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Overview of Flood Risk Assessment of the Taza River Basin, Morocco

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ABSTRACT

The water resources of the Taza region are diverse and consist of important surface water and groundwater resources. The area is part of the most important groundwater reserves of Morocco. Recently, the region was prone to many flood events where remarkable fluctuations of rainfall and extreme climatic events have been observed. However, there is a lack of studies that cover the different hydrologic aspects of the area and especially, the extreme hydrologic events of the Taza River watershed in which the Taza city is located. To cover this lack, the current study presents an overview of the watershed, including geology, climatology, hydrogeology, geomorphology and especially hydrology. The study focused on the determination of the extreme hydrologic events related to extreme rainfall and streamflow to present basic data sets for further studies. Despite the data scarcity, complexity and the intricate river drainage network of the region, we were able to represent the main hydrologic aspect of the watershed and understand and predicting the system behavior. It was found that the area can be prone to flood risk because of the high flow rates that were calculated using meteorological and hydrological models. In addition, it was found that the basin land use affects directly the hydrodynamic of the river and thus, influence the flood magnitude. The study provides valuable information for understanding the watershed hydrology with a detail never presented before for the study area, where researchers and decision makers can benefit from the outcomes of the study and carry out further assessing the resilience of the watershed to anthropogenic pressure and climate change.

Key words: Hydrology overview, urban watershed, extreme hydrologic events, Morocco

INTRODUCTION

Estimation of the water resources and their availability is one of prime importance. There is currently, an increasing effort for studying the different aspect of the Taza watershed hydrologic system. The analysis of this system is basic to the planning, design and operation of water resource systems. Though, the scope of analysis varies according to local or global strategies, the principles of analysis remain the same. In many parts of the world, watersheds are not well assessed. This is true, even for developed countries, where the gauging network has continued to decline as, a result of the lack of human and financial resources (Mazvimavi, 2003). In Morocco, especially in arid and semi-arid areas, there are many difficulties to assess the different aspect of water quantity and therefore, propose a multipurpose project including; water supply, flood plain management, irrigation and drainage, water quality, etc. The effort to make an overview of these aspects seems of great importance, especially, where there is a lack of studies covering the major aspect of water resources. The region of Taza is one of many parts of Morocco that suffers from the lack of studies assessing its hydrologic system. In addition, the risk assessment of extreme floods has always been an important issue for the development of the urban watershed of Taza River, because of the concentration of human activities and major thorough fares in this valley. Many times the river overflows its banks and the water covers wide areas. Downstream areas are often affected, even when, they did not receive much rain. This is due to the fact that the south part of the basin is highlands and receives much rain than the north part, which is a plain area. An estimation of water volumes that can flow in the river during extreme rains can help to understand the occurrence of floods and provide valuable data sets for further studies like hydraulic modeling.

Despite the data scarcity, complexity and the intricate river drainage network of the region, there was some studies that tried to study water quality and quantity (Zemzami, 2008; Abbou *et al*., 2013; Layan, 2014). However, there were few studies that focused on the climatic and hydrologic aspects of the area. In addition, there is a lack of hydrologic data that can be used for practical purposes. The hydraulic modeling, which is necessary for any flood management of the urban watershed of Taza can not be applied in the current situation, because of the lack of hydraulic inputs. However, Layan (2014) and Zemzami (2008) tried to calculate the extreme floods, which are the main inputs for hydraulic modeling, based on the available data. The results were a somewhat similar.

The current study was carried out on the Taza River watershed and aims to present an overview of the watershed hydrology. The purpose of the study is to present useful information for management and planning of human activity and the hydrologic system (risk management, human's impacts, etc.). The study was also focused on the calculation of the hydrologic extreme events that can occur in the area. A combination of climatic and hydrologic models was used to extract with accuracy the design floods of different return periods.

MATERIALS AND METHODS

Study site: The province of Taza belongs administratively to the region of Taza-Al Hoceima-Taounate. It covers an area of 14,408 km^2. It borders to the north the provinces of Al Hoceima and Nador, to the west the Wilaya of Fez and the province of Tauonate, to the east the Wilaya of Oujda and to the South the Province of Boulemane (Fig. 1).

The current study was carried out in the Taza River Basin, which is located in the north of Morocco. The watershed is located in the transition zone between the Middle Atlas plateaus and the southern part of Rif Mountains. The Taza River flows from the South to the North. The urban valley, which crosses the capital city of the province, is a remarkable area for its landscape and its proximity to the city center. It is indeed a good site for the installation of a future park or a parceling project. The left bank is currently occupied by crop fields and weeds land, while a number of houses occupy the right bank. The path that follows the river presents a risk for the actual urban watershed banks.

