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CHARACTERISTIC FEATURE OF THE FLOOD VULNERABILITY IN URBAN AREAS. CASE OF SKIKDA CITY (NORTH EAST ALGERIA)

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Abstract

Floods are incredibly dangerous and disruptive, and flooding is on the rise around the globe due to climate change. For these reasons, flood management will be one of the top challenges for communities around the world for the next half-century and beyond. This study is based on the knowledge of extreme hydrological mechanisms and a strong urban growth. It constitutes a first step towards a better management of the flood risk, in particular by the proposals materialized by documents in the form of cartographic tools as decision support. In this article, we'll provide a sky-high view of the configuration of the flood risk management solution through a new scientific approach by hydroclimate analysis. The study relied on the maximum daily rainfall data over an observation period of 47 years (1970-2017). The statistical treatment of the Maximum daily rainfall and short duration showers highlights the frequency values characterizing the intensity of rainfall representative of the study area. The peak flows were evaluated using the rational method and the Sokolovski flood hydrograph method. The objective of this study is to assess the flood risk in the city of Skikda by comparing the hazard and vulnerability and to propose cartographic tools to assist decision-making.
Keywords: Watershed, Peak flow, Flooding, Maximum rainfall, Risk, Skikda, Vulnerabilit.

1. Introduction

Today, floods are the first natural risk, they have at their origin meteorological-hydrological events that, because of their stochastic nature, are very difficult

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to predict in terms of their return period and their intensity. They are all the more feared when they occur in cities, where there is a high concentration of human activities. Floods represent more than 80% of the world’s natural disasters between 1996 and 2006 and were responsible for about 500,000 deaths and $600 billion in economic losses. In fact, they are the most spectacular natural disasters that produce the most damage (Klijn, 2008). As a result, economic activities are severely disrupted and the costs to society become exorbitant, hence the need to anticipate and prevent the return of these disasters. Algeria is classified at the plantar scale in the orange zone by more than 60 floods during the period 1974-2003. 2,470 floods have occurred internationally over the past 20 years (1989 and 2009). 147,457 people lost their lives and damage was estimated at US$ 372.5 billion (according to EM-DAT). Many cities in Algeria are confronted to the phenomena of floods that occur recurrently, thus constituting a major constraint for economic and social development. Climate change often intensified by aggravating factors (accelerated urbanization, occupation of flood-prone areas, sealing, deforestation, fires, failure of rainwater networks, etc.) have largely contributed to modifying the hydrological response of hydrographic systems, thus favoring the extent of anarchic runoff. Numerous works carried out to understand the functioning of hydrological systems and the anthropization of natural landscapes Ghachi, 2015; Oberlin, 1993; Behloul, 2009; Benjamin, 2004) deduce an increase in runoff and drainage caused by the transformation of undeveloped natural land into urban waterproofed land. On the other hand, cities have always practiced stormwater drainage and the protection against flood. What offers the particularity of the urban area is the active presence of the anthropogenic factor which by its activities, by the density of its constructions etc. increases the vulnerability of certain factors, including the population. As a result, the passage from the hazard stage to risk stage increases more quickly in time and space (Grecu, 2011). Another peculiarity is the pluri- and interdisciplinary nature of the genetic type of risks because in most cases risks, so-called natural, also have anthropogenic causes (Grecu, 2018). The flooding problem has given rise to numerous works on the assessment and management of flood risks in urban areas (Ghachi, 2015; Khaled and Amireche, 2021, Grelo, 2001). The empirical approach is to relate the characteristics extracted from flow chronicles to the geomorphological, hydrological and climatological characteristics of watersheds (Bishop and Church, 1992; Cemagref, 1986; Dingman, 1981; Liebscher, 1972). The models resulting from this approach are presented either in cartographic or mathematical form. For consistency, the same method was used and validated during modeling work at daily time steps (Perrin, 2000; Perrin et al., 2001, 2003), monthly and annually was adopted. The extreme economic importance of flood studies is largely explained by geographical considerations: areas of high urban concentrations are very often near rivers; the richest agricultural land is generally in the lower valleys (Laborde, 2000; Bujan, Veliz, Manzanares, 2004.). The stated objective is to manage risks in order to eliminate any possibility of disaster. However, the exceptional rainfall events recorded in recent years (Constantine, Skikda, Annaba, Bab el Oued, Ghardaïa, Bechar, Sidi Bel Abbes) have highlighted the importance to be given to the risk of flooding and to seek the natural and anthropic causes in order to limit losses. It is not to stop a flood but to reduce the risk and minimize the cost of damage. It has been estimated that in developing countries, more than 40% of the urban population is threatened directly or indirectly by natural phenomena likely to cause damage to people and property (Khaled and Amireche, 2021). This context corresponds well to what is observed, for example, in the agglomeration of Skikda where a strong demographic growth. The last decades have led to a rapid expansion of the city, resulting in the urbanization of areas exposed to flooding. The objective of this study is to assess the flood risk in the city of Skikda by comparing the hazard and vulnerability and to propose cartographic tools to assist decision-making.

