % of Morocco's water resources. All the factors that make the Rharb plain a vulnerable area are: climatic factors, lithology, geomorphology, the limited number of natural outlets for water drainage towards the Atlantic Ocean. The methodology adopted is based on the determination of flood zones and the hydraulic modeling of the main tributaries of the Oued Sebou and the main sanitation channels, in order to monitor the evolution of flood zones and evaluate the flow of the Oued Sebou to understand the functioning of the hydrographic network and the overflow points. According to the hydrographs established by the Gharb plain flood protection department, the maximum flow at the entrance to the city of Kenitra was estimated at 2600 m3/s and the flow of the Oued at this level is of the order of 1600 m3/s, which explains the overflows recorded at the level of the left bank of the Oued Sebou, the dead arm of the Oued. The results of these studies as well as the analysis of the history of the floods of the Oued Sebou, show that one to two major floods occur every 10 years and that the overflows reach upstream of the highway to the dead arm of the Oued and cover Merja-Fouarate such as the case of the flooding of the city of Kenitra in 2010.

Keywords: Gharb Basin; Oued Sebou; Kenitra; Flood; Hydraulic Modeling; Flow Dynamics; Morocco.

RESUMEN

Las inundaciones son uno de los peligros naturales más impredecibles. En Marruecos, la llanura de El Gharb es la más afectada. La cuenca del Rharb recibe entre 500 y 600 mm de precipitación y abarca el 30 % de los recursos hídricos de Marruecos.
Todos los factores que hacen de la llanura de Rharb una zona vulnerable son: los factores climáticos, la litología, la geomorfología y el número limitado de salidas naturales para el drenaje de agua hacia el Océano Atlántico.
La metodología adoptada se basa en la determinación de las zonas de inundación y la modelización hidráulica de los principales afluentes del Oued Sebou y de los principales canales de saneamiento, con el fin de seguir la evolución de las zonas de inundación y evaluar el caudal del Oued Sebou para comprender cómo funciona la red hidrográfica. obras y puntos de desbordamiento.
Según los hidrogramas establecidos por el departamento de protección de la llanura de Gharb contra las inundaciones, el caudal máximo a la entrada de la ciudad de Kenitra se estimó en 2600 m3/s y el caudal del Oued a este nivel es del orden de 1600 m3 /s lo que explica los desbordes registrados en la margen izquierda del Oued Sebou, el brazo muerto del Oued.

Los resultados de estos estudios, así como el análisis de la historia de las inundaciones del Oued Sebou, muestran que cada 10 años se producen una o dos inundaciones importantes y que los desbordamientos llegan aguas arriba de la carretera hasta el brazo muerto del Oued. y cubre Merja-Fouarate, como el caso de la inundación de la ciudad de Kenitra en 2010.

Palabras clave: Cuenca del Gharb; Oued Sebou; Kenitra; Inundación; Modelado Hidráulico; Dinámica de Flujo; Marruecos.

INTRODUCTION

Like other countries, Morocco is potentially confronted with natural phenomena, sometimes extreme, due to its geographical position and climatic conditions.[1] Increasingly recurrent, these phenomena generally cause heavy economic and social damage often affecting vulnerable populations and territories.[2]

Indeed, over the last two decades, Morocco has been hit by several natural disasters that have caused loss of human life, material damage and significant socio-economic and environmental deficits. This is evidenced by the floods of November 2002 in Mohammedia; the earthquake in February 2004 in Al Hoceima; the Gharb floods in 2008-2009, those that occurred in Tangier in October 2008, December 2009 and January 2013 and those produced in November 2014 in the Southern Provinces,[3] in September 2023, the Alhaouz earthquake. Events that have exposed several weaknesses linked to the vulnerability of the socio-economic fabric and basic infrastructure.

The Gharb has experienced severe floods. The most devastating occurred in the years 1963, 1973, 1989, 1996, 2009 and 2010. These catastrophic events caused the flooding of several thousand hectares of agricultural land,[4] damaging infrastructure, the collapse of houses, the evacuation of several disaster-stricken families and the submersion of homes for several days. They also caused significant economic and social damage.

Due to global changes related to global warming, and other phenomena related to the movement of the intertropical front towards the North, Morocco is far from being spared from episodes of thunderstorms that can cause overflows of rivers in several regions and particularly the plain of El Gharb.

The objective of this work is that it is possible to confront the recurring floods that take place in the El Gharb region by way of the historical flooding events modeling. In other words, first, the detection and analysis of the high-risk areas are considered to be part of the flood risk mitigation strategy; second, to suggest the best measures to tackle the problems of varying water inflows so that the systems can be adapted to severe droughts. This means the process of creating a database to detect and analyze flood hazards, which can be a viable instrument for the decision makers and interested parties involved in regional planning and development.

