

Floods And Floodings In The Sebou Watershed (Morocco) Between 1980-81/2013-14: Statistical And Mapping Approach

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Abstract:

The ultimate aim of the study is to examine the hydrological variability of flow causing floods, as well as its distribution in the Sebou watershed. It is also aimed at assessing the risks of flooding in the lower valley of the Sebou and its tributaries. In March 2010, flood caused significant financial and human damage. Eventually, it was necessary to determine the return periods of the extreme flows, and the importance of the floods in the watershed. Therefore, the study is based on the statistical approach to examine the instantaneous maximum flows. The results yielded that there is an increase in extreme flows in the stations studied, which gives rise to numerous floods in the Sebou watershed. In this regard, we have modelled the floods; then we selected the biggest flood -March 10th, 2010- in the Gharb plain using geographic information systems (ARC-GIS 10.2 and HEC-RAS 5.0.7). Therefore, the flooded area in the Gharb varies depending on the water ratio, the intensity of the flow and the topography of the plain.

Keywords: Sebou watershed, Floods, Gharb Plain, Flood risk, Statistical and cartographic approach.

LES CRUES ET LES INONDATIONS DANS LE BASSIN VERSANT DE SEBOU (MAROC) ENTRE 1980-81/2013-14: APPROCHE STATISTIQUE ET CARTOGRAPHIQUE

Résumé : L'objectif de cette étude est d'analyser la variabilité hydrologique de débit provoquant des crues, ainsi que sa distribution dans le bassin versant de Sebou afin d'apprécier les risques d'inondation dans la basse vallée de l'oued Sebou et de ses affluents. Alors que l'épisode de mars 2010 a été à l'origine d'importants dégâts matériels et humains ont laissé des séquelles sur les populations sinistrées, ce qui exige la détermination des

périodes de retour des débits extrêmes, et l'importance des crues dans le bassin. En effet, nous nous sommes basés sur l'approche statistique à travers l'étude des débits maximums instantanés. Les résultats obtenus indiquent une augmentation des débits extrêmes dans les stations étudiées, qui ont provoqué de nombreuses crues dans les sous-bassins de Sebou. À cet égard, nous avons modélisé la forte crue historique (10 mars 2010) dans la plaine du Gharb, en s'appuyant sur les outils des systèmes d'informations géographiques (ARC-GIS 10.2 et HEC-RAS 5.0.7). Par conséquent, la zone inondée dans le Gharb varie en fonction de rapport d'eau, de l'intensité du débit et la topographie de la plaine.

Mots clés : Bassin de Sebou, Crues, Plaine du Gharb, Risque d'inondation, Approche statistique et cartographique.

Introduction:

The latest report from the Intergovernmental Panel on Climate Change concludes that the planet's climate is undoubtedly warming rapidly, partly due to human activities (IPCC., 2007). In this context, Morocco is among the countries of the world which are influenced by the phenomena of flooding and hydrological intumescences, the repercussions of which are harmful on the economies of the countries. At the provincial level, Sebou watershed due to its climatic, topographic and lithological characteristics, monopolizes 29% of Morocco's water resources by draining a hydrological system marked by an irregular and torrential flow, mainly on the Rif chain, which causes harmful flooding in urban centers near the rivers, as well as the submersion of a large part of the Gharb plain (CHKHAMI. K., 2020 et CHKHAMI. K and all., 2021).

The geographical location of the watershed, the intense rain showers and the steep slopes of the mountain contribute to the predominance of the low retention of the shaly-marl substratum of the Rif and are the source of these extreme hydrological phenomena, namely floods and floodings.