Study area setting

The study area located in the humid Mediterranean zone between 6°54' and 36°35' N (Fig.1) Skikda is characterized by a rugged site surrounded to the north by the sea, to the south by land with high agricultural value, to the west by an accentuated orography and to the east by a large industrial zone.

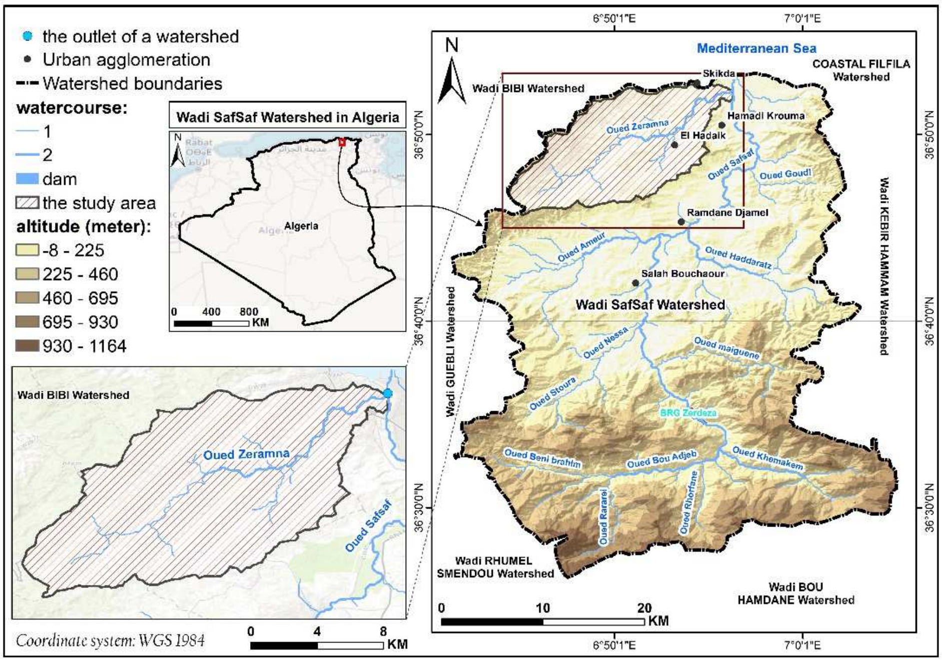

Figure 1. Situation of the semi-urban watershed studied

Due to its central location, the Algerian North East is subject to heavy rains, which generally occur between September and May. The damage to property is growing, in recent years in connection with the urbanization of flood-prone areas where the drainage systems are non-existent. The city has long been sheltered from rising waters because installed on the heights (city of Bouabaz, downtown, Brothers Bouhadja etc.). However, the urban growth difficult to control in recent decades has led to the use of flooding areas for construction purposes. This situation can only worsen in the coming years if there is no consideration of the flood risk in the current development plan. The choice of watersheds as a framework for the study was guided by the hydrological approach in order to evaluate the maximum flows of floods generating overflows without losing sight of the complex interaction between urbanization and the flood hazard.

2. Data and methods

The morphometric characteristics of the watersheds (wadi Saf-saf 03) and the data of maximum daily precipitation as well as rainfall (Skikda rain gauge), used in the determination of the flood flows, constitute the basis of this study. The statistical processing of the series of maximum daily rains (Pj max) using the Skikda pluviograph (code 03 08 01) with an observation period of 47 years (1970-2017) is considered to be representative of the study area.

– ***Morphometric parametric***

Morphometric parameters allow a better understanding of the reaction of the watersheds to hydropluviometric events. They present a relatively dense hydrographic network with steep to medium slopes, known for its rapid transmission of floods downstream during intense rainfall events.