Geologic setting: The Taza River basin is in the transition zone between the Middle Atlas plateaus and southern part of Rif Mountains. The southern Rifan Sillon, in the North, is considered as a corridor, corresponding to an elongated depression in the EW direction. It extends west to the Atlantic Ocean and to the east, to the plain of Guercif. The Middle Atlas plateau, located in the South, is elongated in the NE-SW direction, parallel to the main structures of this mountain chain. Figure 2 presents the geologic map of the Taza River watershed. The Triassic Middle Atlas rocks present generally, the combination of three terms: Detritic and clay-salt rocks in the base, basalt

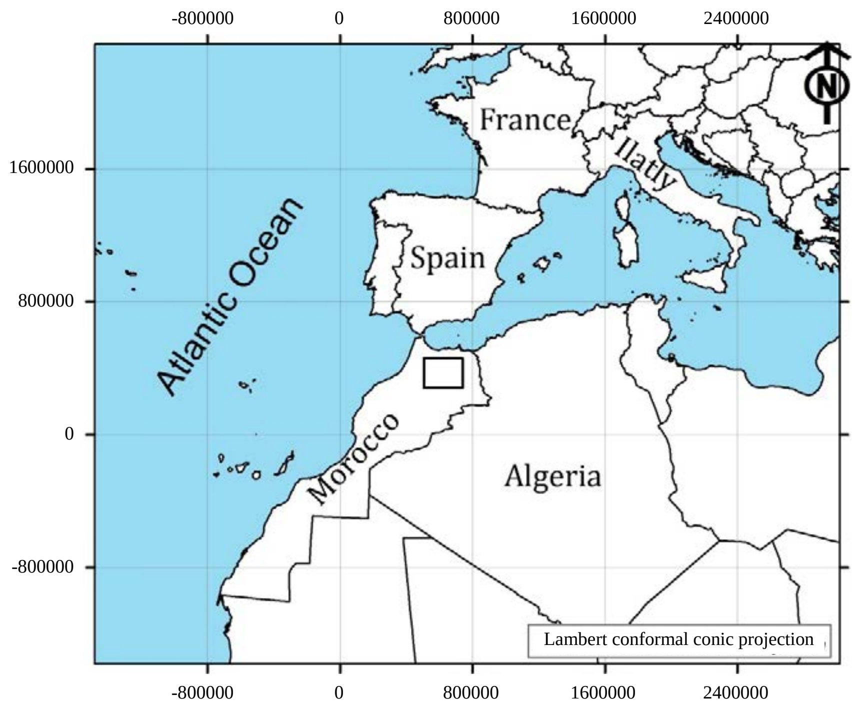

Fig. 1: Location of the study area

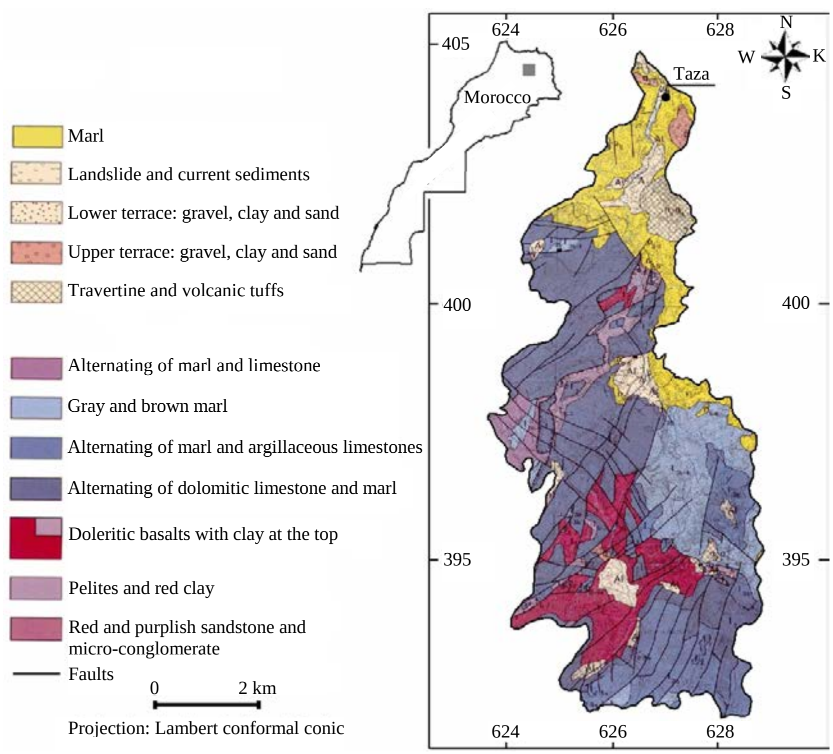

Fig. 2: Geologic map of the Taza watershed (extracted from the geological of Morocco 1/1000000)