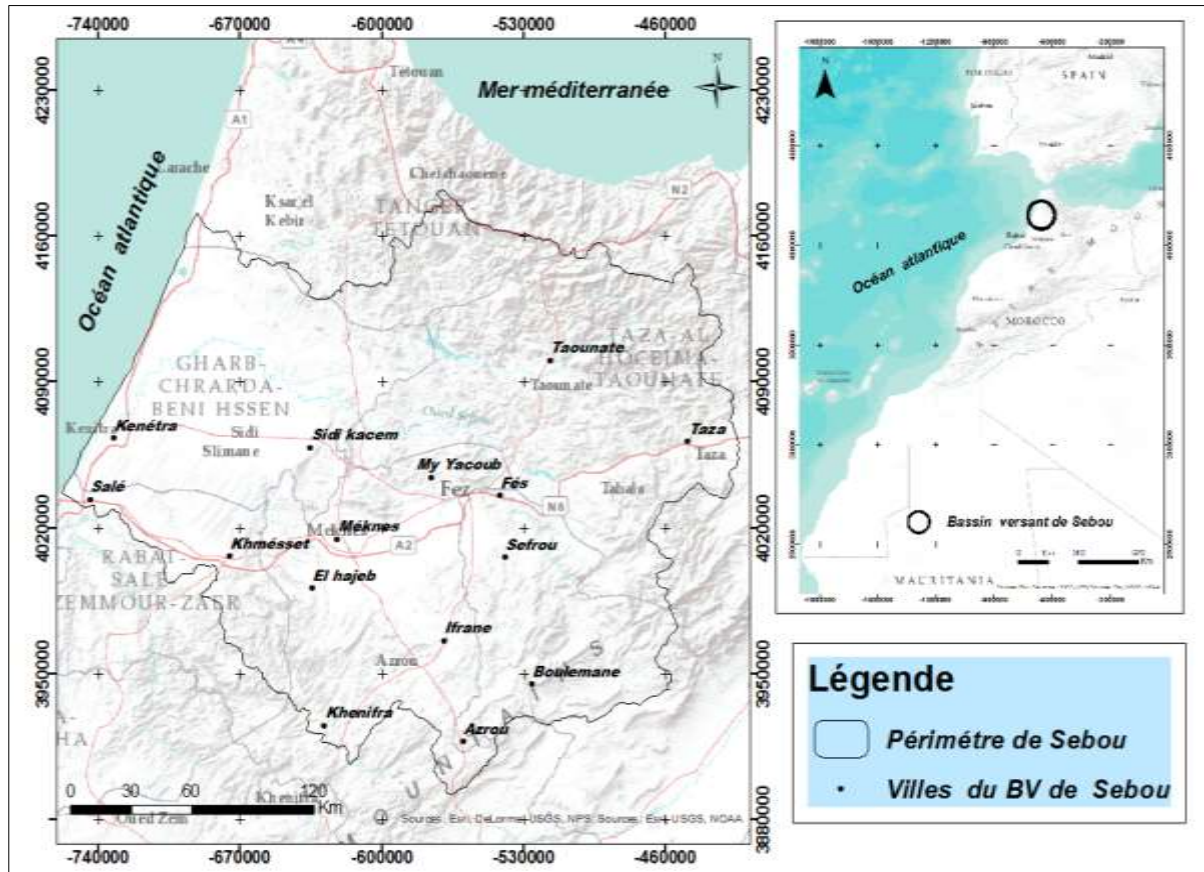
1. MATERIALS AND METHODS

1.1. Study area

The Sebou watershed occupies, in the northwest of Morocco, an area of 40,503 km², or about 5,5% of the national territory. Its limits fall between the meridian -3° and -6° West, and the 33° and 35th parallels to the North. It is limited to the north by the Loukkos watersheds and Mediterranean coastal watershed to the East by the Moulouya watershed, and to the south by the Bou-Reguereg

and Oum Er-Rabia watershed (AHBS., 2010 and 2011). The Sebou river begins 600 km upstream from the watershed. Its watercourse is subdivided into three sections: the High Sebou which takes its source in the Middle Atlas and then collects the water from the Inaouene and Beht river, the Middle Sebou joined by the Ouergha which is the most important tributary of the watershed and the lower Sebou which empties into the Atlantic Ocean (Gharb) (AHBS., 2010 and 2011).

Figure n°1. Geographical location of the Sebou watershed.



1.2. method applied

The study is based on a multidisciplinary method; it depends on a broad bibliographic reading that covers on the various issues related to the risks of floods. Then, studying the frequency of instantaneous flows allows us to know the maximum amount of flow that can occur once over durations defined as 2, 5, 10, 20, 25, 50 and 100 years. In this regard, we have used E-J. Gumbel's law which fits very well with these exceptional hydrological phenomena. This was applied using the graphic method (GUMBEL, E. J., 1957). Next, we tried to explain the meteorological causes which were at the origin of the flooding in the Sebou watershed. Finally, the data for the instantaneous maximum flood flows take from the files of the Sebou Hydraulic watershed Agency. These

flows are recorded at the levels of the 7 hydrological stations distributed over the entire northern part of the watershed. The observation period varies from 27 to 32 years (Table 1).

TABLE. n°1. Hydrological stations and observation period in the Sebou watershed (AHBS., 2015).