– ***Maximum daily rainfall and showers.***

The study of maximum daily rainfall and rainfall intensity and their impacts on urban concentrations, reveal an increasing importance for the study of flood control projects. Expressed most often as Intensity-Duration-Frequency curves, they represent the probable maximum values of the related showers at different time intervals and provide useful values for the evaluation of extreme flows. The statistical treatment of the series of maximum daily rainfall at the Skikda rain gauge (code 03 08 01) with an observation period of 47 years (1970-2017) is considered representative of the study area.

– ***Calculation of the peak flow and the flood hydrograph Rational method***

The rational method is the most used empirical model in the world. It is based on the idea that the maximum runoff at the outlet of a watershed is obtained when the entire area of the watershed contributes to the flow.

– ***Calculating the intensity of rainfall***

The intensity of rainfall I(tc,T), observed during an equal time of concentration (TC) of watershed was evaluated using the relationship established for the Skikda region.

$$H(Tc, T) = Pjmax(T) . (tc/24)^{0.38}$$

In which: H (Tc, T): Height of precipitated water during a time equal to the time of concentration of the watershed in hour.
T: return period of the value calculated in years.
Pjmax (T): maximum daily rainfall of the same frequency T.

When the area is expressed in Km^2, the rain intensity in mm/h and the flow rate in m^3/s the rational method takes the form:

$$Q(t) = 0.278\ C\ I(tc,T)\ A$$

In which: Q(T): flow of the flood of frequency (T).
I(tc, T): rain intensity (mm/h) of frequency (T).
Tc: concentration time of the watershed.
A: Area of the watershed in Km^2.
C: runoff coefficient related to soil characteristics (slope, permeability, vegetation cover).

The layout of the Zeramna wadi

The flood vulnerability map was based on the DTM of the Skikda region. The use of the DTM in the ARC GIS software allowed to produce the contour lines and the hydrographic network (Fig. 2).

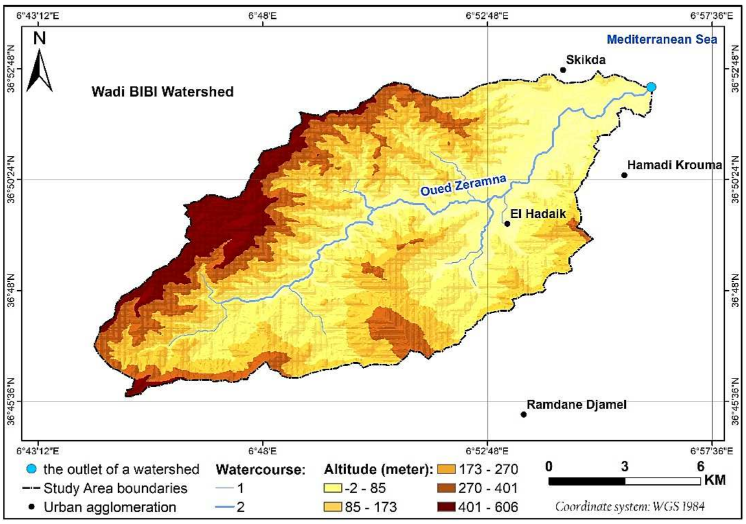

Figure 2. Hypsometric map watershed Wadi Zeramna

From the topographic map and the hydrographic network, the Zeramna wadi was traced using the HEC-GEO RAS tool in the software. ARC GIS. HEC-GEO RAS is the link between these two software.

3. Results

The Pj max series fits the Gumbel law correctly and gives the frequency values with the respective recurrence period summarized in Table 1.

Table 1

Maximum daily frequency rainfall values (mm) at the Skikda rain gauge

Return period T (year)	Frequency (F)	Gumbel's reduced variable	Rain height (mm)
2	0,5	0,37	50
5	0,8	1,5	72
10	0,9	2,25	87
20	0,95	2,97	101
50	0,98	3,902	119
100	0,99	4,6	133

Source: ANRH data. Processed and prepared by Ghachi, 2018

The short duration rainfall is obtained from the Pj max. according to the study of Body K.1981.According to the formula of Montanari and based on ANRH (National water resources agency) data, the relationship Intensity- Duration- Frequency (IDF) is of the form:

$$P_t = \text{Pj max\%}\ (t/24)^b$$

For the Skikda region, the climatic exponent b = 0.38 Table 2. summarizes the hourly intensities in mm/h for the different time steps and the respective return periods.