Geographic, climatic and geological contexts

Study area and regional geographical context

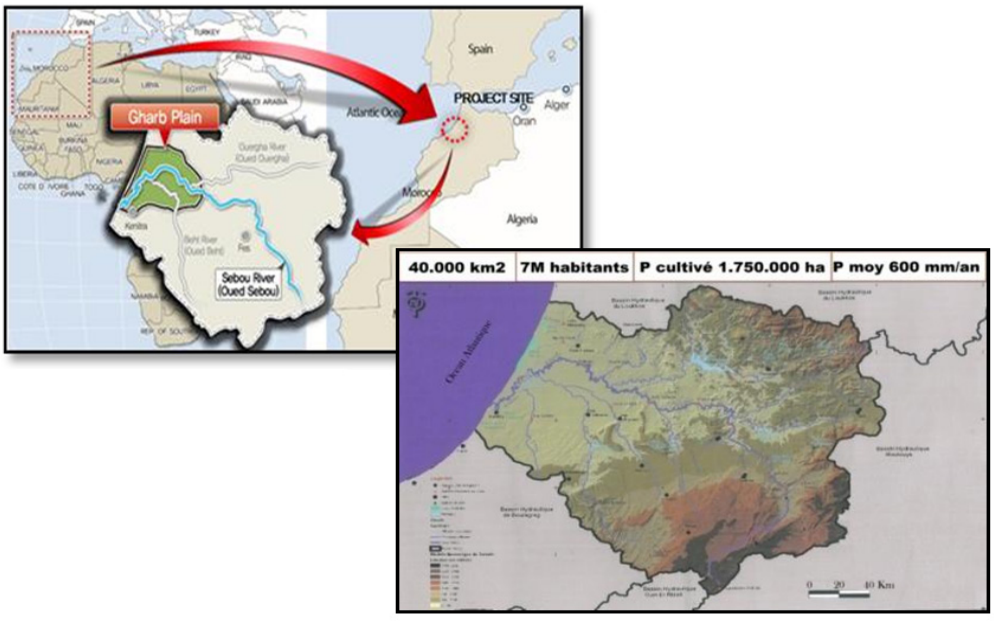

Figure 1. Situation of the Sebou watershed and its watershed[4]

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The Sebou watershed forms a basin between the Rif in the North, the Middle Atlas and the Meseta in the South, the Fez-Taza corridor in the East and the Atlantic Ocean in the West[5] (figure 1). It covers an area of approximately 40,000 km2 which has a total population of nearly[6] 7 million inhabitants[7] or approximately 20 % of the country's population, 49 % of who live in urban areas and 51 % in rural areas, spread over a vast territory encompassing 17 provinces. The Sebou watershed is bounded to the North by the Loukkos watershed, to the South by the Oum Rbiaa and Bouregreg watersheds and by the Atlantic Ocean to the West.[8] The climate of the watershed is Mediterranean; the average annual precipitation is 600 mm / year. This basin monopolizes 30 % of Morocco's water resources, composed of significant surface water (33 % of the volume of water stored in 10 large dams) and groundwater consisting of significant water tables

Geological framework

The El Gharb plain is limited to the north by the Lalla Zohra hills (which separate it from the Drader wadi basin), to the east by the pre-Rif hills, to the south by the edge of the Moroccan Meseta (Maâmora plateau) and to the west by the Atlantic Ocean.

From a structural point of view,[9] the region is located between two major structural groups in Morocco: the Rif domain to the north with thrust sheets moving from NE to SW and the Paleozoic Meseta represented by a rigid unit inclined at 3° and plunging regularly from south to north, overlain to the north by the units of the Rif domain.

The Ghard plain appears as a basin that was subsiding since the Middle Tortonian and throughout the Quaternary. This subsidence movement seems to be much more pronounced in the Miocene. The Quaternary formations plunge under a recent cover of the plain and only the Soltanian outcrops on the edge and the Rharbian in the center.

The Early Quaternary (Moulouyen and Salétien) is well developed on the edges of the Rharb, it is not the same for the Middle Quaternary (Amirian and Tensiftian). We can clearly recognize the terraces belonging to these stages in the valleys that open into the Rharb (Beht and R'Dom valleys, Sebou and Ouerrha), but destroyed by erosion or plunging tectonically, disappear as soon as we approach the plain under the recent Quaternary.

This drowning is clearly visible for the pebbles of the Early Quaternary. The same phenomenon is observed for the Soltanian, the red silts of this stage appear on the southern edge of the Rharb where they form low silt terraces in all the valleys. These terraces advance further into the plain and gradually disappear under the Rharbian deposits.[10,11]

On the sea side, the Rharb plain is bordered by two lines of consolidated dunes. These dunes are not very old. Most of them belong to the recent Quaternary (Soltanian and Rharbian).

The marl-dominated base makes the plain a favorable environment for water accumulations which manifest themselves in marshy areas and seasonal lakes; and offers a predisposition to probable floods.

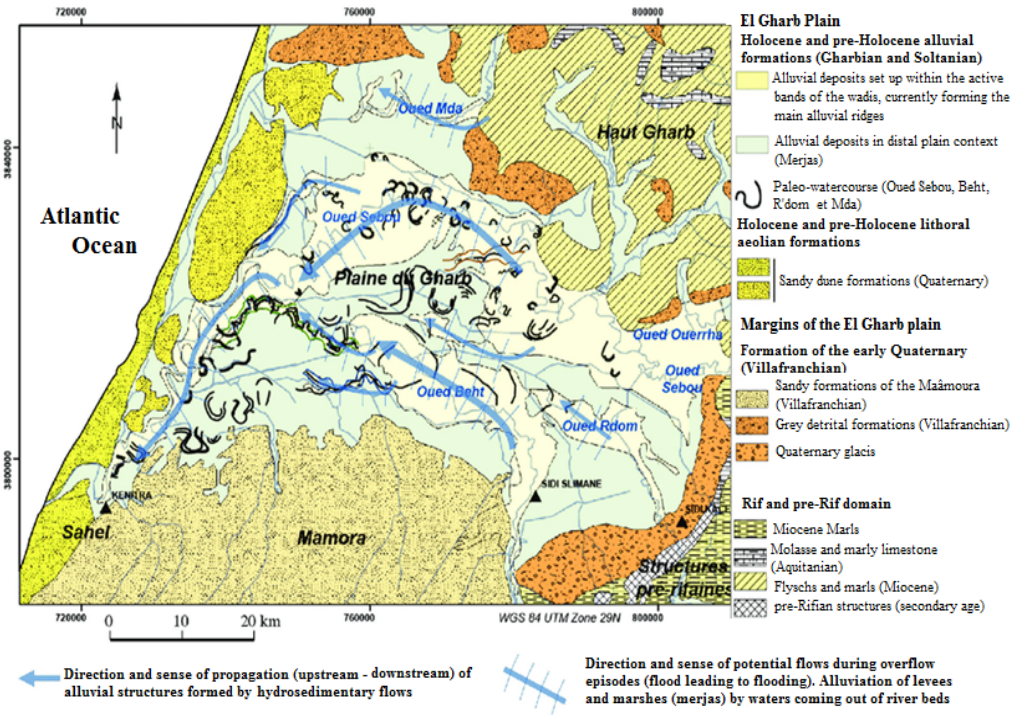

Figure 2. Geology of the El Gharb plain[7]

