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RAINFALL-RUNOFF MODELING USING THE HEC-HMS MODEL FOR THE MEKERRA WADI WATERSHED (N-W ALGERIA)

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ABSTRACT

The objective of this study is to examine the rainfall-runoff relationship in the Wadi Mekerra watershed located in northwest Algeria, in order to propose effective solutions for flood protection. The methodology is based on the processing of meteorological and physical data in the geographical environment and on the extraction of data using remote sensing techniques (Landsat satellite imagery) and GIS. Using this database, we were able to develop a hydrological flood model for Mekerra watershed using the hydrological modeling software HEC-HMS. In this study the frequency storm was used for the meteorological model, the SCS curve numbers was used to determine the hydrological losses of the study area and the SCS unit hydrograph method have been applied to simulate the runoff rate. After calibration and validation, the simulated peak discharges were very close with observed values. The Nash–Sutcliffe efficiency coefficient was 0.869, indicates that the hydrological modeling results are satisfactory and accepted for simulation of rainfall-runoff.

Keywords: Mekerra, floods, hypothetical rainfall, HEC-HMS, hydrological modelling, semi-arid climate.

INTRODUCTION

Floods are among the natural disasters that cause loss and damage worldwide (Hafnaoui et al., 2022; Hafnaoui et al., 2023; Remini, 2023). They are the most widely distributed hazard in the world (White, 2001). In 2011, floods accounted for one in two natural disasters and were responsible for 20.4% of disaster-related deaths worldwide (Guha-Sapir et al., 2012). Algeria is one of the Mediterranean regions affected by floods, which are generally due to the overflow of rivers passing through cities and towns (Bekhira et al., 2019). These floods, which appear suddenly, are often difficult to predict, have a rapid rise time and a relatively large specific flow, and are generally linked to intense rainfall episodes and occur in moderate-sized basins (Yahiaoui, 2012). 485 (1/3 of 1541) of the country's communes, regardless of geographical location, are subject to flood risks, according to civil protection statistics (Sardou et al., 2016). The spectacular and catastrophic floods of 10 November 2001 in Algiers at Bab El Oued (Oued Koriche watershed) were the deadliest of all those recorded in the countries of the Mediterranean basin. They caused more than 710 deaths, more than 115 disappearances, affected more than 45,000 people and caused material damage of more than 33 billion dinars according to the statistics of the National Economic and Social Council. Flooding in the Mekerra basin in north-western Algeria affects more than 200,000 people in this region. From 1986 to 2007, floods caused significant damage, 10 deaths and 929 homeless families are reported by Atallah et *al*.