Table 2

Maximum average intensities (mm/h) for various time intervals Δt as a function of their return time T

Return period T (year)	Reference intervals Δt (in minutes)					
	15mn	**30mn**	**1h**	**2h**	**3h**	**6h**
2	35	23	15	10	7,5	5
10	61	40	26	17	13	8,5
50	84	55	36	23	18	12
100	94	61	40	26	20	13

Source: ANRH, ONA of Skikda + Personal contribution 2019

The Intensity-Duration-Frequency curves at the above-mentioned rain gauge were established. These curves make it possible to estimate the frequencies of exceedance F and return period T of the observed rainfall events generating flows from their durations and their intensities by graphic interpolation (Fig. 3), essential in the field of evacuation of the flows of protection project against floods.

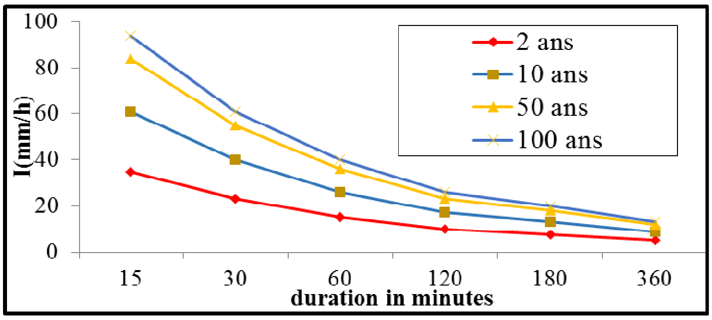

Figure 3. Intensity-Duration-Frequency (IDF) curves at the Skikda rain gauge

3.1. Generated flood flows

The catchment areas draining the outskirts of the city of Skikda and its extension area are characterized by rapid floods accentuated by anarchic urbanization whose consequences can be catastrophic. Table 3 summarizes the frequency intensity values calculated for different times of concentration (TC).

Table 3

Determination of rainfall intensity I (tc, T) in the watersheds studied

T(years)	Frequency	Pjmax(T)/mn	H(tc,T)/mn	I(tc,T)mn/h
Watershed of oued El Ouahch (Tc= 160mn)				
10	0,10	87	37,7	14,2
20	0,05	101	43,8	16,4
50	0,02	119	51,6	19,4
100	0,01	133	57,6	21,6
Watershed of oued Beni Malek (Tc=103mn)				
10	0,10	87	29,8	21
20	0,05	101	34,3	24
50	0,02	119	40,5	28,3
100	0,01	133	45,2	31,6
Watershed of oued Zeramna (Tc= 435mn)				
10	0,10	70	44,2	6,2
20	0,05	74	46,6	6,5
50	0,02	80	50,4	7
100	0,01	83	52,3	7,3

The maximum flows calculated for the return periods 10, 20, 50 and 100 are summarized in Table 4.

Table 4

Frequency flood flow in m^3/s (rational method)

Watershed	**Return period (T in years)**			
	10	**20**	**50**	**100**
Oued El Ouahch	8,9	10,2	12	13,4
Oued Beni Malek	10	11,5	13,6	15,2
Oued Zeramna	79	83	89,2	93

Source: A.Ghachi. 2019

The rational method remains very sensitive to the choice of the runoff coefficient. The latter seems to reflect the specificity of the basins studied which are lithologically impermeable. Added to this, an accelerated urbanization thus favoring the runoff more solicited in the calculations of urban networks where the artificial impermeabilization of the grounds is very obvious. The values of the peak flows obtained by the latter can characterize the flood hydrograph and evaluate the volume (V) produced. In the absence of flood hydrographs actually observed on the watercourses of wadis El Ouahch, Beni Malek and Zeramna, we used the method proposed by Sokolovski (1968), for the construction of flood hydrographs. This approach gives satisfactory results in the case of small watersheds. This author gives the flood hydrograph the shape of a curve, formed by two parabolas joined at the top of the flood hydrograph the shape of a curve, whose equations are the following: Synthetic flood hydrograph method (SOKOLOVSKI, 1968). Equation of the rise curve:

$$Q(t) = Qmax\ (t/tm)^m \text{ in } ^{m3/s}$$

Where: Q(t): flow at time t in hours after the beginning of the flood (m $^{3/s}$).

Qmax: maximum flood flow ($^{m3/s}$)

tm: time of rise of the flood in hours; the author recommends for the small basins tm=tc.

m: exponent of the parabola, m=2 (for small basins).