Stations	Statistical series	X	Y	Z
Azzaba	1980-81 /2011-12	559,95	359,57	478
Ain Aicha	1980-81 /2011-12	565,2	428,8	230
Bab Ouender	1980-81 /2006-07	559,5	440,1	312
Bab Marzouka	1980-81 /2006-07	615,85	400,85	368
Azibe Soltane	1980-81 /2006-07	492	413,9	45
M Belksiri	1980-81 /2011-12	448,25	441	16
O Soltane	1980-81 /2011-12	456,25	338,06	305

2. RESULTS AND DISCUSSIONS

2.1. The flood in the instantaneous maximum flows

The study of instantaneous flows is important for studying extreme hydrological cases (floods). Through the analysis of the data provided by the stations studied between 1980-81 and 2011-12, these hydrometric data allow us to make observations concerning the variation of instantaneous flows which can give an idea of the extreme flows during the years of strong hydraucity. These are considered to be years liable to flooding in the various rivers of the Sebou watershed:

- **In the High Sebou:** at the Azzaba station (1983-84/2011-12) contributes in a different way to the drainage system of the Sebou river. From the five-year level, we have a return period of 50 years, 1405,4m³/s. Likewise, if at the centennial level, we have a probability of reaching 1624,8m³/s. (CHKHAMI. K., 2020). This is from one hand, it is linked to West-North and North flows during the cold period and advection activities during the hot period (thunderstorms). On the other hand, it has to do with the karstic zone characterized by the permeabilization of geological formations and the regularization of flow during the cold season.

- **In the Inaouene River:** the Bab Marzouka station (1980-81/2006-07) is located in an intermediate zone between the Prérif and the Middle Atlas which contributes to a different way to the flow system of the river. At the five-year level, 1167,3m³/s can be recorded once (CHKHAMI. K and all., 2021). The Rif seems to be

the most generous part of the water supply. This is linked to the West-North and North flows. On the contrary, the Middle Atlas is a karst area characterized by the permeabilization of geological formations and the regularization of flow during the cold season. But the centennial flow at the station appears lower during the cold season, which affects $1336,8\text{m}^3/\text{s}$.

- **At the Ouergha River:** the frequencies and values corresponding to the return periods as shown in the table clearly indicate the superiority of the floods of Ain Aicha (1980-81/2010-11) and Bab Ouender (1980-81/2006-07) in the Ouergha watershed. From the five-year level, we have a return period of 5 years, $1614,9\text{ m}^3/\text{s}$ at Ain Aicha and $670,6\text{ m}^3/\text{s}$ at Bab Ouender. Likewise, at the five-year level, we have a probability that reached $3501,6\text{ m}^3/\text{s}$ in Ain Aicha and $1299,3\text{ m}^3/\text{s}$ in Bab Ouender. These latter values remain more or less than the maximum flood actually recorded at this tributary because indeed, the water volume of $4050,1\text{m}^3/\text{s}$ at Ain Aicha is almost a hundred-year flood, $4050,1\text{m}^3/\text{s}$ at Bab Ouender. The Rif appears to be the most productive part of the water supply and experiences higher return frequencies of flood values. This is linked to the sensitivity of the months to the rainfall supreme brought by West-North and North-West flows well loaded with Atlantic humidity. For example, we can say that the flood of December 18th, 1993: ($2260\text{m}^3/\text{s}$), December 24th, 1996: ($2176,02\text{ m}^3/\text{s}$) and of November 30th, 2011: ($2344,9\text{m}^3/\text{s}$) to Ain Aicha (CHKHAMI. K and JANATI IDRISSE. A., 2018).

- **In the Middle Sebou, Beht and Gharb,** the Azibe Soltane station (1980-81/2006-07) recorded a fairly high instantaneous flow at the five-year level, we have a return period of 5 years: $440,1\text{m}^3/\text{s}$ and a period of 50-year recurrence: $819,5\text{m}^3/\text{s}$ and a 100-year period: $929,8\text{m}^3/\text{s}$. The climatic situation in the Middle Sebou is characterized by the influence of continentality which leads to a decrease in rainfall. Even so, it is also influenced by disturbed North-west situations. Oueljet Soltane station (1990-91/2011-12) at the level of the Beht river, which originates from the Middle Atlas, contributes in a different way to the flow system of the river. At the five-year level, we can record an instantaneous flow of $916,5\text{m}^3/\text{s}$ and at the centenary level, the flow rises to $1025,5\text{m}^3/\text{s}$. The Middle Atlas is the most productive part of the water supply. This is linked to West-North and North flows and the specificity of the permeable karst zone regulates the flow during the cold season.