Flood damage will increase over the years due to population growth and socio-economic development, as well as climate change due to the global warming effect. Therefore, there is a need to define a methodology to predict flash floods in order to protect the city from flooding. The widely used approach to determine the occurrence of flash floods and the relationship between precipitation and runoff data is hydrological modelling, which takes into account the hydrological process to estimate the stream flow in river basins and helps forecasters to compare the simulated flow with observed flood data to predict and understand the hydrological process. Hydrological studies often aim at establishing rainfall-flow relationships (Shah et al. 1996). Rainfall-flow models can be classified according to the type of model. According to Clarke (1973) and Ambroise (1998), hydrological models can be classified into four main categories: deterministic or stochastic, global or semi-distributed, kinematic or dynamic and finally empirical or conceptual. The choice of model depends on the catchment and the objective of hydrological forecasting in the catchment. In this study, the conceptual approach is adopted for hydrological modelling, using a semi-distributed hydrological model HEC-HMS (Hydrologic Engineering Center-Hydrologic Modelling System) developed by the US Army Corps of Engineers, in order to study rainfall-flow relationships in the semi-arid Mekerra catchment in northwest Algeria. It is applicable in various geographical areas to address a wide range of problems. Many scientists have conducted important hydrological studies using the HEC-HMS model, which has proven its ability to simulate and predict streamflow. For example: Sintayehu (2015) used the HEC-HMS model by employing the Snyder unit hydrograph and the exponential recession method to simulate the runoff from the upper Blue Nile basin. Norhan et al (2016) modelled rainfall-flow relationships using the HEC-HMS model in an arid environment at Wadi Alaqiq, Madinah, Saudi Arabia. Sampath et al (2015) modelled rainfall-discharge relationships using HEC-HMS in a tropical catchment in Sri Lanka. Meiling et al (2016) used HEC-HMS to simulate runoff in the semi-arid region of northwest China. Laouacheria and Mansouri (2015) used the HEC--HMS model employing the frequency rainfall method to simulate runoff in a small urban catchment in northeast Algeria. Mokhtari et al (2016) modelled the rainfall rate by HEC-HMS in the Oued Cheliff-Ghrib catchment in northern Algeria. Skhakhfa and Ouerdachi (2016) used HEC-HMS to estimate short duration floods in the Oued Ressoul catchment in North-East Algeria. WAŁĘGA (2013) reconstructed a flood event in an uncontrolled basin using the HEC-HMS model. This paper presents a methodological approach to the rainfall-flow model using the HEC-HMS software integrated with DTM data as input to the basin model in a semi-arid environment to simulate peak flows for 10, 20, 50, 100 and 1000 years (mean recurrence interval) in the Oud Mekerra catchment.

MATERIALS AND METHODS

Data

The data of the temporal series of precipitations are collected from the meteorological station of the region, that of Sidi Bel Abbes (for 1967-1998), and the flow data are collected from the National Agency of Hydraulic Resources (ANRH) from the measuring station of Sidi Bel Abbes (for 1968-1998)

In addition, spatial data were downloaded from the USGS (https://earthexplorer.usgs.gov/) in the form of ASTER (Advanced Spaceborn Thermal Emission and Reflection Radiometer) as a global digital terrain model with a resolution of 30 m. We adopted the DTM to define the Mekerra catchment and its physical characteristics

Methods

Our objective is to examine the rainfall-flow relationship in the Mekerra catchment area, in order to propose effective solutions to protect the city from flooding. The methodology is based on the processing of meteorological and physical data in the geographical environment and on data extraction using remote sensing and GIS techniques. Our methodology can be separated into six main steps:

- description and geographical location of the study area;
- DTM processing, definition of the river network, topography and catchment characteristics, using HEC-HMS v4.8 tools;
- Calculate the number of runoff curves (NC) of Wadi Mekerra from the GCN250 map of global gridded curve numbers for hydrological modelling and design (Jaafar et al., 2019);
- import the data of the physical characteristics of the catchment into the HEC-HMS model;
- run the rainfall-flow simulation and compare the calculated and observed flows;
- calibration and validation of the model.

Presentation of the study area

Geographical location

The Wadi Mekerra basin belongs to the big basin of Macta which is located at the North-West of Algeria (Fig. 1). It occupies a surface area of approximately 3000 km^2 and a perimeter length of approximately 391.3 km. This basin isdrained by the Wadi Mekerra which develops a talweg of 144 km length. The two main Wadis, the Wadi Mekkera in the West and Wadi El Hammam in the East meet near the Mediterranean Sea coast to form the Macta basin (Fig. 1).