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METHOD

Problematic

All the factors that make the Rharb plain a vulnerable area and facing several natural challenges are:

- Climate change: succession of dry years and years of floods.
- The geomorphology and the very low altitude level of the Gharb plain (depressions, Merjat....).
- Lack of natural outlets for water drainage towards the Atlantic Ocean, with the exception of Oued Sebou (figure 3).
- Low flow rate of Oued Sebou.
- 50 % of the basin not regularized.

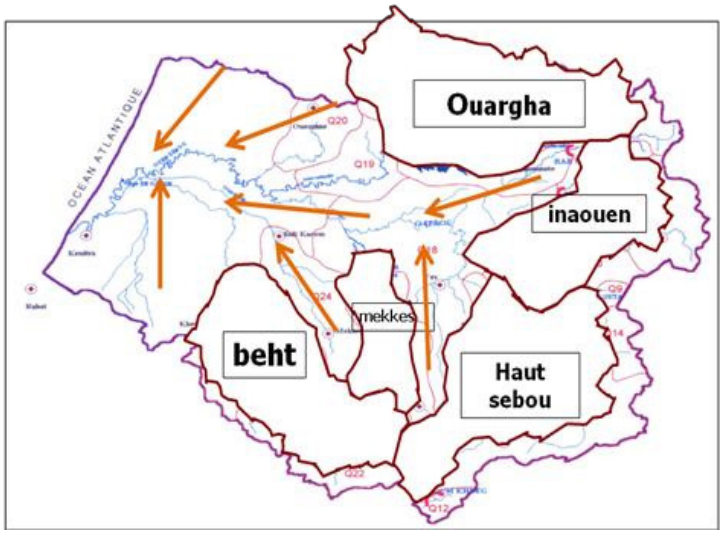

Figure 3. Water flow in the Sebou watershed[12]

Methodology

The methodology adopted in this work is an approach based on the determination of flood zones in the city of Kenitra and the hydraulic modeling of the main tributaries of Oued Sebou and the main sanitation channels of the Gharb plain in order to monitor the evolution of flooded areas and to evaluate the flow rate of the Oued Sebou on its different sections and to understand the functioning of this hydrographic network and overflow points, as well as the dynamics of flows across the plain.[13]

The flood risk assessment in the El Gharb plain is based on a deterministic qualitative approach in which we combined the conditioning factors with the history of climate data associated with the history of floods that have previously occurred in the region and considering the degree of vulnerability of the different sectors affected: housing, transport, agriculture, industry, etc

RESULTS AND DISCUSSIONS

The combination of several factors, including topographic, lithological and pluvio-hydrological can contribute to the modeling of floods in the Gharb plain which is located within the Sebou watershed.

Soil nature and hydrogeology of the Gharb basin (Kenitra region)

The Gharb plain covers an area of 4 200 km2 and includes a strip of coastal dunes along the ocean margin.[14] The morphology of the entire plain corresponds to a vast basin, 4/5 of which are at an altitude of less than 20 m, while the edges have very gentle reliefs. All the Quaternary formations plunge beneath the plain and only the most recent ones outcrop: the sandy Soltanian on the edge and the clayey Rharbian in the center.[15]

From a hydrological point of view, the hydrographic network of the Sebou watershed is composed of major rivers, namely the Sebou, Ouergha, Beht and Rdat wadis and their tributaries. This network also includes about a hundred small tributaries and chaâbas (figure 4).

The basin contains nearly a third of the country's surface water (30 %) and can be subdivided from a hydrological point of view into four groups.[16] In addition to its surface water potential, the Sebou basin contains hydrogeological units that provide drinking water to a large part of urban and rural centers and the development of large irrigated areas, thereby contributing to the economic and social development of the basin.[17]

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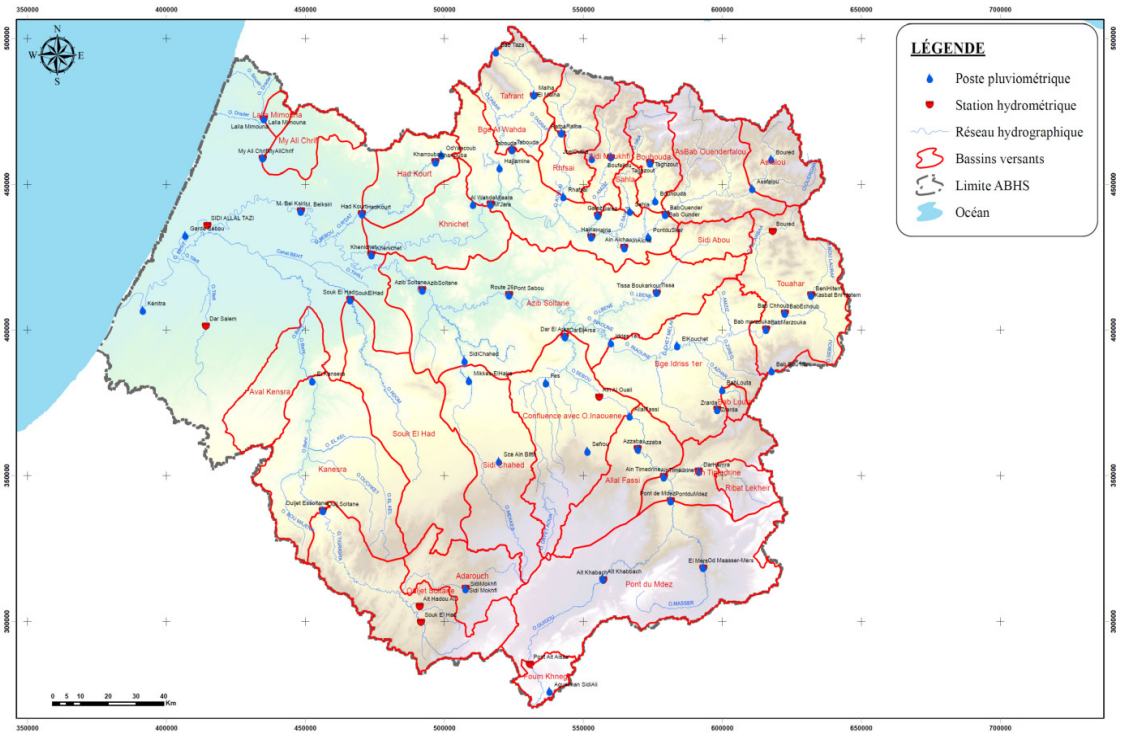