in the middle and clay-salt on the top. The limestone and dolomite of Lias are widely present in the watershed, where a karstic network was developed (Robillard, 1978). The Miocene deposits of the South Rifain Sillon are organized in two sedimentary units (Cirac, 1985). Sandstones and calcareous marl well developed in the southern borders of the corridor. Quaternary deposits are represented mainly by fluvial deposits, Terra Rossa and travertine rocks.

The lithology of the Taza River watershed influences directly on the hydrological processes. Two thirds of the outcrops (limestone and dolomites) promote infiltration of rainwater and contribute to the karstic aquifer recharge.

Most of the watershed rocks belong to carbonate terrains, which marked the current geomorphology of the basin through the development of travertine waterfalls and plateaus. Similarly, because of the predominance of faulted and fractured limestone, resurgences of karstic aquifers ensure the low flows of rivers during summer and influence the chemistry of water resources (Abbou *et al*., 2014). The result of such phenomena is the sustainability of flows even during extreme weather periods and the guarantee of the necessary chemical elements provision for sedimentation, which is mainly travertine.

DATA

The data used in this study are rainfall, temperature and geomorphologic characteristics. The calculation of climatic variables is carried out to obtain the water balance of the watershed. The calculation of different design floods are based on the data of Taza rain stations. The hydrographic characteristics including; area (S), Gravelius index (Kg), watershed slop (Ip), thalweg slop (Tp) drainage density (Dd) and maximum thalweg length (T) are calculated using a GIS software and are expressed as:

$$Kg = \frac{P}{2\times\sqrt{\pi\times S}} \approx 0.28\times\frac{P}{S}$$

$$Ip = \frac{D\times L}{S}$$

$$Tp = \frac{DH_{max}}{L}$$

$$Dd = \frac{\sum L_i}{S}$$

where P, S, D, L, Li and H are respectively watershed perimeter, watershed area, the contour interval, length of the contour lines, stream length and maximum elevation of the river.

The calculation of potential and real evapotranspiration is expressed by the following equation.

Potential evapotranspiration (ETP): Thornthwaite (1948) established a correlation between the monthly mean temperature and the monthly potential evapotranspiration. This author defined a monthly index "i" as:

$$i = \left(\frac{T}{5}\right)^{1.514}$$

Thus, the estimation of the ETP is expressed as following:

$$\mathrm{ETP} = 16 \times \left(\frac{10 \times \mathrm{T}}{\mathrm{I}}\right)^{\alpha}$$

$$\alpha = \left(\frac{1.6 \times \mathrm{I}}{100}\right) + 0.5 = 0.49239 + 1792.10^{-5} \times \mathrm{I} - 771.10^{-7} \times \mathrm{I}^2 + 675.10^{-9} \times \mathrm{I}^3$$

Where:
ETP = The potential evapotranspiration in mm
T = The mean temperature of the month, expressed in °C
I = The sum of the monthly indices of the year

Concerning the calculation of the ETR, Turc (1961) has adapted the following formula from the family of curves of D = ETR = f (P, T) established from observations of 254 watersheds in all climates of the world:

$$\mathrm{D} = \mathrm{ETR} = \frac{\mathrm{P}}{\left(0.9 + \frac{\mathrm{P}^2}{\mathrm{L}^2}\right)^{\frac{1}{2}}}$$

$$\mathrm{L} = 0.05 \times \mathrm{T}^3 + 25 \times \mathrm{T} + 300$$

Where:
P = The annual average rainfall
T = The annual average temperature in the basin (°C)
ETR = The reel evapotranspiration in mm

For the purposes of the design flood calculations, it is necessary to perform the following steps:

- The statistical modeling of maximum daily rainfall using Talbo-Montana model
- The choice of the unit hydrograph
- The calculation of peak flows, rainfall intensity and runoff coefficient for each return period

OVERVIEW OF SOME WATER ASPECTS OF THE REGION

Climate

Rainfall: The main rainfall stations near of the Taza watershed are Bab Boudir, Bab Azhar, Bab Merzouka and Taza. The average inter-annual rainfall is 578 mm in Taza, 800 mm in Bab Azhar, 1100 mm in Bab Boudir and 550 mm in Bab Merzouka. The analysis of the inter-annual rainfall variability of Taza, Bab Boudir, Bab Azhar and Bab Merzouka stations shows a strong variability with a coefficient of variation ranging from 27-42% (Table 1). The rainfall recorded at Bab Azhar station is the highest, with a maximum of 1700, followed by Bab Boudir (1600 mm), Taza (954 mm) and Bab Merzouka (854 mm). On the other hand, the geographical location affects directly the precipitation variability, quantitatively and qualitatively. Indeed, the amount of precipitation increases in highlands, where we have snow.

