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DEVELOPING A PROTECTION PLAN AGAINST THE RIVERINE FLOOD RISK IN URBAN AREA THE CASE OF SKIKDA (NORTH-EAST ALGERIA)

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RESUME

Due à son emplacement, la ville de Skikda reçoit un important écoulement de surface, en provenance d'un bassin de grandes aptitudes physio-géographiques et pluviométriques à la genèse et l'évolution des crues. En aval, ces crues se propagent sur des terrains de grande inondabilité, par conséquent, de larges terrains comportant des activités humaines, socioéconomiques et pétrochimiques sont pertinemment exposés aux risques d'inondation fluviale. Le retour d'expérience hydrologique a permis la délimitation des zones inondables, et l'élaboration d'un plan de protection qui, met en place des dispositifs de réduction des dommages grâce à un projet d'aménagement intégré, visant la maitrise des écoulements extrêmes au niveau du bassin versant, entant que zone d'alimentation en écoulement d'un coté, et d'un autre, l'atténuation de la submersion en milieu urbain grâce à une gestion efficiente de la plaine inondable.

Mots clés : Saf-Saf-Skikda-Aléa-Vulnérabilité-Inondation-Protection.

ABSTRACT

The hydrological hazard in the city of Skikda is particularly due to the combination of the physio-geographic characteristics of the basin, and the effect of the climatic circumstances, but the vulnerability to the flooding risk has increased following to the human interventions often irrational. The hydrological feedback represented by the exceptional flood of December 1984, has been served as a tool for the hazard quantifying and mapping, and also allowed the elaboration of a protection plan against the risk of flooding. This plan offers techniques and recommends measures in order to reducing damages, through controlling the hydrological extremes on the upstream, in parallel with the sustainable and efficient management of the floodplain on the downstream.

Key words: Saf-Saf-Skikda-Hazard-Vulnerability-Submersion-Protection.

INTRODUCTION

The Hydro-meteorological archive of the Saf-Saf basin and consequently the city of Skikda is particularly marked by a peak hydrology, which mainly translated into floods of sudden, violent and widespread features. For example, the floods of 1957 and December 1984 which were the most important hydrological events that affected all several areas in the Algerian north east. This article aims at understanding the flooding risk, focusing on the study of vulnerability, determining the hazard origins and delineating the flood zones, in order to develop a prevention plan against flooding. This plan would include proposals and recommendations as part of an integrated project, to reduce damages.

The exorheic basin of Saf-Saf belongs to the watersheds called "*Coastal Constantinians*" in the north eastern Algeria, it extends over 1150 km^2 of surface area, and its main water path is of 55 km of length and of south-north direction (Figure 1).

With approximately 225 000 people (The National Office of Statistics, NOS, 2008), the city of Skikda is an urban and a petrochemical pole including important technical infrastructures (Highways, railways and ports...), allowing it to play a major role in the national economy. The lower city of Skikda is located in the downstream of the basin in the vicinity of its outlet (Figure 2). It is drained by two water courts: wadi Saf-Saf in the east which divides the industrial zone into two parts, and wadi Zeramna that crosses the urban agglomeration in the west. During the flood season, the two streams submerge the bordering areas and cause serious damages, and this, reflects the high vulnerability to the flood risk in Skikda.

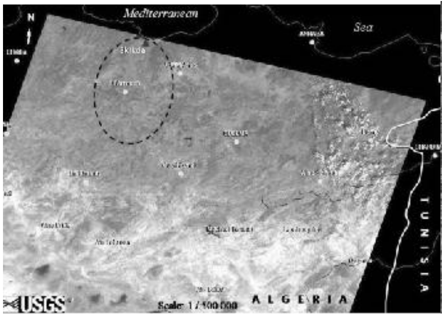

Figure 1: Geographical situation of the Saf-Saf basin in Algeria (*USGS global visualization*)

Figure 2: Situation of Skikda city with regard to Wadi Saf-Saf (Google earth, 2012)

VULNERABILITY TO THE RIVERINE FLOOD RISK

The Saf-Saf basin belongs to the humid and subhumid bioclimatic zone, where the wet season is characterized by torrential rains of high intensity. As result, frequent floods have affected the city of Skikda causing serious damages. The table 1 shows the most severe flooding recorded during the period 1973-1998, in the hydrometric station of *Khemakhem* related to the rainfalls of *Zardézas* post.