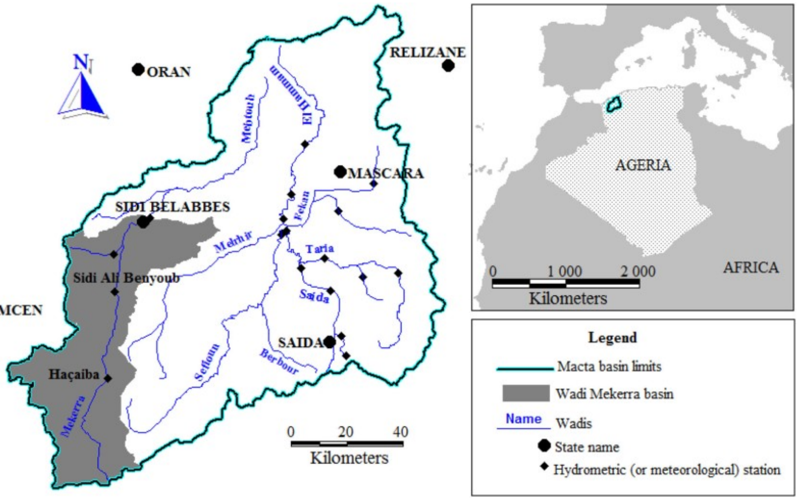

Figure 1: Location of the Wadi Mekerra basin.

Topographical description

The catchment area has an elongated shape from south to north (Fig. 1). The surface area of the basin is 50% located at a height of over 1000 m. The Mekerra wadi crosses two distinct relief zones (Hallouche, 2007):

- The mountainous massif of Daya in the South with an altitude that varies between 1500 m and 800 m. The average slope of the wadi up to Sidi Ali Ben Youb is about 1 to 1.5%.
- The wadi flows downstream from Boukhanafis into the alluvial plain with a slope of 0.3 to 0.8%, resulting in relatively low flow speeds. From Boukhanafis to Sidi Bel Abbes, the Mekerra wadi receives a series of tributaries such as Oued Tissaf, Oued Negadi, Oued Nadjen and others which are dry during most of the year.

Overall, the catchment area can be subdivided into three sub-catchments according to the hydrometric observation stations which are: Haçaïba, Sidi Ali Benyoub and Sidi Bel Abbès (Korichi et al., 2016). The use of the different types of morphometric parameters (Table 1) aims at quantifying the characteristic factors of the physical environment of the catchment area. The value of the Gravelius compactness index indicates that the catchment has a rather elongated shape, it therefore implies a slow concentration time. The characteristic elevations and the difference in altitude are deduced from the hypsometric curve of the catchment. The purpose of the Roche slope index is to characterise the average slope with actual catchment data. The drainage density provides information on the extent of drainage in the catchment and its suitability for surface runoff. The value of this parameter indicates that the basin drains well.

Table 1: Characteristics of the sub-basins of the Mekerra wadi.

Features	Unit	Haçaïba Station	Sidi Ali Benyoub Station	Sidi Bel Abbes Station
Basin area	Km^2	957	1890	3000
Compactness index	-	1.15	1.29	1.43
Maximum height value	m	1440	1715	1714
Minimum height value	m	925	635	437
Rock Slope Index	%	0.099	0.0936	0.0913
Wadi's length	Km	54	92	144
Drainage density	Km/Km^2	0.06	0.050	0.02
Torrentiality	-	0.20	31.25	6.86
Time of concentration	h	6.369	10.560	13.448

Geology

In the Oued Mekerra watershed there are quaternary and plio-quaternary formations characterised mainly by alluvium and conglomerates. Humus-bearing calcareous soils are predominant (Fig. 2). This calcareous crust is permeable and plays an important role in the rise of floods. The northern part of the basin is much more permeable than the southern part. There is a surface contact with the conglomerate channel which contains the water table. In addition to the humus-bearing calcareous soils that occupy most of the catchment area, there are calcareous soils, calcareous soils and alluvial soils. The torrential flow leaves the bedrock bare in some places (*Cherif et al.*, 2009).