Table 1: Statistics of annual rainfall for different stations

Station	Taza	Bab Merzouka	Bab Boudir	Bab Azhar
Average rainfall	578	550	1100	800
Min	275	305	540	406
Max	954	854	1600	1700
Standard deviation	164	144	345	263
Variation coefficient (%)	30	27	42	37

The monthly precipitation analysis shows that the high rainfall period starts from the month of September for all observed stations and extends to May. The period of low rainfall begins in the month of June (early summer) and ends in September. The dry period is characterized by low and irregular rainfall. Rainfall recorded in Bab Boudir, Bab Azhar, Bab Merzouka and Taza during low rainfall period are, respectively, 540, 406, 305 and 275 mm. Indeed, the months, when rainfall is low, are very common but in some months, we observe high rainfalls especially in May and during the summer. These rainfalls, which are in the form of showers, are characterized by a very high intensity and are expressed in the rivers by torrential flows that generate overflow water and floods. The intermediate rainfall year is relatively characterized by high rainfalls, which can reach 1120 mm in Bab Boudir, 790 mm in Bab Azhar, 540 mm in Bab Merzouka and 550 mm in Taza. This spatial difference is due to the effect of altitudinal contrast of the observed stations. The year of highest rainfalls can reach 1850 mm in Bab Boudir, 1640 mm in Bab Azhar, 850 mm in Bab Merzouka and 970 mm in Taza. The floods events are very strong during this period especially the floods of 2000/2001, which caused high damage to the area.

Evapotranspiration: Evapotranspiration is an essential component of the water cycle, its evaluation allows comparing the amounts of incident precipitation in both continental and local scale (Zemzami, 2008). The evapotranspiration is the combination of the direct evaporation from open water surfaces, soil and plant transpiration. We can distinguish:

- Potential evapotranspiration (ETP) is the maximum amount of water expected to be lost as vapor phase in a given climate, with specific continuous vegetation cover (well watered)
- Reel evapotranspiration (ETR) which is the sum of the amounts of water vapor evaporated from soil and plants when the soil is in some moisture level and the plants at a specific physiological and health development stage

Potential evapotranspiration (ETP): The values of the ETP calculated by the Thornthwaite expression on a monthly scale are generally higher than rainfall, except for the months of November-April (Fig. 3). The ETP reached its maximum, during the summer (June-September).

Reel evapotranspiration (ETR): The calibration of Turk formula for the Moroccan conditions requires the use of the following expression:

$$T' = 0.75\times T = 0.75\times 22°C = 16.5°C$$

Thus, we get that the annual ETR is equal to 485 mm, which is less than the annual average rainfall for all the stations.

Water balance: Based on the previous calculations, we can estimate the water budget which takes into account the concept of soil saturation (Fig. 3). Indeed, in arid to semi-arid areas, the soil is