Table 1: The historical floods in the Saf-Saf basin, and contribution of rainfall (*Zardézas*) in the runoff (*Khemakhem*) during the period 1974-1998

Flood date	Flood peak flow (m^3/s)	Monthly rainfall (mm)	Daily rainfall (mm)	(B/A)	Daily runoff (mm)	Daily discharge coefficient (%)
		(A)	(B)		(C)	(C/B)
02.17.1975	23,51	120,8	69,5	58	6,31	9,08
02.03.1984	283,2	271,7	103,7	38	75,99	73,28
12.30.1984	**404**	**452,5**	**137,0**	**30**	**108,4**	**79,12**
12.21.1989	38	204,8	48,0	23	10,22	21,29
12.24.1991	47	169,5	51,5	30	12,82	24,89

The year 1984/85 was singled out by its record rainfall: annual, monthly and daily. In 10 days, the basin received a cumulative rainfall of 401.3 mm, which generating an exceptional peak flow 404 m^3/s (The national Agency of Water resources, ANRH). However, the floodplain received a much more important runoff; this overflow is difficult to drain and caused an extent submersion. The impacts were serious: human loss, destruction of buildings and infrastructures, flooding of the petrochemical industrial zone and isolation of Skikda for more than 10 days.

THE HYDROLOGICAL HAZARD NATURE

The hydrological hazard in the city of Skikda has a double origin: a natural one which is due to the watershed characteristics that encourage the surface runoff, and a human one resulting from the mismanagement of the urban areas.

The natural origin: important physiographic abilities to the surface runoff

Physically, the basin area is divided into two entities of contrasting features: as a zone of supplying runoff, the headwater offers favorable physio-geographical, climatic and morphometric terms to the surface runoff and flood genesis. This is due to the rugged relief which could be classified among the severe relief (Vertical drop = 400.15 m). The dominance of formations of low permeability (51.82%), added to the low cover of the perennial vegetation (31%), and also the dominance of lands with high slopes (68.62%), leads to the formation of dense water system (Drainage density = 3.39 km/km ^{2}) and especially, to an important capacity of the runoff mobilization (Concentration time = 6.56 h).
However, the floodplain is a Zone of receiving runoff because of its low slopes (less than 5%) and low permeability (Quaternary formations); which provides favorable circumstances for the overflowing and immersion.

The anthropogenic origin: Uncontrolled urbanization

Following the creation of the industrial zone in 1972, Skikda has become a national pole of the petrochemical industry. Consequently, it suffered a population growth mainly due to migration and rural depopulation (Table 2) and (Figure 3).

Table 2: Skikda tell 1992: urban expansion and demographic growth

Phase	Population	Occupied area (in hectares)
Before 1962	55 727	162,3
1962 – 1975	84 543	230
1975 – 1985	112 860	687,56
1985 – 1992	135 633	1085,52

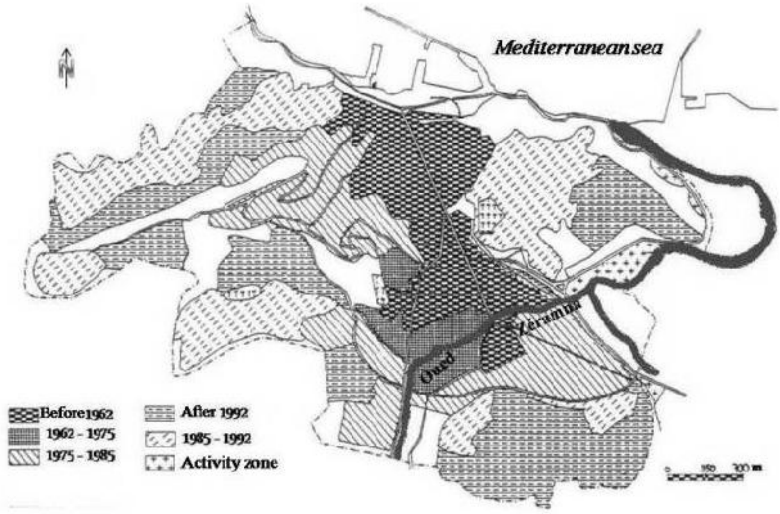

Figure 3: Phases of the urban extension of Skikda

To cope, the authorities have tolerated the construction on the floodplain, wadi Zeramna was cemented into a channel for sewage disposal (Figure 4), and these have reduced the infiltration capacity. Also, the construction of undersized bridges (Figure 5) can hinder the streamflow and causes submersion.