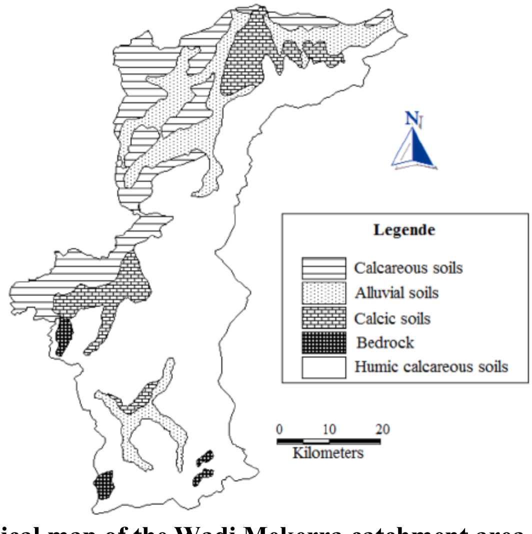

Figure 2: Pedological map of the Wadi Mekerra catchment area.

In the geological section made along the South-North direction, which crosses the Wadi Me-Kerra along its length, three faults appear from the South to the centre, thus playing an important role in the attenuation of floods, by reducing the maximum flow that infiltrates.

Plant cover

As in most parts of western Algeria, the vegetation cover of the Wadi Mekerra catchment area has been largely degraded and cleared by fires and by extensive small-scale agriculture and overgrazing. This has led to water loss through evaporation and accelerated erosion (*SPI Infra*, 2001).

In the Mekerra basin, the irrigation areas are mainly located in the Sidi Bel Abbes and Sfisef plains. The crops grown are dominated by market gardening and some fruit tree orchards. Forests, scrub and bushes occupy practically the entire strip of mountains located in the Upper Mekerra area. Only part of the catchment area (20%) is covered by forests, mainly in the mountainous massifs of the region between Haçaïba and Mouley Slissen and extending as far as Sidi Ali Benyoub, as well as on the periphery of the catchment area, in the uncultivable hilly zones. They are essentially made up of Aleppo pines and holm oaks. This forest cover only provides very little protection of the soil against erosion

Between Ras El Ma and El Haçaïba, where esparto used to cover large areas, has been replaced in recent decades by cereal crops. Between Sidi Ali Benyoub and Sidi Bel Abbés, in the Mekerra plain, where cereal crops are generally associated with secondary crops such as orchards or olive groves, sometimes irrigated (vines) (*Hallouche*, 2007).

Climate

The Wadi Mekerra watershed is under the influence of a semi-arid Mediterranean climate characterised by a hot, dry summer and a relatively mild, wet winter (*Yahiaoui*, 2012). The umbrothermal diagram, which presents both precipitation and temperature data for the Sidi Bel Abbes station, is shown in Fig. 3. It allows us to identify the dry and wet periods during the hydrological year. This diagram shows that the wet period extends from the beginning of October to the end of April and the rest of the year represents the dry period.

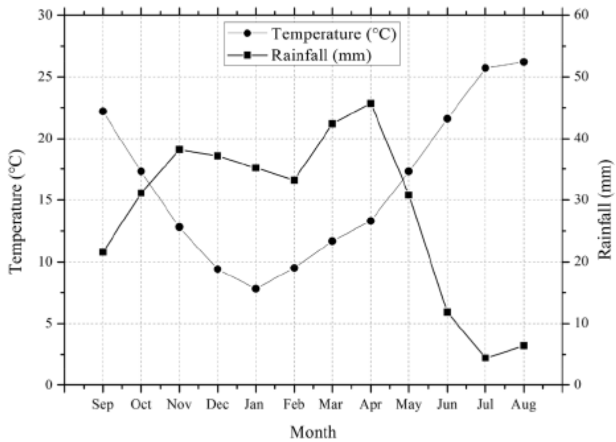

Figure 3: Umbrothermal diagram of the Mekerra wadi.