The instantaneous flow in the Gharb plain at the Mechrâa Belksiri station (1981-82/2011-12) appears to be very high because it is a collection area for water inflows from the watershed, which

contributes to the increase in the flow of the Sebou river at the level of the plain. The floods are more voluminous, and have a return period of 50 years is 2328,5 m³/s, the 100-year flood is higher equal to 2640,5 m³/s. The atmospheric situations dominated the Sebou watershed, the physiographic and hydrological elements contributed to flow at the level of the Mechrâa Belksiri station, during the winter seasons on January 02nd, 1987: (1690m³/s), on December 31st, 1995: (1214,47m³/s and on November 03rd, 2011: (1135,63m³/s). We can notice that the flow of the Sebou river at the level of the Azibe Soltane and Mechrâa Belksiri stations is frequently influenced by the operations of the Idris I and AL Wahda dam flow caps (JANATI IDRISSE. A., 2012 and CHKHAMI. K., 2020). Floods in instantaneous flows and their return probabilities are as follows:

TABLE. n°2: High flood of the Sebou river and its main tributaries.

Return time	2 years	5 years	10 years	20 years	50 years	100 years
Azzaba	294,1	650,3	886,2	1112,5	1405,4	1624,8
Ain Aicha	724,6	1614,9	2204,3	2769,8	3501,6	4050,1
Bab Ouender	374	670,6	867	1055,4	1299,3	1482
Bab Marzouka	309	584,2	766,4	941,1	1167,3	1336,8
Azibe Soltane	261	440,1	558,6	672,3	819,5	929,8
M Belksiri	748,7	1255,2	1590,5	1912,2	2328,5	2640,5
O Soltane	346,4	541,4	658,6	771	916,5	1025,5

2.2. The historical flood mapping of March 10th, 2010 in the Gharb plain and their hydro-meteorological genesis

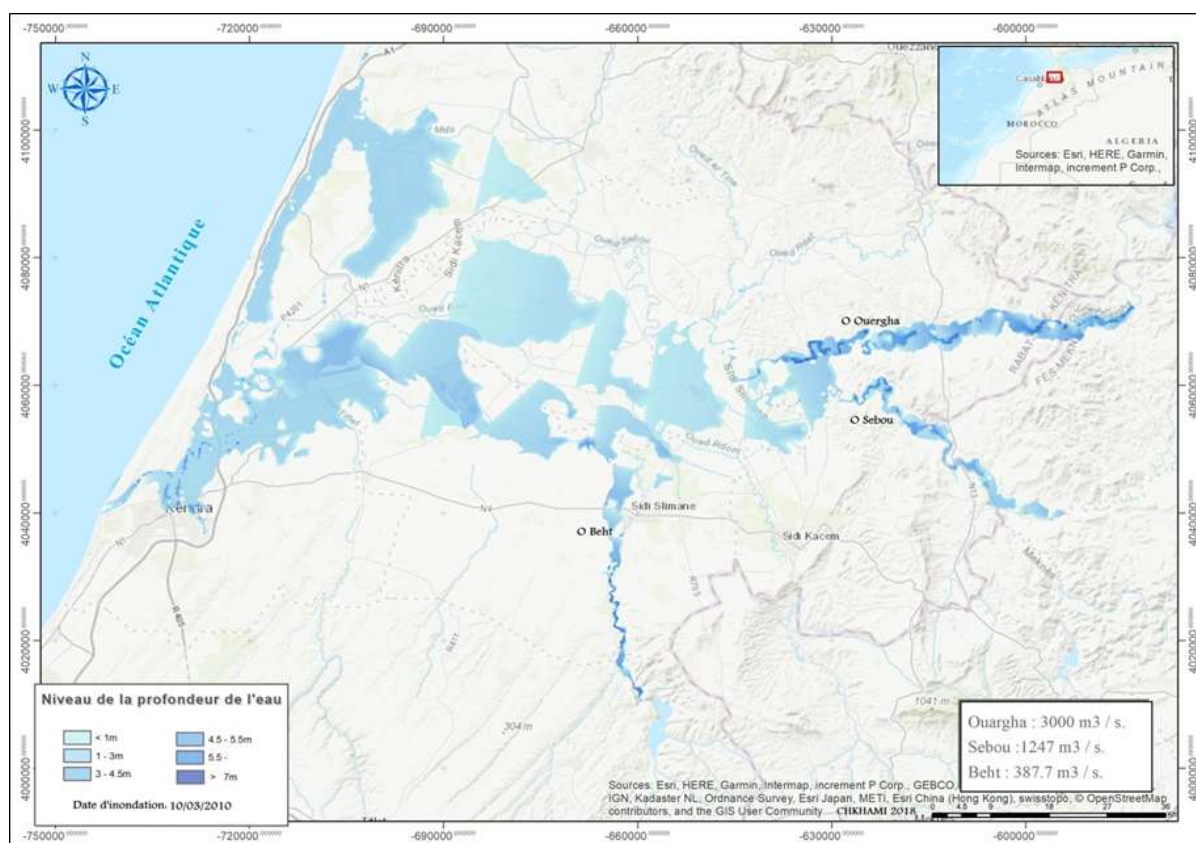
The flooding of the Gharb plain on March 10th, 2010 is one of the memorable hydrological cases in the Sebou watershed, given the inflow of water carried into the Gharb plain. Figure n°2 shows the extent of this exceptional hydro-climatological phenomenon. The atmospheric genesis of these floods can be explained by the origin of the humid North-west Atlantic air masses. The rainy situation installed in the Sebou watershed is linked to the presence at an altitude 500 hPa of a vast planetary valley formed by the subtropical jet, where the Atlantic depressions are forced to move towards Morocco because of the presence of a hot ridge located over Great Britain, supporting masses of warm air over northern Europe.