Figure 4. Hydrographic network and altitudes of the Bv de Sebou

Determination of flood zones in the city of Kenitra

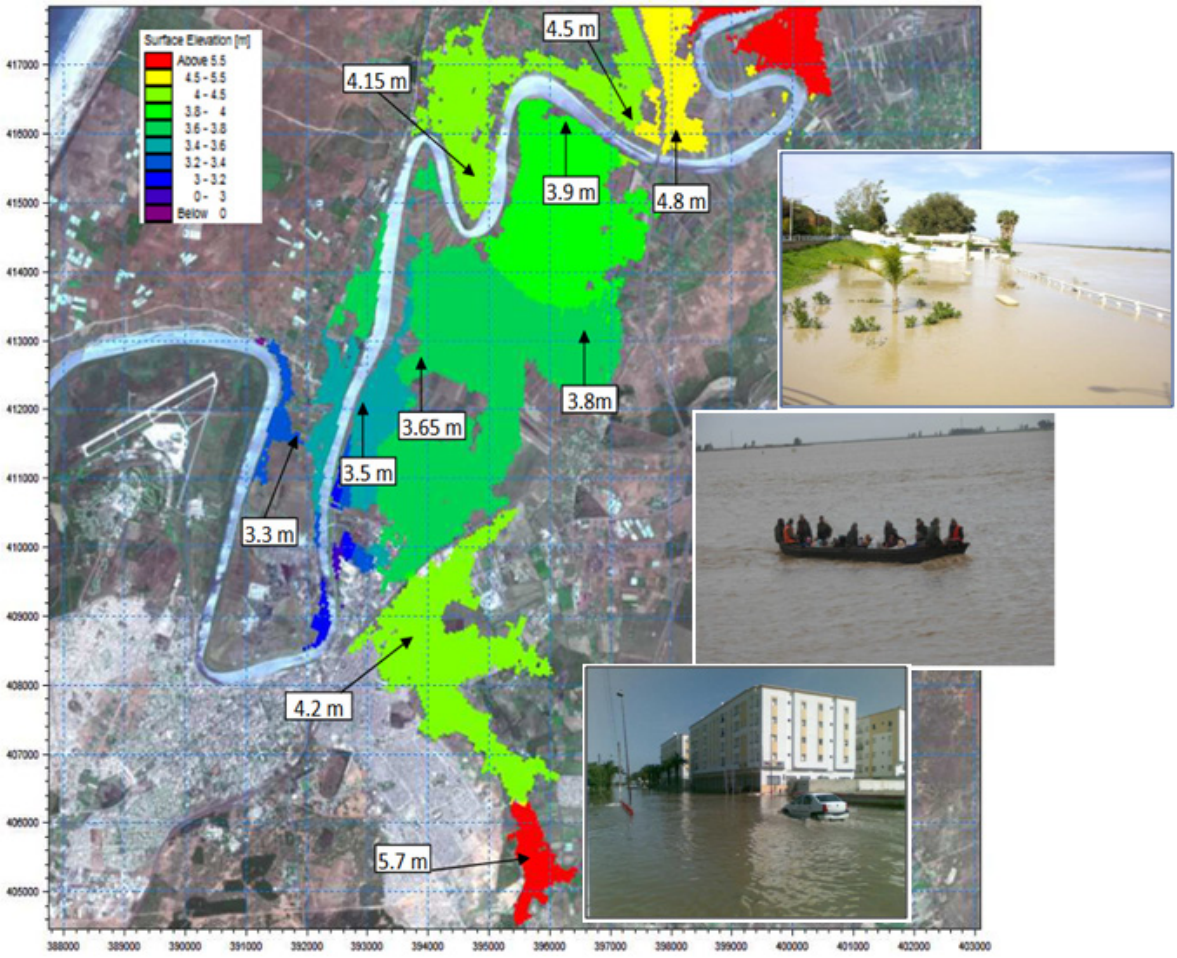

Figure 5. Areas submerged during the 2010 flood in Kenitra

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The Gharb has experienced severe flooding. The most devastating occurred in the years 1963, 1973, 1989, 1996, 2009 and 2010. These catastrophic events caused the flooding of several thousand hectares of agricultural land,[4] damaging infrastructure, the collapse of houses, the evacuation of several affected families and the submersion of homes for several days. They caused significant economic and social damage. In this regard, to determine the flood zones, we based ourselves on the field visit using the testimony of the population (historical approach) and the GPS to locate the flood overflow points. The results, which were thus illustrated in the map, show the flood zones. In this work, we only cite the remarkable floods in 2010 (figure 5).[18,19]

In terms of flood duration (20 days), 2010 was an exceptional year. This type of long-term flood occurs when the capacity of the hydraulic network (Oued, canals, chaâbas, etc.) is no longer sufficient for continuous rainfall and reaching the maximum level of the dams' filling capacity requires significant releases.