From a rainfall point of view, the average interannual amount of rainfall is in the order of 390 to 400 mm, but it can decrease to 110 mm/year in particularly dry years, hence the annual variation in the liquid contributions of the Mekerra wadi. As an indication, this watercourse carried 13 million cubic metres during the 1960-1961 hydrological year and 92 million cubic metres during the 1950-1951 year, which constitutes an exceptional contribution compared to the interannual average estimated at 57 million cubic metres (*SPI Infra*, 2001; *Hallouche et al.*, 2010). Most of the rainfall is distributed between winter and spring (70% of annual rainfall). In rainy years, the sum of rainfall can reach 800 mm (the Sidi Ali Benyoub station on 25 May 1929 recorded 104 mm), and in dry years, it can decrease to 110 mm (*Yahiaoui*, 2012).

The average annual air temperature is around 15° C, and the average number of days with frost is around 35 days (*Yahiaoui*, 2012). In seasonal terms, temperatures vary between 7.8° C in January, generally accentuated by the proximity of continental effects, and 26.2° C in July and August, when the Saharan inflow invades practically the entire region in summer. Evaporation is high in June, July and August and low in November, December, January and February. In our region the relative humidity decreases from north to south during the winter. It reaches relatively high values especially in the mountainous areas. The average annual value is 69.5% in Sidi Bel Abbes (*Hallouche*, 2007). The prevailing winds are from the northwest and west. The interannual average maximum wind speed is around 20 m/s (*Yahiaoui*, 2012). They blow throughout the season for 10 to 15 days per month. The sirocco (a hot, sandy southern wind) blows for about 15 days a year in July and August.

Flow regime of the Oued Mekerra

The Wadi Mekerra is an ephemeral river (*Atallah* et al., 2016). During the period 1942-2001, the average daily flow rate of the Wadi Mekerra - which is the ratio of days when the Wadi is flowing to the days in the hydrological year - is relatively low. It is around

10%, which corresponds to approximately 37 days when the wadi is flowing and 328 days when it is dry. However, during the period between 1997 and 1999 it became intermittent with a daily flow rate reaching the value of 73% in 1999 (*Maref,*2010; *Korichi*, 2013).

In the Mekerra basin, floods are more frequent and stronger in autumn than in spring. They are characterised by a rapid rise in water levels during the flood phase and a slower and more regular descent during the flood phase. This regulation is justified by the spreading areas located downstream. In the flood phase, the water from the outwash areas and the water stored in the alluvial deposits (banks and bed) flows back into the river via an overflow. The recharge is relatively slow, which favours the filling of the water table and the settling of natural fertilising elements. The peak flows are greater in the upper Mekerra (Sidi Ali Benyoub) than in its lower part (Sidi Bel Abbes town), where a flattening (lamination or natural regularisation) of the flood wave is recorded (*Sadeg*, 2003).

Fig. 4 shows the inter-annual variation of flows in the studied basin. A strong fluctuation of flows from one year to another is observed. During the period from 1942 to 2001 the Wadi Mekerra went through two long dry periods. The first lasted for nine (9) years; from 1952 to 1962 when the average annual flow for this period was 0.221 m^3 /s with the characteristic dry year of 1956 (0.039 m^3 /s). The second period lasted seventeen (17) years from 1968 to 1985 with average flows of the order of (0.141 m^3 /s). The driest year was 1978 (0.022 m^3 /s) (*Maref* , 2010; *Korichi*, 2013).

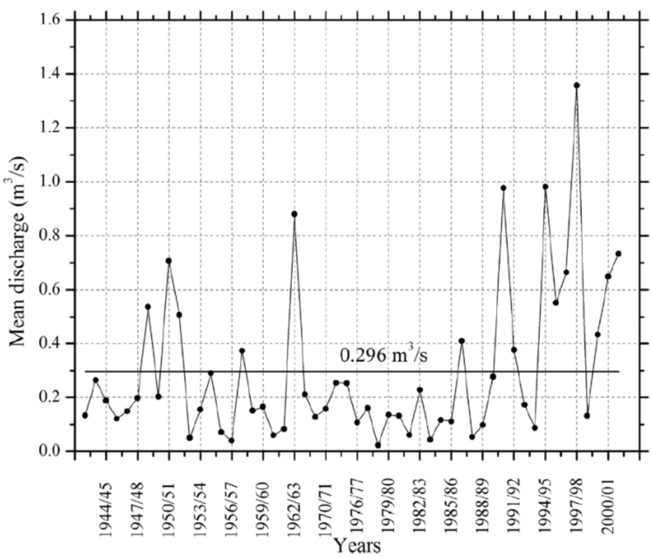

Figure 4: Interannual variation of flows in the Oued Mekerra basin.