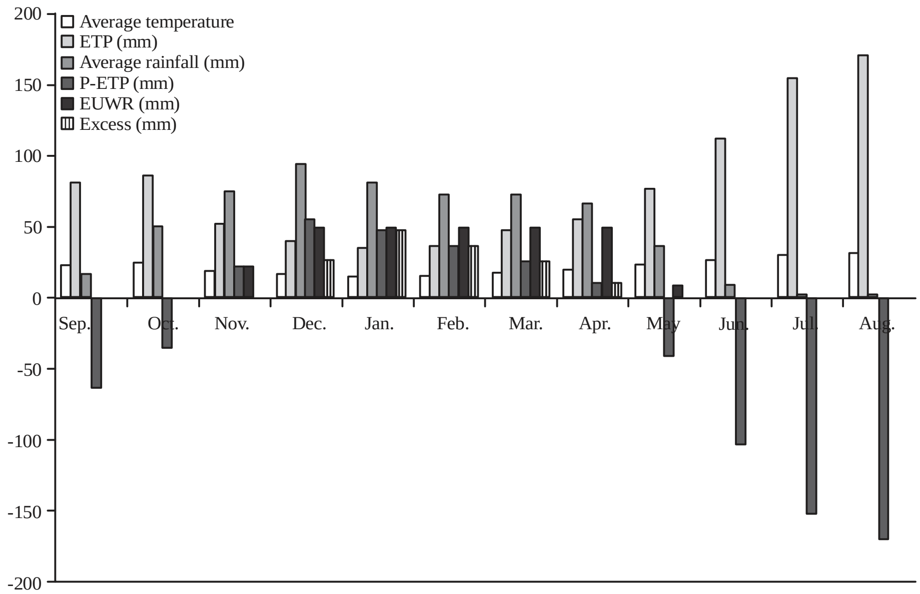

Fig. 3: Monthly variation of the different terms of the water balance

considered saturated, when it absorbs a volume of water equivalent to 50 mm of rainfall. The Easily Used Water Reserves (EUWR) is defined as, the water resource easily usable by plants, which depends on the soil saturation and precipitation.

Hydrogeology: The region of Taza has important water potentials. Indeed, the geological context allowed the formation of large Liassic aquifers in limestone and dolomite that are strongly karstified (Fassi and Feskaoui, 1998). In addition, the karst resurgences allow the support of surface runoff during periods of low water. The spring of Ras El Mae is the best known throughout the entire region, which is used for agriculture and local drinking water supply.

The valley of Taza River is fed by the waters of several aquifers (Fig. 4). These aquifers are:

- The Magoussa aquifer (the smaller aquifer in the region), which is perched on the northern slope of Tazzeka Mountain. The outlets of this aquifer are:
  - Magoussa borehole No 693/16IRE used for water drinking of Taza city
  - Some springs feeding the Inaouen River and Taza River. The total flow output of the aquifer is between 100-150 L sec^{-1}
- The Ras El Mae-Ain Laanaceur aquifer consists of a set of small karsts, crossed by a large fault network. The surface of its impluvium is 88 km^2 and its outlet consists of two main springs:
  - Ain Laanaceur spring, which is in contact with the Lias and Triassic formations and drained entirely the aquifer without any downstream leakage flow (the average flow is 400 L sec^{-1})
  - Ras El Ma spring which is karstic and mostly known extreme variations of its flow. The flow rate varies, depending on weather conditions, between 50 L sec^{-1} during low flows and several L sec^{-1} during high flows
- The Taza aquifer is limited in the west by the Triassic outcrops separating it from the aquifer of Magoussa, in the south by the Triassic outcrops of Ras El Ma in the east by the watershed line division between Inaouen River and Melloulou River and in the North by Prerif Mountains.

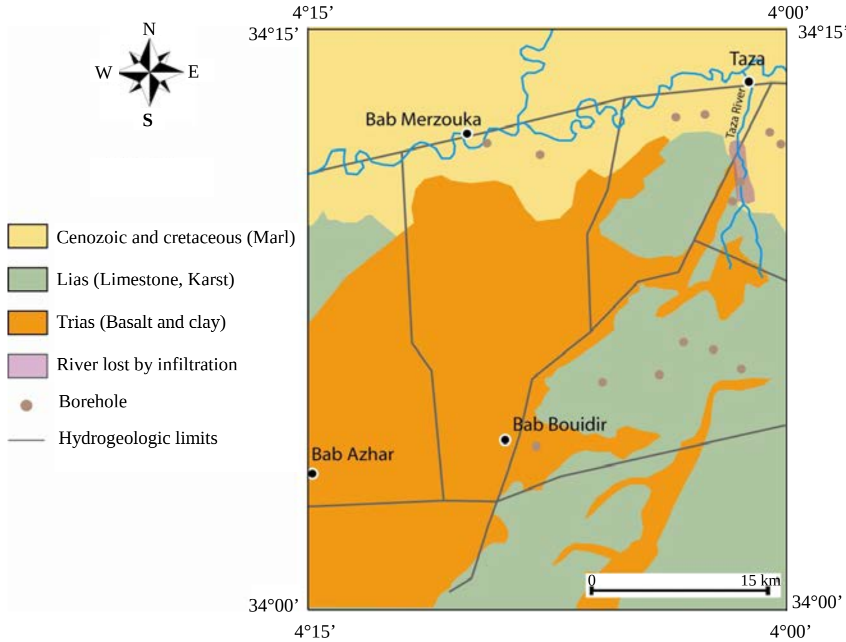

Fig. 4: Hydrogeologic sketch map of the Taza area (ABHS., 2001, modified)

The surface of the aquifer is approximately 110 km^2. Its former outlets were springs (Ain N’ssa, Ain Anemli and Ain Cherchar) of total output flow of about 180 L sec^{-1}

Aquifer characteristics: From the previous sections, we note that the region of Taza, in its southern part, has important hydrogeological units favorable for accumulation of groundwater. The low drainage density in the South, compared to the importance of rainfall shows that runoff is low, which led to important infiltration rates toward aquifers. However, the north part, where dominate impermeable rocks is quite poor in groundwater resources. This contrast of hydrodynamics properties explains, why the major high streamflows are recorded in the rivers that flow from the North.