Morphometric data

The Oued Sebou has its source under Oued Guigou in the Middle Atlas at an altitude of 2030 m.[9] It flows for about 500 km before reaching its outlet in the Atlantic Ocean at Mehdia (province of Kenitra). This watercourse drains a large watershed with an area of about 40000 km^2.[4]

Showers in the city of Kenitra

The city of Kenitra is of the Mediterranean type. The graph showing the cumulative annual precipitation recorded by the M'nasra meteorological station located 5 km north of the city of Kenitra shows that these cumulative amounts vary between a minimum of 217 mm (2015/2016) and a maximum of 978 mm (1995/1996) (figure 6).

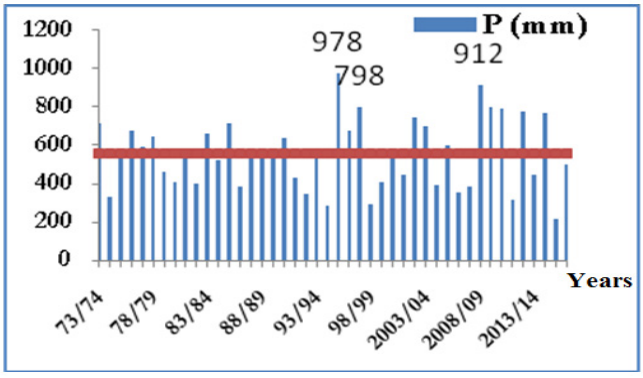

Figure 6. Cumulative average annual precipitation in mm - Mnasra station (period 1973/74-2016/17)[18]

Inter-annual monthly precipitation calculated over a period of 43 years (1973-2017) reveals that the hydrological year can be split into a wet zone extending from October to May where most of the precipitation occurred in December 105,7 mm and a dry season extending from June to September (figure 7).

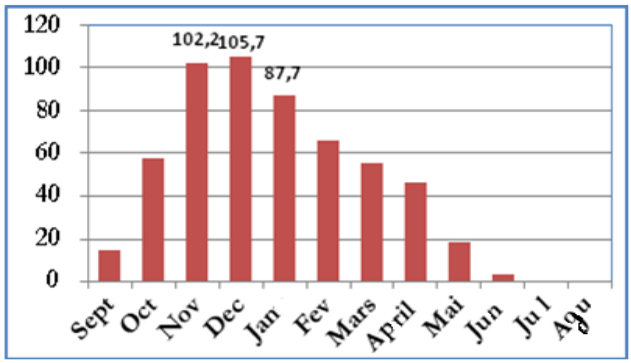

Figure 7. Average monthly precipitation in mm - Mnasra Station (period 1973/74-2016/17)[18]

The floods recorded from 26 to 30 November 2014 are short-term floods (with significant rainfall in a short period of time).[20] The overflows of the hydrographic network are punctual. These last floods have caused significant damage.

Flooding in maximum instantaneous flows

In terms of flood duration (20 days), the year 2009/2010 was exceptional. This type of long-term flood occurs when the capacities of the hydraulic network (wadi, canals, chaâbas, etc.) are no longer sufficient for

continuous rainfall and when reaching the maximum level of the dams' filling capacities requires significant releases.

Table A below shows the contributions in millions of m3, the dam flow and the durations of floods during the flood periods recorded in the Gharb plain.

Table 1. Inputs, dam flow and flood durations during flood periods recorded in the Gharb plain[12]

Year	1941	1950	1963	1970	1996	2009	2010
rainfall rate Mm^3	1530	1515	3167	5974	4850	5930	13970
flood periods (j)	5	2	7	16	-	-	20*
Dam flow m3/s	6000	8000	7000	6000	3000	5200	7000

The floods that occurred in February and March 2010 (14/02/2010 to 25/03/2010) are of the long-term flood type that occur when the capacities of the hydraulic network (Oued, canals, chaâbas, etc.) are no longer sufficient for continuous precipitation and the maximum level of the filling capacities of the dams is reached, requiring significant releases.