On March 07th, 2010, the low centred of Portugal (1000hPa) commanded cold and warm fronts which crossed Morocco in a northwest direction. Indeed, the rainfall exceptionality of this

hydrological year lies in a close alternation of wet meteorological situations throughout the winter season which saw more than 85% of the annual rainfall fall during a period from November 29th, 2009, to March 11th, 2010, that is, in three months and a few days. For example, in the Rif, it fell 1911mm at Ratba station, 1158mm at Galaz and 1110mm at Bab Ouender. However, in the Middle Atlas, the rains are less influx at the genesis of the floods in the Gharb by the contribution of the Rif domain. In this sense, we can cite the rainfall amounts recorded between March 06th and 10th, 2010, which are; 19mm in Ait Khabache and 38mm in Azzaba.

These rains, being more torrential in the mountain peaks of Sebou, in particular in the Rif, produced an excessive drainage of the Ouergha river. The daily flow of the Ouergha river flood gradually rose to 1127m³/s on September 03rd, 2010 at Ain Aicha station, 235m³/s at Galaz and 606m³/s at Tabouda. At the bottom of Ouergha, the flows at the entrance to the AL Wahda dam are obviously considerable due to the fact that we recorded an instantaneous high flow of 7000m³/s during this day (CHKHAMI. K et al., 2018 and JANATI IDRISSE. A., 2012). Thus, the flow responsible for the flooding of the Gharb plain on March 10th, 2010, and that released by the AL Wahda dam; 3000m³/s on the Ouergha river, 1247m³/s on the Sebou river and 188m³/s on Beht river. These coverings inundated the plain over a flooded area estimated at 253 800ha (CHKHAMI. K., 2021). From the map present, we observed within the Gharb plain that the height of the flow of the flood of March 10th, 2010 is very similar to the height of the spread of the flood of January 1963. The height of the water rises to more than 7m within the Ouergha river at Jorf El Melha and Khenichet. On the scale of the Sebou river, many regions are inundated; Laabiyate, Ouled Jerrar, Tekna and Mograne. For Beht river, the commune of Sidi Yahya is the most affected. In addition, this body of water varies between 1m and 3m in marshy areas (Merja) in the province of Kenitra-Sidi-Yahya (Dar Gueddari, Sidi Kamel, Allal Tazi, Tarchan and Lemnassera) and in the province of Sidi Kacem (Laabiyate and Khenichet) (BOUCHAIB. M., 2010 and MAGRANE. B., 2010).

Figure. n°2: Spatialization of historical floods (October 10th, 2010) in the Gharb (CHKHAMI. K., 2021).



Finally, the spread of the March 10th, 2010 flood becomes shallower and recedes to less than 1m in the highest areas of the plain, such as El Haouafate, Mechrâa Belksiri and Souk Larbaa du Gharb. These submersions are mainly owing to the strong overflow of the Sebou river and its tributaries (R'dom river, D'rader, M'da and Beht ...) from the breaches and meanders that characterize the main course of the Sebou within the plain.

CONCLUSION:

Climate change has a tremendous impact on floods of Sebou watershed. These hydrological phenomena appear only in the winter and spring seasons. Their characteristics and changes depend on the duration, intensity and spatial distribution of the rains as well as the state of the various reservoirs before the onset of the rains. Consequently, the Gharb plain remains the scene of this hydrological phenomenon, including the historic flooding of March 10th, 2010 in the plain, which allowed us to extract the water level from the Sebou, Ouargha, and Beht river. It also explains the spatial propagation of floods which has changed from one area to another depending on the topography of the Sebou river and its tributaries and the volume of water flowing in each section within the plain. Thus, the spatialization of flooded areas could be a tool for developing informative maps of historical hydrological phenomena, a database for the sustainable

management of the risk of flooding, and a cartographic support for decision-makers in the field of development and town planning.

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