Regarding the distribution of water resources, there are two areas of unequal importance:

- The northern part of the region is the poorest part regarding availability of groundwater resources (generally impermeable rocks). In fact, the aquifers in this area are of low productivity and geographically very limited. The formations that can present hydrogeological interest are those of the Cretaceous and Jurassic parts of the Rifan Mountains. The Cretaceous aquifers contain significant reserves of water closely related to the total thickness of the limestone beds. These aquifers are of low hydrodynamic characteristics but with significant extension. Several wells are exploiting these aquifers with pumping rates up to 3 L sec^{-1} but with significant drawdowns. The Jurassic aquifer in the Prerif is relatively important because of its high permeability and the importance of rainfall in the outcrop areas. However, this permeability favors an important discharge of springs and a rapid depletion of resources
- The southern part of the region has considerable groundwater resources of good to medium quality (Abbou *et al*., 2013). There are many springs in this part. The transition between the northern and southern parts begins with the south part of the Rifan Corridor where Liassic limestone constitutes a very important aquifer with good physicochemical quality. The Middle

Atlas constitutes the biggest groundwater reserves in Morocco. The importance of this unit appears in the spring rates that can exceed 300 L sec^{-1}. Here too, it is the Liassic limestones that play an important hydrogeological key role. However, the dramatic topography makes their use by hydraulic constructions a little difficult

Geomorphologic characteristics: Knowledge of geomorphologic characteristics of a basin gives an idea about the different factors affecting the dynamics of the watershed and the river system. The analysis of these elements is the key to understand the interactions between the physical environment and the hydrological aspects of the watershed related to the behavior of rainfall events. The physiographical characteristics of a watershed influence its hydrological responses and especially, the flow regime during floods and periods of drought (Musy, 1998). The knowledge of the various physiographic parameters is the first step of any subsequent analysis of a catchment. Geometry, slope, topography and other parameters constitute the physical context of a geological, hydrological and/or a hydrogeological system. Thus, it is important to identify these different characteristics to better understand the general physical aspect of the system.

There are many parameters that can be calculated and express the physical characteristics of the watershed. The most important are:

- **Watershed shape:** The shape of the watershed influences directly the shape of the hydrograph at the outlet. In our case, the Graveluis index is greater than one (1.93), indicating that the watershed has long shape. This kind of watershed generates, for the same rainfall, a lower outlet flow, as the concentration time is higher. This phenomenon is related to the concept of concentration time of water in the bed of the stream
- **Slope:** The watershed and hydrographic network slope is of great importance in any hydrologic and hydraulic paper. It is obvious that runoff is more important, when the slope is important. Thus, in mountains, we find it, for a given rainfall, strong floods than the plains. For this reason, the time and magnitude of runoff are strongly influenced by topography. The Taza River has generally, a very steep slope because the river is still young and has not yet reached its equilibrium as, its middle part has the form of hyperbole
- **Drainage density:** Drainage density depends mainly on the geology (lithology and structures), topographic characteristics of the watershed, climate and anthropogenic conditions. Indeed, the Taza River watershed is mostly characterized by cracked limestone where infiltration limits the development of a dense hydrographic network. On the other hand, slopes that are relatively more important are observed at the upstream part of the river, which influence directly, the concentration time. The drainage density of 2.59 indicates that in Taza River watershed, the surface flow is centralized and has reached a very limited development level

RESULTS

To determine the extreme flows in the Taza River, we used the rational method. This is the oldest method which uses a simple model that transforms a so-called design rainfall (characterized by its intensity I), assumed to be uniform and constant in time, into a maximum instantaneous flow.

The rational method is among the methods for estimating peak flows for different frequencies. It is based on the principle that the flow at the outlet of a basin, which is under a homogeneous rainfall (with intensity I) in time and space, reaches its maximum when the duration of the storm is equal to the time concentration of the basin.

The maximum flow rate can be expressed by:

$$Q = C \times I \times A$$

Where:

C = The runoff coefficient

I = The rainfall event intensity m/s of a duration equal to the time of concentration of the watershed and a frequency equal to that of the desired flow rate

A = The drainage area (m^2)

The intensity of the rainfall event with a duration equal to the concentration time of the watershed and a frequency equal to that of the desired flow rate is determined from the IDF curves.