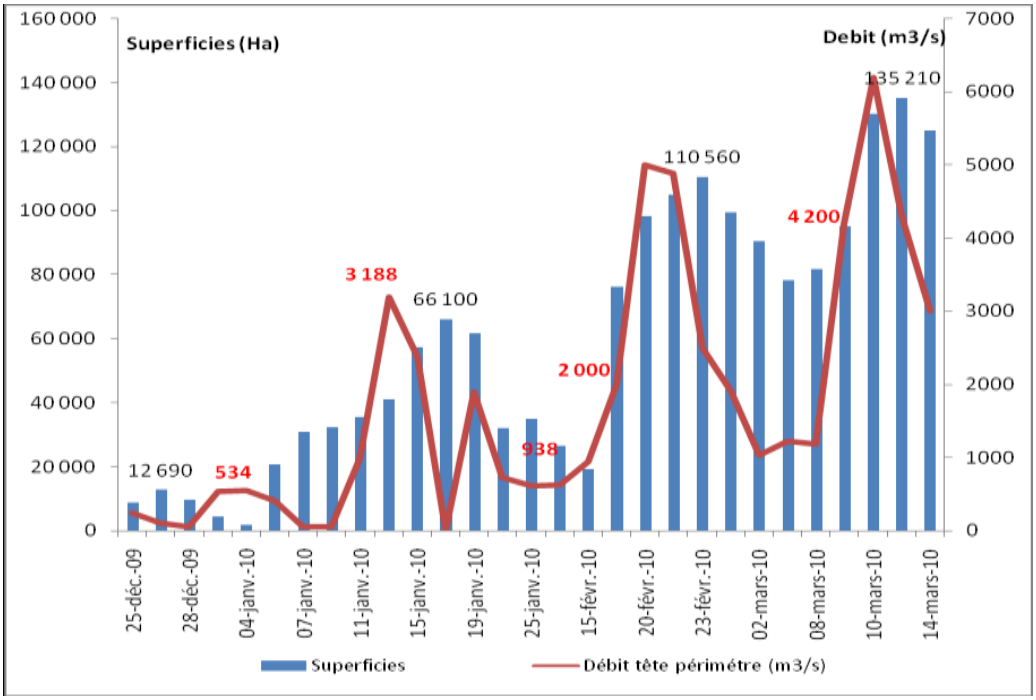

Figure 8. Evolution of flooded areas[18]

Hydraulic modeling of the main tributaries of Oued Sebou (Ouergha; Sebou; Beht and Rdat (470 km) and the main drainage channels of the Gharb plain (420 km) based on the 2010 flood made it possible to monitor the evolution of the flooded areas from 25/12/2009 to 14/03/2010 (figure 8) and on the other hand, to evaluate the flow rate of the Oued Sebou on its different sections and to understand the functioning of this hydrographic network and the overflow points, as well as the dynamics of the flows across the plain (figure 9).

According to the hydrographs established by the study of the master plan for the protection of the Gharb plain against floods,[4] the maximum flow rate at the entrance to the city of Kenitra (Center of the Gharb plain) was estimated at 2600 m3/s. The flow rate of the Oued at this level is around 1 600 m3/s. which explains the overflows recorded at the level of the left bank of the Oued Sebou, the dead arm of the Oued (North Merja sfassef, oulad Salma) and Merja Alwi. In the city of Kenitra and during the 2010 flood, the overflows of the Oued Sebou are observed just upstream of the highway, at the level of the dead arm of the oued and at the level of the power plant and the waters have returned towards Merja Fourate. They passed under the railway line to submerge the roadway at the entrance to the city. The Hmich district flooded by the return of water via the wastewater network (filling of the Al Fouarate canal and return of water to the sanitation network).

The analysis of the chronology of historical floods of the Oued Sebou highlighted that one to two major floods occur every 10 years.

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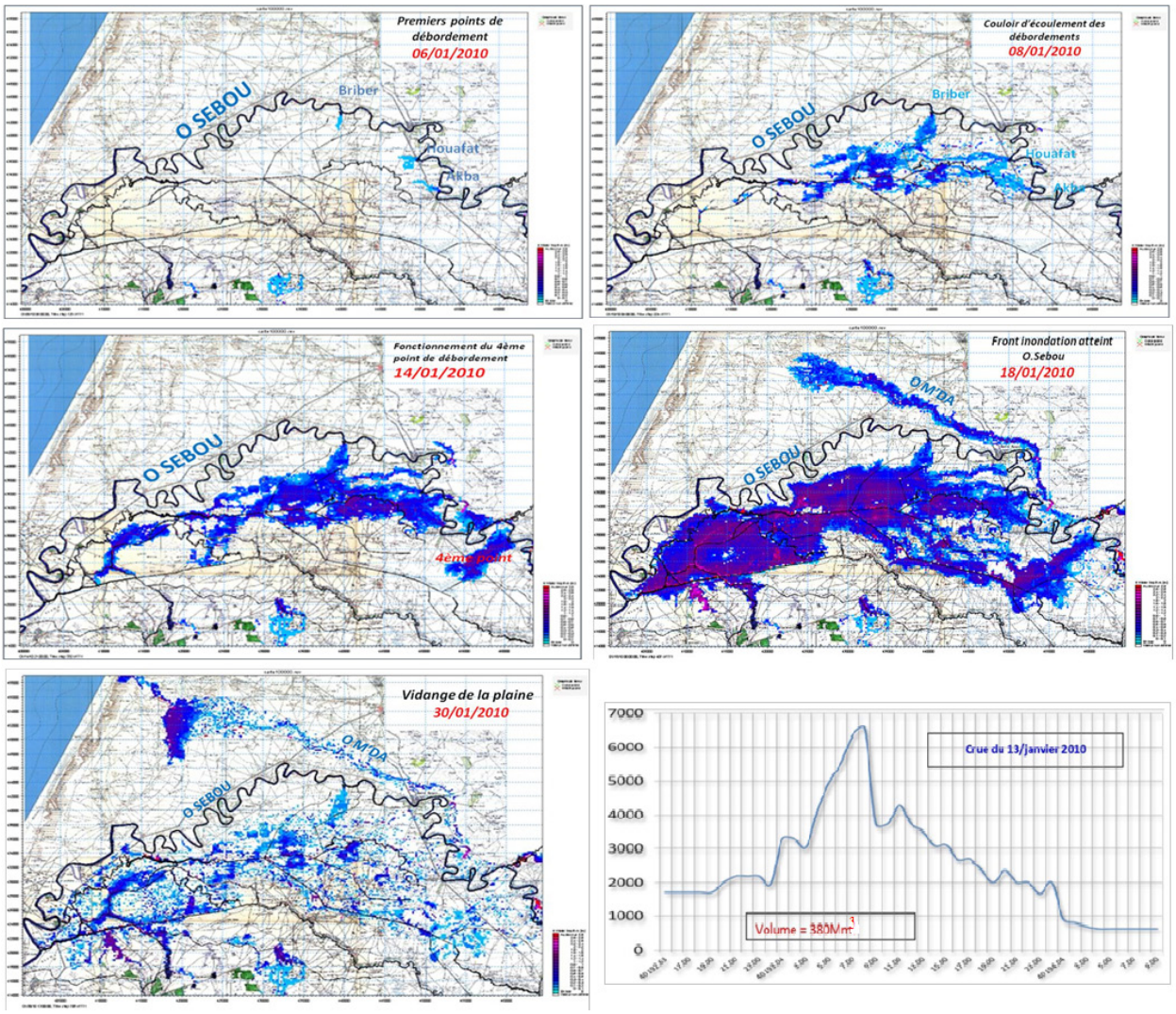

Figure 9. Simulation of floods in the Gharb plain (2010 flood)[12]

Anthropogenic factors and increased flood risk

During the flood in 2010, the flood control effects were low due to the insufficiency of the preliminary releases (figure 10).