It is interesting to note that the pre-1945 drought coincides with the global drought period of 1932-1945 (481) and corresponds to the annual global thermal peak in 1940 (*Tardy and Probst*, 1992). The lack of rainfall observed from the mid-1970s onwards confirms the drought that has plagued North Africa for the last four decades (*Mitchell and Murray*, 1963). It has manifested itself in particular in a dramatic drop in water inflows drained by the Maghreb wadis. *Meddi et al* (1998) estimate a 67% drop in comparison with normal flows in northwestern Algeria.

The variation of the average monthly flows in the Oued Mekerra shows that the flow is often observed in the months of September to October and sometimes in May (cf. Fig. 5). These periods correspond to the flood periods of the Wadi during which the flows are considerable. They can reach the value of 0.721 m^3/s in September and 0.789 m^3/s in October. For this period the monthly flow coefficient is about 2.44 in September, 2.67 in October and 1.14 in May. This explains the fact that the flows in these months are higher than the annual average.

The seasonal variation in average monthly flows is presented in Fig. 5. It indicates that the Oued Mekerra flows with a fairly high average monthly flow in autumn (0.6 m^3/s) where the rainfall in this season is stormy and intense. Spring is also characterised by a relatively high flow. This is probably linked both to the intervention of the rainfall in this season and to the fact that the soil in the basin is characterised by saturation due to the winter rain.

Although winter is the wettest season (cf. Fig. 5), it represents the season of low hydraulic capacity of the Oued Mekerra. Autumn is the dry season, but it gives a high water level for the Oued Mekerra. This hydraulic capacity is the result of the floods that characterise this season. The hydrological response of the Wadi seems to depend strongly on the intensity of the rainfall. Like most Mediterranean floods, the floods observed in our basin, particularly the autumn floods, are characterised by a fairly short rise in water levels. This is characteristic of floods in the Mediterranean region (*Bontron and Obled*, 2003).

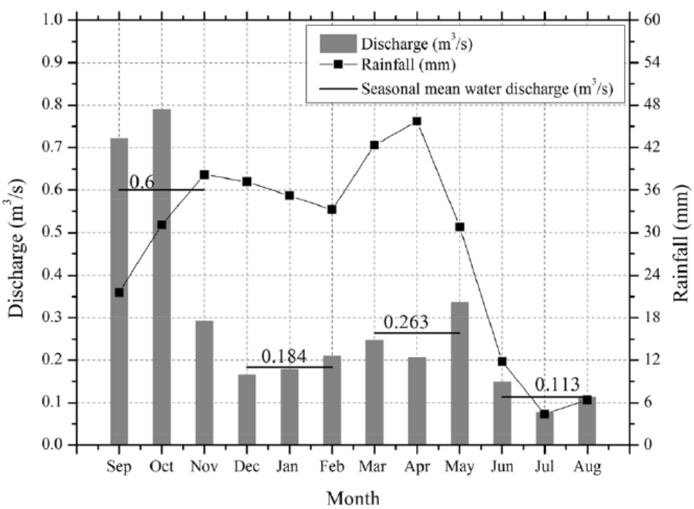

Figure 5: Interannual variation of flows in the Oued Mekerra basin.