Figure 4: Construction on the floodplain of wadi Zeramna *(low water season)*

Figure 5: An undersized bridge over wadi Zeramna *(low water season)*

QUANTITATIVE AND SPATIAL ASSESSMENT OF THE HYDROLOGICAL HAZARD

Predetermination of flood flows

Due to the absence of a gauging station in the downstream, we used the rational method of *Turraza* to estimate peak flow values on return periods at the Saf-Saf basin and the wadi Zeramna sub-basin (Table 3). The *Turraza* method admits that the frequency of the peak flow is equal to the frequency of the maximum rain divided on the concentration time of the watershed, it has the convenient form:

$$Q\max_{f\%} = \frac{C * Rct_{f\%} * A}{3.6 * Ct} \quad (1)$$

- $Q\max_{f\%}$: The maximum instantaneous flood of the frequency F on (m^3/s).
- C : The discharge coefficient of the basin by the flood in question (for the same frequency).
- $Rct_{f\%}$: The maximum rainfall corresponding to the concentration time of the basin for a given frequency on (mm), given as:

$$Rct_{f\%} = Mdr_{f\%}\left(\frac{Ct}{24}\right)^{b} \quad (2)$$

- $Mdr_{f\%}$: The maximum daily rainfall calculated for the frequency F, given as:

$$Mdr_{f\%} = \frac{\overline{Mdr}}{\sqrt{cv^2+1}} e^{X * Ln\sqrt{cv^2+1}} \quad (3)$$

- $\overline{Mdr}$: The average of the maximal daily rainfalls on *El Harrouch* pluviometric post (1974/1998).
- X: The Gaussian random variable.
- cv : The coefficient of variation of the maximum daily rainfall series.
- *b*: The Climatic exponent of *Body*.
- Ct : The concentration time of the basin in (hour).
- A : The basin area on (km^2).

Table 3: Estimation of peak flows by the Turraza formula in Saf-Saf basin and Zeramna sub-basin

Basin	C	b	Ct (hour)	T (year)	Mdr $_{f\%}$ (mm)	Rct $_{f\%}$ (mm)	Qmax $_{f\%}$ (m^3/s)
Saf-Saf	0,5	0,40	14,57	10	80,6	66	726
	0,6			100	132	108	1425
Zeramna	0,5	0,40	6,08	10	80,6	46,5	121
	0,7			100	132	76,2	277,8

For the entire Saf-Saf basin, the centennial flood is estimated at 1425 m^3/s, an important value that can offer a total volume of 83.3 million cubic meters (obtained volume by applying the method of the unit hydrograph of *Sokolovsky*), the overflow affects the industrial zone especially the petrochemical sector located at the outlet. Otherwise, the sub-basin of wadi Zeramna produces a probable centennial flood estimated at 277.8 m^3/s; therefore, a total volume of 5 hm^3 that widely surpasses the drainage capacity of the water court and submerges vast urban areas.

Delineation of the flood zones in the city of Skikda

To identify the flooded areas, we used the hydraulic method of *Chezy - Manning* which considers that any flood flow Qmax (m^3/s) is related to the height H (meters), and submerges a wet section S (m^2). From the values of the flow through the channel (m^3/s), the topographic slope of the site (%) and the channel width (m), we obtained the submerged area (m²). We followed the following approach:

1. Realization of topographical surveys in sites that meet the homogeneity of slopes and type of obstacles on a few hundred meters (Figure 6), in order to extrapolate the results of calculation. Sites are wadi Zeramna and Saf-Saf before and after the confluence in the vicinity of the industrial zone (Figure 7).