He plain is the outlet of the Sebou basin (confluence of the Sebou, Ouergha, Beht and uncontrolled Oueds). The main causes of these floods, according to the damage assessment and assessment reports, can be summarized as follows:[20]

- The characteristics of the basin and hydrology, with the gentle slope of the Sebou Oued and the Gharb area, the regional disparity in precipitation, and the insufficient capacity of a channel.
- The lack of awareness of the need for the flood defense project.
- The insufficient cleaning of watercourses and the sanitation network.
- The urbanization of flood risk areas (flood sites, banks of Oueds, etc.).
- The undersizing of hydraulic structures and engineering structures and their dilapidation.
- Road and railway infrastructures that constitute a logjam modifying the beds of the watercourses and leading to overflows; they act as a threshold by causing a water retention that modifies the flow conditions.

The topography of the plain marked by low altitudes, its location downstream of the Sebou watershed; its complex hydraulic network, the vulnerability of the networks, buildings and infrastructures and its high rainfall.

The Oued Sebou and its tributaries therefore have a low transit capacity (siltation and very low slope). The water spreads into the plain through a number of overflow points located on the left and right banks of the Oued.

The presence of several Merjas in the plain (topographic depressions), evacuation through the sanitation channels (during the flood recession) and the impact of the tide on the flow (delayed emptying) are also aggravating factors.

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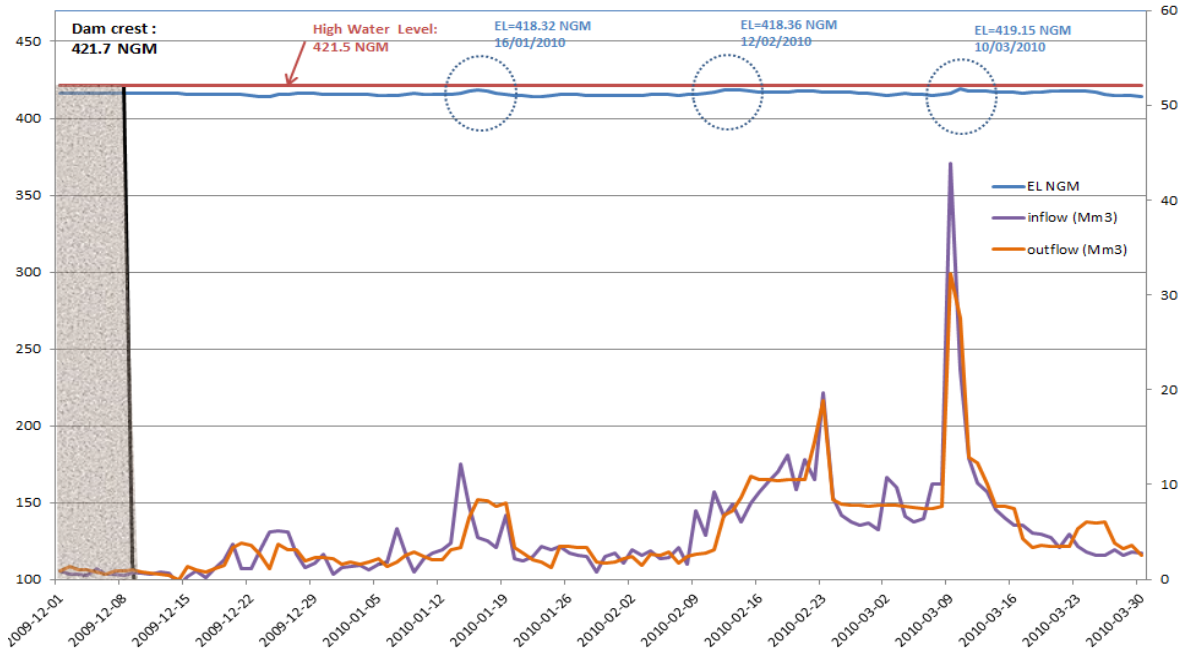

Figure 10. Water level, inputs & releases from the Al Wahda Dam[4] (at the mouth of the Sebou basin) in 2010[12]

Proposed solutions for the management and protection of the city of kenitra against flood risks