Runoff coefficient estimation: The soil infiltration plays a significant role in surface runoff. This property of the surface formations is difficult to estimate and measure. Some software, such as; SWAT and Stanford Watershed can be used to estimate it but they require many parameters that are not available in our case. The amount of infiltrated water is related to moisture and soil permeability, the presence of vegetation, topography and the volume and intensity of precipitation. Natural factors are generally important elements to increase or decrease infiltration. For example, low permeable land is capable of promoting surface runoff compared to infiltration, while a permeable terrain is favorable for infiltration. The vegetation also contributes greatly to the ratio runoff / infiltration. However, grassed land helps reducing runoff and erosion by slowing down the speed of water flow. Previous studies carried out by Zemzami (2008) and Layan *et al*. (2013) on the watershed of Taza River, has found that runoff coefficients of different return periods were 0.23, 0.33, 0.43 and 0.49, respectively, 10, 20, 50 and 100 years return period.

Concentration time: The concentration time is the time that rainfall needs in order to travel from the remotest place in the catchment to the point in the sewer system, where the design calculation is made (Chow, 1964).

There are several empirical methods and formulas for estimating the concentration time. They generally, express the concentration time depending on the length of the river (L), the average slope (Ip) and the drainage area (S). To get a good approximation of time concentration, we used several formulas expressed as flowing:

Turazza:

$$T_C = 1.662 \times S^{\frac{1}{2}}$$

Johnstone and cross:

$$T_C = 5.66\left(\frac{L}{I}\right)^{\frac{1}{2}}$$

Kirplish:

$$T_C = 0.01947\times L^{0.77}\times I^{-0.385}$$

The calculation of the time of concentration by the different methods and the adopted value are reported in Table 2.

Intensity-duration-frequency curves: The IFD curve is a relationship that explains the behavior of a universal distribution of observed rainfall. It gives an idea about the frequency or return period of a mean rainfall intensity that can be expected within a certain period. It can be used for the determination of design storm and it is linked to hydraulic design. Indeed, the determination of storm water flow is directly related to the knowledge of heavy rainfall intensity. Modeling real rainfall allows calculating rainfall intensities for different frequencies. The model of Talbo-Montana was considered as the most appropriate formula for the Moroccan case (Zemzami *et al*., 2013), because it provides a good prediction for different return period flows.

The Talbo distribution for a return period T, gives the intensity I with the duration d as:

$$I(d) = \frac{c}{e + d}$$

where, c and e are parameters of the Talbo model.

For the Montana law, the return period T for the Talbo law becomes:

$$I(d) = a.d^{-b}$$

where, a and b are two parameters to be estimated based on graphical fitting. Indeed, in a double log graphic, the Montana law can be expressed by a line as:

$$\ln(d) = \ln(a)\text{-}b.\ln(d)$$

Using Talbo and Montana relationships, a combined law has been developed by many authors to fit the low durations using Talbo model and the high durations using Montana model (Melan and Musy, 1999). The combined relationship of Talbo-Montana is expressed as:

$$c = \frac{a}{b}\, d_p^{(1-b)}$$

where, d_P is the pivot duration and represents the limit between Talbo and Montana curves.

Table 2: Time of concentration using different methods

Methods	Time (h)
Turazza	1.75
Johnstone and cross	1.61
Kirplish	1.60
Adopted value	1.65

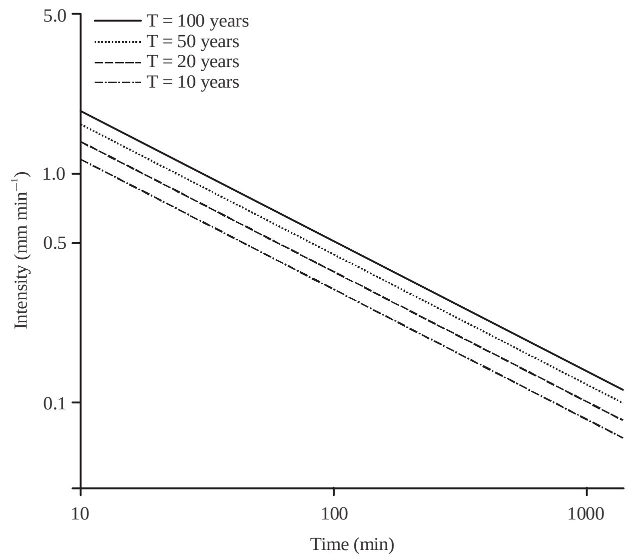

Fig. 5: Intensity-frequency-duration curves of Taza city

Table 3: Summary of the different results for different return period and comparison with results obtained by other authors

	Time (years)			
Frequency	10	20	50	100
Intensity (mm min^{-1})	0.34	0.40	0.49	0.55
Runoff coefficient	0.23	0.33	0.43	0.49
Extreme flow (m^3 sec^{-1})	52.00	88.00	140.00	180.00
Layan (2014)	54.00	71.00	162.00	231.00
Zemzami (2008)	46.00	88.00	140.00	180.00

The IDF curve for different return periods using Talbo-Montana model at the Taza station is illustrated in Fig. 5.