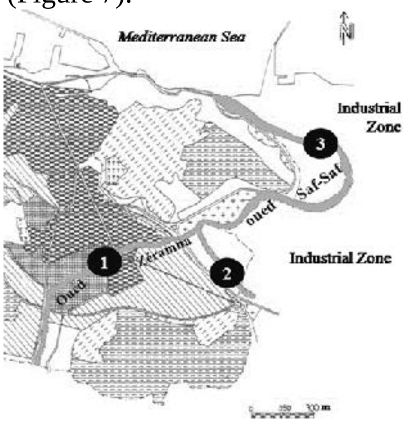

Figure 6: Sites of the topographical surveys

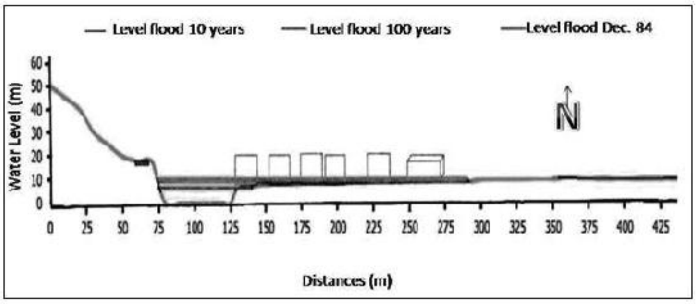

Figure 7: Wadi Saf-Saf in vicinity of the industrial zone: Cross section and levels of the probable peak flows

2. Determination of the maximum water level and the real flooded area during the flood of December 1984, to obtain the real flooded areas corresponding to the probable peak flows by the following relation: the real section (m^2) = C * Theoretical Section, where "C" is a correction factor representing the ratio: real flooded section (flood of Dec. 1984) per the theoretical section (flood of Dec. 1984), this one is calculated by *Canal-P* software.
3. Calculating of the flood zone areas corresponding to every probable flow.
4. By knowing the report between the three elements: peak flow, flooded area and the maximum water level, we obtain the spatial extent of floods, and can delineating the flood zones according to each return period (Table 4).

Table 4: Estimation of the flooded areas for different return periods in the floodplain of Skikda

Site	Flooded area (Dec. 1984)		Cc	Flooded area (Decennial flood)		Flooded area (Centennial flood)	
	R	T		T	R	T	R
	(1)	(2)	(3)=(1)/(2)	(4)	(5)=(3)*(4)	(6)	(7)=(3)*(6)
[1]	182	205	0,89	24	21	65	58
[2]	324	273	1,2	73	88	117	141
[3]	500	460	1,09	85	93	298	325

R: The Real flooded Area
T: The Theoretical Flooded Area
Cc: The Correction Coefficient

The highly exposed area to flooding risk is determined by the boundary of the centennial flood, it is a band of about 60 meters on each side of wadi Saf-Saf and Zeramna. The exposed area to flooding risk is a band that exceeds 150 meters is defined by the limit of the 1984. Most area in the city of Skikda is seriously exposed to the risk of flooding: streets of *Merdj Eddib*, *20 August 1955*, *Salah Boulkeroua*, *Frères Saker* and others, in addition to bridges, the national highway no. 3, local roads, the railway and the eastern part of the industrial zone (Figure 8).

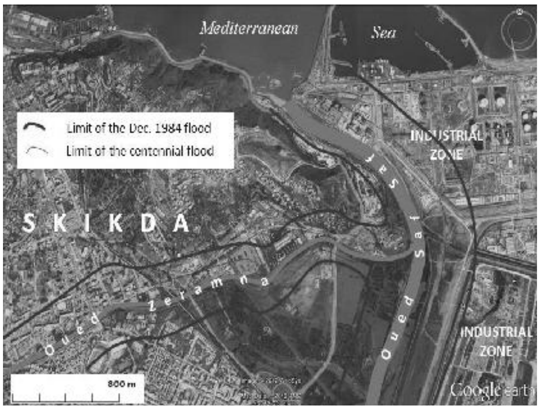

Figure 8: Delineation of the flood zones in Skikda

PROTECTION PLAN AND MEASURES FOR DAMAGES REDUCTION

On the watershed

This part includes the works of defense and soil restoration, which aim to stabilize the slopes through the attenuation of runoff and improvement of the infiltration capacity, the appropriate reforestation, installation of benches, spreader benches and torrent control. Also, the construction of a flood retention reservoir in the sub basin of wadi Zeramna is recommended, especially under the existence of the following conditions:

- Topographical conditions: presence of valley sites.
- Geological conditions: the dominance of the metamorphic formations (gneiss) ensures the stability of the dam.
- Hydrological conditions: the centennial flood flow 277.8 m^3/s offers a dam capacity of 5 hm^3.
- Bio-geographical conditions: the perennial plant cover (52%) attenuates the silting of the reservoir.

As shows the table 5, the basin was divided into zones; the nature of the actions to realize depends on the characteristics of every zone (Figure 9).

Table 5: Saf-Saf basin: the development proposals

Zone	Sub basin	Characteristic			Current land occupancy	Proposed development
		Slope (%)	Rainfall (mm)	Lithology		
A	Khemakhem	3-12,5	+ 640	Clay	Annual crops, fallow	Reforestation on benches v-shaped
B	B. Adjeb	12,5-25	600-620	Sandstone Marl		arboriculture on benches in cut slope
C	B. Adjeb	3-12,5	580-600	Flysch		Cereals on benches with double curvature
D	N'ssa	3-12,5	540-560	Marl Flysch		Cereals and forages on benches with double curvature
E	Maiguen	12,5-25	600-640	Flysch Marl		arboriculture on benches in cut slope
F	Ameur	3-12,5	540-640	Clay Marl Flysch		Cereals and fruit trees on benches single curvature
G	Haddaratz	0-25	600	Sandstone Limestone		Vineyard on benches in slope cut
H	Goudi	+ 25	600	Schist	Cork-oak, forests	Strengthening reforestation on spreader benches
I	Zéramna	+ 25	640	Gneiss		Strengthening reforestation and flood regularization reservoir

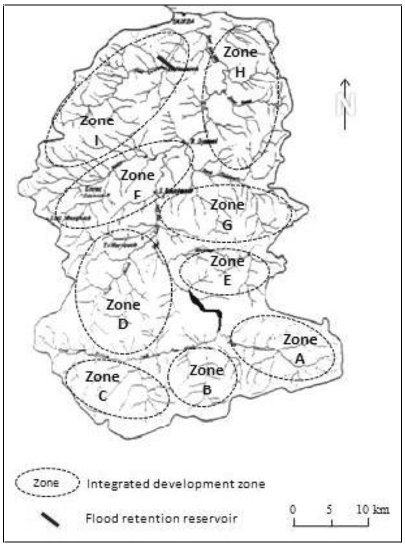

Figure 9: The proposed developments in the Saf-Saf basin

At the floodplain

Earthen dykes at the two sides of wadi Zeramna should be constructed to protect the streets of *August 20*, *Salah Boulkeroua*, *brothers Saker*, and *Timgad*. Another dyke on wadi Saf-Saf in the industrial zone is highly required (Figure 10). The construction of those dykes increases the water level and decreases their spatial extension (Table 6).

Table 6: Determination of dyke's heights in Skikda city and the industrial zone

Dyke's site	Flood	Flooded area (m²)	Water level before/After the dyke construction (m)		Dyke's height (m)
			Before	After	
Skikda city	F 0,99	36	4	4,6	10
	Dec. 84	74	4,8	9,5	
Industrial zone	F 0,99	173	6,5	7,5	5,5
	12/84	650	9,7	14,7	

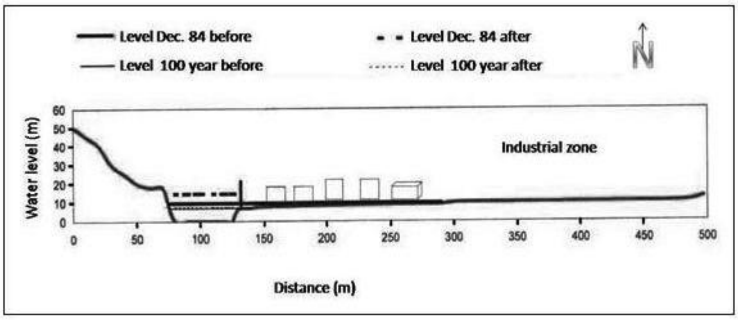

Figure 10: The Effect of dyke construction on flood levels in the industrial zone of Skikda

MANAGEMENT OF THE FLOOD RISK

The floodplain management

Regulating the floodplain use by limiting or, acquiring the flood areas by local authorities.