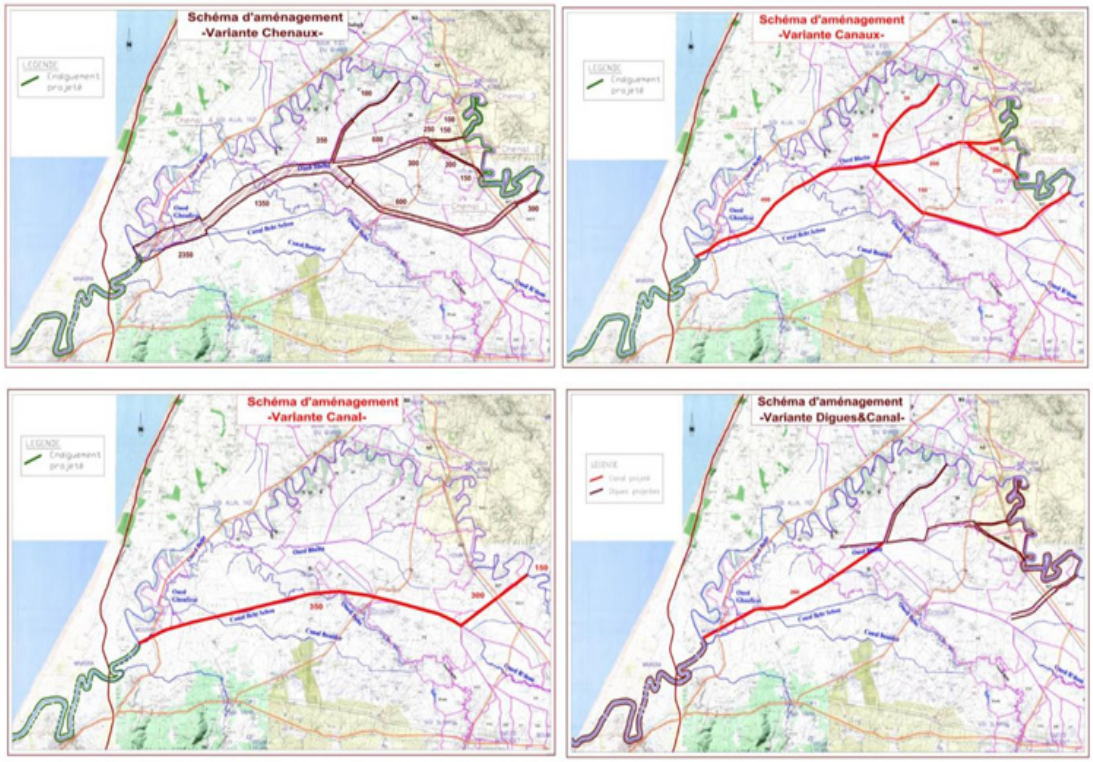

Figure 11. Proposed solutions for the protection of the Gharb plain against floods.[4] 1- channel variant, 2- canal variant, 3- canal variant, 4- dike and canal variant.[21]

Due to the hydraulic infrastructure it benefits from, the Sebou basin, which includes 10 large dams with a current total storage capacity of 5783 Mm3 and 44 small dams and hill lakes that provide indirect protection for the plain.[17]

Several flood protection studies for the main centers and cities in the Gharb plain and potentially affected by this natural hazard can be illustrated in this research.

The development plans for the direct protection of the plain aim to control overflows and mitigate the risk of flooding. Among which, we can cite:

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- Containment of the Oued Sebou: the operation consists of damming the Oued Sebou at the most sensitive overflow points by building dikes that run along the watercourse on both banks.
- Development plans corresponding to the "total control" of overflows: the aim of these developments is to regenerate the initial corridor of the Oued Sebou by building dikes or channels to convey the significant flows generated by the flows of the high basins from the first overflow points of the Sebou and intercept them downstream of Oued Sebou. These developments concern linear distances varying between 61 km and 110 km and will require significant costs between the works and the expropriation, and the adaptation to the irrigation network of the Gharb plain (rainwater drainage channels), to the road network and tracks (figure 11).[4]

Other non-structural measures are recommended by the Sebou Watershed Agency (ABHS), and are based on two components:

- Support for urban planning documents and investment projects to avoid any construction in flood zones.
- Implementation of warning systems to reduce the most dramatic consequences of flooding.
- Modernization of the flood warning system (Vigirisque project: see photos below, figure 12) by continuing to equip the flood warning stations with telemetry systems: 40 hydrological stations and 11 dams.
- Preventive management of dam reservoirs: Satisfying AEPI, irrigation and electricity production.

Construction of new dams, within the framework of the PNAEPI 2020-2027:

Figure 12. Images of the implementation of the vigirisque project

CONCLUSIONS

The deterministic and geo-historical modeling approach allowed us to define a framework for data collection as well as for spatial and temporal modeling. It allowed us to exploit and structure supports used by different actors (local authorities, researchers, Urban Agency, hydraulic agency and civil society ...), for this purpose a database was established.

In this study we have highlighted the importance of post-flood strategies in estimating damage on the urban level, road traffic and agricultural activity.

Indeed, all the factors that make the Rharb plain a vulnerable area and facing several natural challenges are: Climate change, Geomorphology with the very low altitude of the Gharb plain (depressions, Merjat ...), soils with too high clay content, as well as the lack of natural outlets for water drainage towards the Atlantic Ocean, with the exception of Oued Sebou.

We were able to delimit the flood zones at the level of the El Garb plain, particularly in the city of Kenitra, and establish a hydraulic modeling of the main tributaries of Oued Sebou and the main sanitation channels founded in the El Gharb plain. By following the history of the evolution of the flooded areas and by evaluating the flow rate of the Oued Sebou on its different sections, and with the identification of the overflow points, we were able to understand the functioning of this hydrographic network and the dynamics of the flows across the plain responsible for the floods. Among the solutions that were proposed: i) the containment of the Oued Sebou, at the level of the most sensitive overflow points, by building new dikes or channels to convey the significant flows generated by the watercourses of the upper basins from the first overflow points of Sebou and intercept them downstream of Oued Sebou. ii) raising the old dikes that run along urban areas, in order to protect the population from future floods iii) preserving and developing wetlands that have an important national ecological value such as the Merja Fouarat. iv) Taking into account buffer zones at high risk of emergence in future urban development plans.

Given that the estimated time for flood propagation is less than 10 hours, crisis management is required. Faced with this emergency, a flood warning system (Vigirisque project) has been installed. This will allow

real-time monitoring of water levels in Oued Sebou upstream of the city, so that public authorities can make decisions.

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Methodology: Ikram khadir.
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