Equation of the recession curve:

$$Q(t) = Qmax. (td-t' /td)^{n} \text{ in } ^{m3/s}$$

Where: Q(t`): flow at time t` in hours, after the peak of the flood ($^{m3/s}$).
td: duration of the recession in hours, td = 2tm according to the author.
n: exponent of the parabola, for small watersheds the author recommends n=3.

The plot of the hydrograph allows to estimate the characteristics of the flood: shape, volume, rise time, t base time: Figures 4, 5, 6m illustrate correctly the flood hydrographs obtained in the watershed.

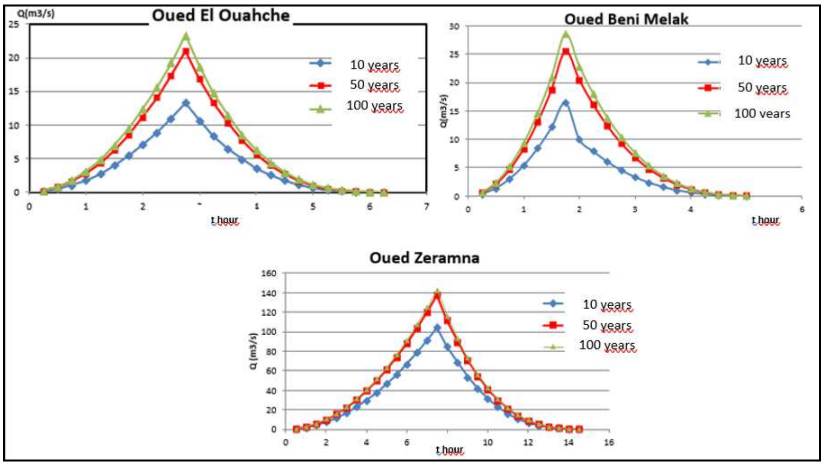

Figure. 4, 5, 6. Synthetic hydrographs of Oued El Ouahch, Oued Beni Malek and Oued Zeramna

The maximum flood volumes for a given frequency were calculated from the following relationship:

$$\mathbf{Vmax. (\%) = Qmax(\%). Tc/f\ (^{m3})}$$

Where: Qmax. (%): maximum flood flow for a given frequency ($^{m3/s}$)
Tc: concentration time (sec).
f: shape coefficient of the flood hydrograph, f = 1,2

Table 5

Values of flows and volumes of frequency flood adopted

Return period (year)	**Frequency of overrun (%)**	**Peak throughput (m3/s)**	**Flood volume (Hm3)**
Watershed of Oued El Ouahch			
10	10	10,25	0,084
50	2	13,95	0,115
100	1	15,55	0,128
Watershed of Oued Beni Malek			
10	10	12,5	0,065
50	2	17,25	0,090
100	1	19	0,099
Watershed of Oued Zeramna			
10	10	63	1,370
50	2	68	1,479
100	1	72	1,566

Source: Ghachi Azzedine 2019

3.2. Characteristics and floods genesis in the city of Skikda

Flooding by urban runoff. It occurs when the evacuation networks are no longer sufficient to absorb the volumes of rainwater generated, mainly due to runoff from new urbanized areas (Impermeabilized) upstream. **The flooding by overflow of** the Oued Zeramna. It is by far the main supplier because it is the collector of the urban sub-basins (O. El Ouahch and O. Beni Malek). It participates in 80% of the city's flooding. On the basis of the calculated frequent flows of the latter, an attempt to establish a map of vulnerability to flooding has been drafted for this city.

Numerical simulation of the flood of the Wadi Zeramna

The 100-year flood flow of Wadi Zeramna was used for the numerical simulation of the flood from the HEC-RAS software.