DISCUSSION

The previous calculations are used to estimate the extreme flows of the Taza River based on the rational method. The obtained results were compared with the studies carried out by Layan (2014) and Zemzami (2008) in which the authors used a different method to estimate the design floods of different periods. These flows represent the design floods of different return periods and can be commonly used as, inputs and transformed to water levels using, a comprehensive hydraulic model. The differences that exist between the results obtained by the different authors are linked to concepts and the approaches used by the authors. However, the results are quietly similar and this helps decision maker to have a choice on which, value; they can use according to the desired safety level. The importance of the design flood relies on their consideration for risk evaluation and planning purposes of relevant facilities and used as design flooding scenario for situations in which the integrity of such facilities must not bet at risk. Table 3 summarizes the important hydrological calculation for different return periods and the comparison between results obtained by different approaches.

The estimated extreme flows are important elements in hydraulic modeling. The economic cost and potential loss of life resulting from the possible failure of hydraulic structures can be enormous and highlight the importance of obtaining the 'best possible' design flood estimate. In the Taza

River Basin, the designer frequently has to resort to estimating a design flood from the available rainfall data. Results obtained are highly important and constitute a platform for hydraulic analysis. In Moroccan case, the 10 year return period is generally used in protection against flooding but this value can change, if there is an important risk for some constructions or some vital areas (Zemzami *et al*., 2013). Regarding the obtained values it seems that the area can be prone to flood risk because of the high flow rates that were calculated using meteorological and hydrological models

On the other hand, the basin land use plays an important role in increasing or decreasing the magnitude of floods. Tree crops, riparian and gardens occupy the urban part of the watershed. The riparian area, located between the main channel and the floodplain, can be an effective buffer zone protecting small crops (fruit trees) from destruction by migration of coarse sediment. It does not necessarily diminish the magnitude of flooding but the damage associated with it. This riparian area, especially, if it is not maintained, can have on the scale of a river system, an action of retention and induce the same hydrologic effects as a forest in the downstream but this time acting hydraulically. However, most of the watershed land is covered by forests. The hydrologic and hydraulic role of this forest is important, because it affects the shape of flood hydrograph, influences the retention of rainfall, the storage, the progressive restoration, etc. Thus, it has a potential effect on the peak and the propagation time of the flood wave. This forest has a significant attenuation function of natural hazards in highlands; through its control action on hydrological and geomorphological processes, because it increases the resistance thresholds of hillslops and thus ensures greater stability of the land. The frequency of gravitational phenomena, event (landslides, mudslides, debris flows, etc.) or chronic (creep, solifluction, gully erosion, etc.) are generally reduced in this area. However, this forests produce wood that is introduced into the stream channel. The mobility of these dead woods cause occasionally obstructions of hydraulic structures and damages them by scour and then cause more intense flooding in the urban part of Taza River watershed.

Through this study, decision makers can get benefit from the outcomes of the study, which provides basic information for understanding the hydrologic system and guidance for the development of the watershed. The importance of this hydrologic study relies on its consideration for risk evaluation and planning purposes of relevant facilities and used as design flooding scenario for situations in which the integrity of such facilities must not bet at risk.

CONCLUSION

This study showed the results of general hydrologic overview of the Taza River watershed. This is the most comprehensive study on the different hydrologic aspect of the Taza River watershed. The study has gathered a significant number of hydrologic aspects of the system. It was shown that, despite the semi-arid climate of the region, water resources are important and deserve more studies to improve the knowledge and the understanding of the watershed. Extreme hydrologic events were typically considered in this study because the Taza River crosses the city of Taza and thus can present a certain risk for the population. The use of statistical model to extract design storm from annual maximum daily rainfall allowed to calculate the design flood of reference based the empirical model of Caquot. However, the Caquot model requires the analysis of a significant number of rainfall events and then determines the design flood of reference. The Talbo-Montana model was used for this purpose to calculate the different parameters of Caquot model. It was found that the risk of flooding is important regarding the high design flood values. The results show also that the basin land use plays an important role in increasing or decreasing the magnitude of floods.

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