Flood forecasting: a trial of modeling

We tried to find the daily correlation rainfall-runoff for the same day during the period 1974-1999, to predict the flow resulting from its generating precipitation, a series of linear correlation rainfall-runoff is refined to obtain the significant correlation, the results are presented in the table 7.

Table 7: A trial of flood prediction in the Saf-Saf basin

Flood flow (m^3/s)	Daily rainfall (mm)	Couples (N)	Correlation coefficient (R)	Linear correlation equation
Qd max	Rd	70	0,72	Qd max = 1.66*Rd – 12.1
Qd max	Rd>10	56	0,79	Qd max = 1.96*Rd – 30.3
Qd max	Rd>20	39	0,82	Qd max = 2.34*Rd – 56.4
Qd max	Rd>30	28	0,85	Qd max = 2.55*Rd – 74
Qd max>10	Rd	47	0,73	Qd max = 1.70*Rd – 6.5
Qd max>20	Rd	34	0,75	Qd max = 1.80*Rd – 2.2
Qd max>30	Rd	17	0,86	Qd max = 1.99*Rd + 16.9
Qd max>30	Rd>30	11	**0,94**	Qd max = 2.56*Rd – 37.3

The most significant correlation coefficient is obtained for the values above 30 for rainfall and flow rates (R = 0.94), we can predict flood flows for a day according to the equation: Qmax = 2.56 * Rd - 37.3 (Figure 11).

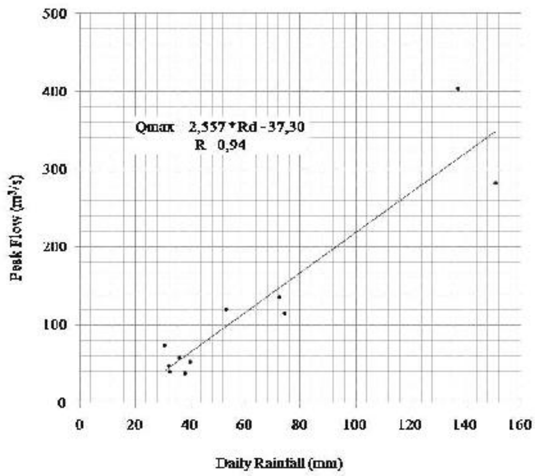

Figure 11: The linear correlation to values above 30: Qd max (*Khemakhem*)-Rd (*Zardézas*)

Installation of warning systems and public awareness

An early warning system is the warning of the population in case of floods. The prediction center must announce the flood warning at the beginning of the flood season in winter and spring, especially the months of December and March.

Legislation and insurance

Any construction in the flood zones should be prohibited (laws, decrees ...). Moreover, insurance of buildings and property against flooding should be mandatory, insurance cost depends on the level of risk exposure.

CONCLUSIONS

The vulnerability of Skikda city to the riverine flood risk is in close connection with its watershed characteristics but, this fragility has been amplified as result of the anthropogenic uncontrolled actions. In spite of the repeatability of peak hydrological events, Skikda is still undergoing floods impacts; recently, the floods of February 2011 have caused serious human and material damages touching the rural and urban spaces, in the absence of a sustainable plan of the watershed management.

To reduce flooding damages in Skikda, This work tried to propose an integrated management plan of three functions:

1) At a regional scale (basin), it is necessary to realize works of defense and land conservation, reforestation and torrent control to regularize the flow in order to reduce peak flood intensity. Also, the realization of a flood retention reservoir on wadi Zeramna can protect the western part of the city by limiting submersion.
2) At the local level (Skikda city and the industrial zone), the construction of dykes can reduce the riverine submersion.
3) The implementation of a flood prediction system is highly required. This system should involve local authorities, hydrometeorology services, media and especially citizens.

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