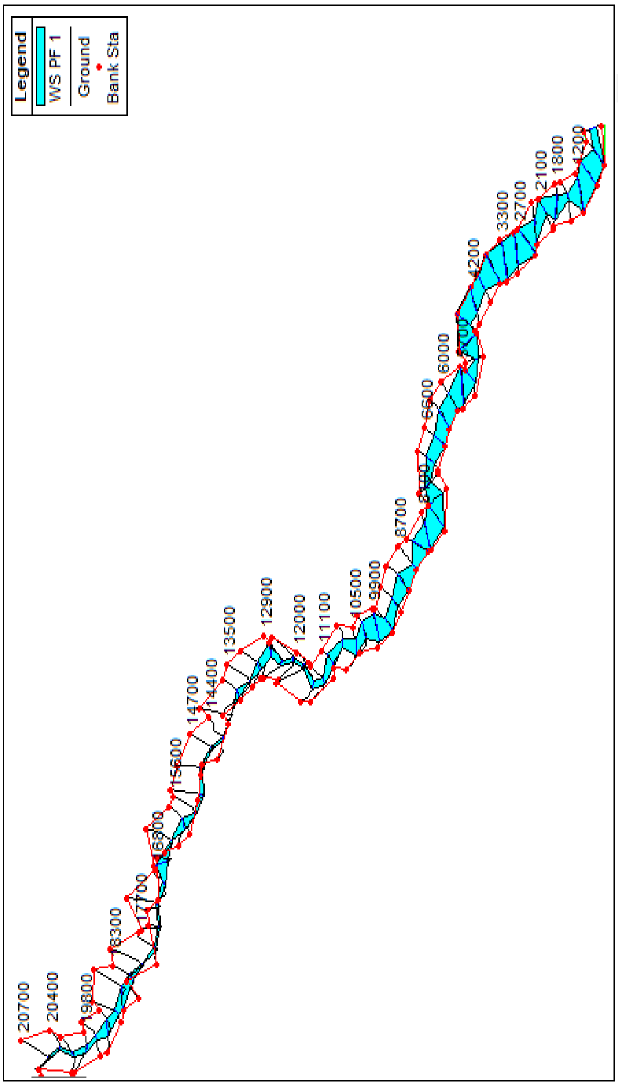

Figure 7. Numerical simulation of the centennial flood of the Wadi Zeramna

The latter is a simulation software of hydraulics in canals and wadis. Figure 7. Shows the result of the numerical simulation of the hundred-year flood of the Zeramna wadi for a flow of 93 m $^{3/s}$. In the same way, the operation was carried out for the ten-year and fifty-year floods (Fig. 8, 9, 10). The flood vulnerability map is created by exporting the HEC-RAS file to ARC-GIS software, which determines the slope and the flooded areas.

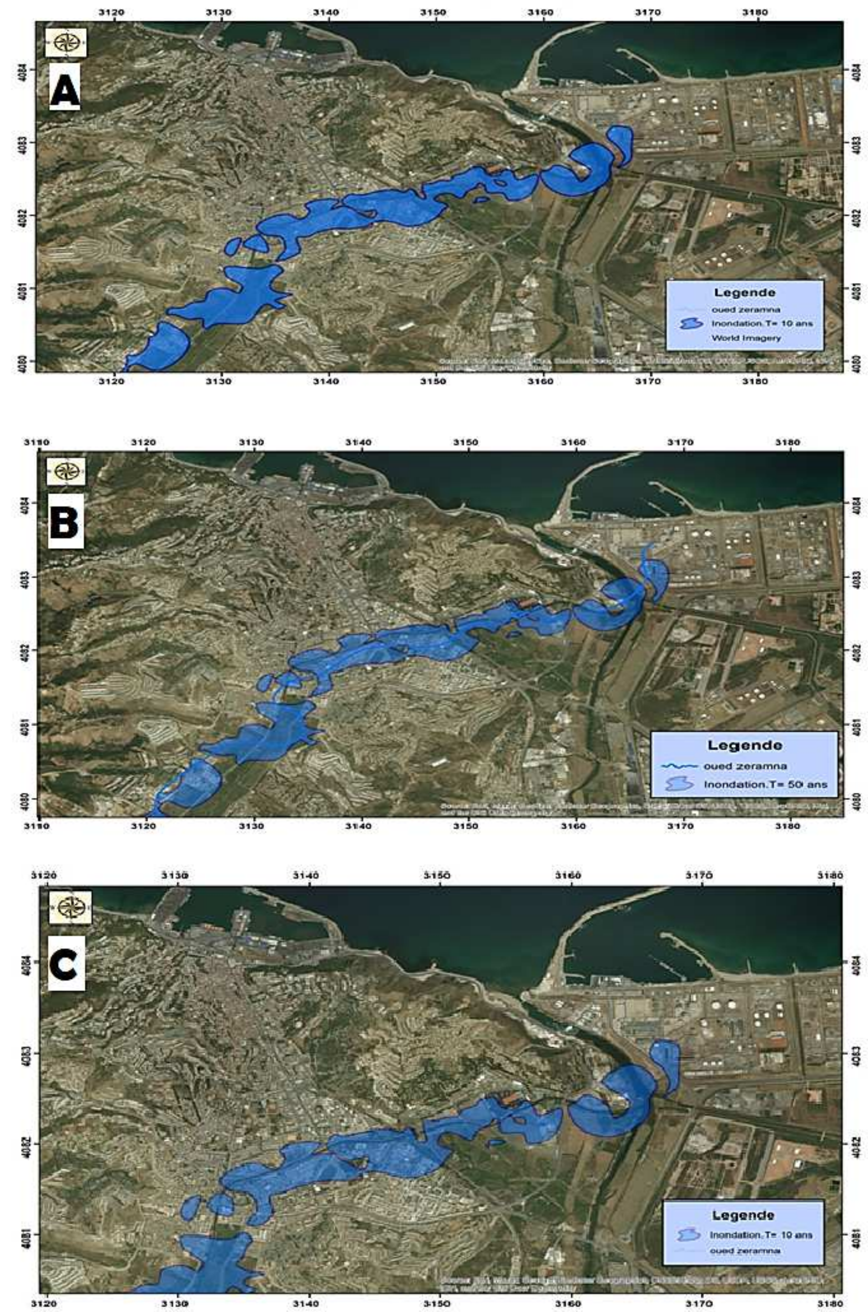

Figure. 8. Flood vulnerability map: A. Flood vulnerability map, Flood = 100 years; B. Flood vulnerability map, Flood = 50 years; C. Flood vulnerability map, Flood = 10 years

The maps show the flood zones for each return period. The decennial, 50-year and 100-year frequency floods correspond to flows of 79m^3/s, 89m^3/s and 93m^3/s. They submerge respectively surfaces of 3.72 Km^2, 3.89Km^2 and 3.92Km^2. In addition, Table 6 provides a historical overview of successive floods and an inventory of the damage incurred. It appears from this table that the main floods that affected the city of Skikda are mainly due to intense rainfall that generated maximum flows sometimes exceptional.

Table. 6

Historical overview of the floods and their impacts on the city of Skikda

Date	Recorded rainfall (mm)	Damage assessment
November 1957	173 mm in 24 h	Flooding of areas: El Hadaek – Skikda center – agricultural land Zeramna — height of submersion reached = 0.8 to 1m at the former Aerodrome.
January 1958	Exceptional rain 223 mm in 72h	The affected areas are the same as those of 1957.
February 1984	Heavy rains of 153 mm Water level reached at wadi Zeramna = 6.3 m	174 houses demolished – 500 families affected – heavily damaged agricultural land.
December 1984	111 mm in less than 24 hours	11 deaths – damaged basic infrastructure – collapsed buildings – 400 ha of agricultural land submerged – damage estimated at more than 5 billion at the time.
December 1990	92 mm in less than 15h	Overflow of the wadi Zeramna – flooding of the low-lying areas of the city.
November 2004	126 mm recorded on the eve of Eid El Fitr from 13 to 14 Nov.	Oued Zeramna overflow – Saf-saf wadi overflow – 100 homeless families – 219 affected families – 13 schools were closed.
February 2011	100 mm recorded between 2 and 3 Feb.	Overflow of wadi Zeramna – Flooding of cities: Merdj Dib – August 20th –saker brothers – El Adjour – Salah Boulekeroua.

Through this historical overview of floods, it appears that the hydrological risk was not sufficiently taken into consideration in the elaboration of successive urban developments since the city continued to develop on land of great flooding, thus causing a limitation to the infiltration capacity by accentuating the vulnerability factor.

4. Discussion

The «flood» phenomenon is widespread in Algeria. High vulnerability has been found in a wide range of countries where flooding remains one of the most dangerous and frequent disasters. (Khaled and Amireche, 2021). It is defined as the realization of a risk resulting from the concomitance of a hydrological hazard, and a vulnerability (land use and urbanization). Certainly, urbanization and flooding; a complex interaction. The natural vulnerability of the site, aggravated by inappropriate modes of urbanization, occupying wadi beds, added to the lack of protection, were then considered as the main causes of this event. (Daoud, 2010). Given the growing hydrometeorological risk such as flooding, scientists, politicians and managers have made it a priority. And the large number of works carried out in recent years in each of these disciplines attests to this. However, This requires interdisciplinary and intersectoral work whose main actors are the hydrologists, planners and managers of the city. (Khaled and Amireche, 2021). The study of natural hazards in Algeria has become an indispensable action in the management of urban spaces, Consideration of the various phenomena is currently providing an important basis for the development of regulatory arrangements for the prediction of natural hazards, in particular, ground movements, floods, etc. (Amireche and Benabas, 2010). It should be noted that new settlements and development in flood-prone areas contribute to densifying the already urbanized territories rather than expanding them, which increases vulnerability. Indeed, we can see that the majority of the victims of floods are inhabitants of cities, a large part of which are located near the rivers (Khaled and Amireche, 2021).

In recent decades, the Skikda population has been increasingly exposed to natural hazards such as flooding, which have caused damage to populations and their environments. The perception of the security of people and goods is constantly evolving and efforts to protect populations and economic issues are becoming more than necessary. The choice of the study area is based on the presence of the human stake downstream of the river for this, we chose Wadi Zeramna, which is among the largest rivers of Algeria and presents a very dense hydrographic network. Strong urbanization is present along the river, practically in its part swallows, made in a random way, and sometimes, without management or respect for the tools of planning and urban planning. Add to this the high frequency of historical events that occurred in this region, where there were almost ten floods in the past century.

This study has been made within the cities management and prevention from the risks of floods, it treats the taking into consideration the risks of space layouts, decreasing the vulnerability as well as determining of the risky areas, actually, making a studies model about risks (floods),in the watershed of " Wadi Zeramna " requires to study the parameters of the hydrogeology, the hydroclimatology and the morphology, an alternation between these aspects and the state of the urban management in the site will allow to make the zoning map of risks. Within these two approaches it is possible to distinguish different sensitivities: retrospectives constructed by the feedback of experiences, prospective aimed at the realization of diagnostics or risk scenario, diachronic or even dynamic studying the temporal evolution of vulnerability (Provitolo, 2002). The study of flood vulnerability of the city of Skikda illustrates the physical characteristics, hydropluviometric flooding and its human and economic issues. The extreme rains which are at the origin of the flood hazard have been used for the passage to the rain of short duration. From the Montanari formula, the probable maximum average intensities related to different time intervals were estimated at the level of the studied semi-urban catchment areas. Frequential peak flows were determined. The two empirical models used for the evaluation of the frequency peak flood discharge give relatively close results. The establishment of the synthetic hydrograph of Sokolovski flood of the Wadi Zeramna allowed to characterize the shape of the flood and its volume. The frequency contribution of the flood (T= 10; 50 and 100 years) is respectively estimated at 1.64 hm3; 1.77 hm3 and 1.88hm3. Based on the probable frequency values, a flood vulnerability mapping test was performed using the HEC-GEO RAS tool in ARC-GIS software. The 100-year, 50-year and 10-year flood discharge of wad Zeramna was used for the numerical simulation of the flood. The established maps show the floodable areas for different return periods on Google Earth image. The surfaces submerged by water are about 4 Km^2. This study based on the knowledge of extreme hydrological mechanisms and a strong urban growth, cannot solve alone the problem of flooding in Skikda. On the other hand, it constitutes a first step towards a better management of the flood risk, in particular by the proposals materialized by documents in the form of cartographic tools for decision support.

5. Conclusion

If the work of a hydrologist is summed up in the search for the distribution of rains in space and during time, the work of a city manager consists of an interpretation of the data in order to arrive at a theoretical and applied design aimed at the management of urban flood risk through well-defined tools and methods. Through this modest work, we have demonstrated that the cartography produced by the climate and hydrogeomorphological analysis makes it possible to have a global and homogeneous vision of flood fields on all the sectors treated by pointing to a first level, the areas most vulnerable to existing buildings and equipment. However, the information provided remains essentially qualitative, even if supplemented, where available, by historical data. In addition, to fully exploit the advantages of the management approach that we have followed, we need a cross-cutting approach for the integration of different levels and disciplines: urban planning, urban risks, hydrology, planning and mapping. The joint action of all these actors is necessary to implement concerted actions of integrated management of watersheds, covering its upstream and downstream part. Finally, as part of this research, we presented a tool to help authorities and deciders understand urban vulnerabilities to flooding. The purpose of which is to promote exchange, and to establish a language shared by actors and scientists to seek a consensus that can foster the construction of local resilience and allow an urban development integrating risk, an essential factor of sustainability.

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