The problem of flooding caused by the cyclical flooding of the Oued Mekerra has always been one of the main concerns of the officials of the Wilaya of Sidi Bel Abbès. Following the observations made during the various floods recorded, these floods can be linked to several causes, namely: (1) Intense and irregular downpours at the level of the upper Mekerra can reach 200 mm/h. (2) Morphology of the Mekerra catchment area, which is particularly elongated, resulting in a very short concentration time (9 hours). (3) Narrowing of the wadi's cross-section in certain sections and structures (bridges). (4) Almost total obstruction of the Wadi section by sediments carried and deposited by previous floods. (5) The downstream tributaries have a very low slope or even a negative slope. (6) Anarchic urbanisation on the banks of the Wadi. This last factor has a serious influence on the extent of flooding (*Korichi*, 2013).

Table 2: Distribution in % of the number of floods of the Oued Mekerra.

Flow classes (m /s)³	>200	200-100	100-50	50-10	<10
Frequency (%)	0.01	0.50	1.44	5.29	92.77

The study of the observations of instantaneous flows, distributed over the three hydrometric stations (Haçaïba, Sidi Ali Benyoub and Sidi Bel Abbes) showed that the predominant flow class is that of less than 10 m^3 /s. While high flows (over 200 m^3 /s) represent only 0.01% (*Korichi et al.*, 2016) (see Table 2).

After testing several statistical methods used in flood frequency analysis (exponential, normal root, gamma, Gumbel, normal, log-normal), the peak flows of Wadi Mekerra for 28 years fit well with the Gumbel law. The statistical methods used allow us to estimate the peak flows (Q_{max}) for different return periods (Tab. 3).

Table 3: Peak rates according to Gumbel's law.

Return period	10	20	50	100	1000
Flow rate	132	166	210	244	354

HEC-HMS model

Description of the model

The HEC-HMS hydrological model was developed by the Hydrologic Engineering Center (HEC) of the U.S. Army Corps of Engineers (USACE). HEC-HMS is designed to simulate rainfall-runoff processes in dendritic watersheds. It is developed to be applicable in a wide range of geographical areas to solve as many problems as possible (Scharffenberg, Fleming 2016). Hydrographs produced by the software are used directly or in conjunction with other software for studies on water availability, urban drainage, runoff forecasting, impact of future urbanisation, dam spillway design, flood damage reduction, floodplain management and system operation (Scharffenberg, Fleming 2016). The structure of the HEC-HMS model consists of four main elements: the basin model, the meteorological model, the control specifications and the input data. A set of different methods is available to simulate seepage losses. Seven methods are included for transforming excess precipitation into surface runoff and six methods are included for the transfer model and eight methods are included for the meteorological forecast model. The software allows for each process to choose from several choices of mathematical models that are empirical formulas and allow for the simulation of each flow. Each mathematical model included in the software is adapted to different environments and conditions. The HEC-HMS hydrological model includes a user-friendly graphical interface, capabilities for handling data, results and graphics, a specific data management and storage system (DSS View), as well as display and printing capabilities for results, and management tools.

Structure of the model

In this study, the SCS curve number loss method (CN) will be used to determine the hydrological loss rate, the SCS unit hydrograph method will be used to calculate the runoff rate. The modelling of river flows is done using the Muskingum-Cunge method and the hypothetical Frequency storm has been used for the meteorological model.

Catchment model

This model represents the physical watershed. In order to increase the performance of the modelling, in this study the catchment is subdivided into five sub-catchments. The representation of these sub-catchments is shown in Fig. 6. The hydrological parameters of the sub-catchments of the Ain Sefra catchment are presented in Table 3.

Figure 6: HEC-HMS display of the Wadi Mekerra catchment area and its five sub-catchments.

Production function

In this study, the Soil Conservation Service (SCS) Curve Number (CN) model (now the Natural Resources Conservation Service) is used to determine the rate of hydrological loss. This model estimates excess precipitation as a function of cumulative precipitation, cover and initial soil moisture from the following equation

$$P_e = \frac{(P - I_a)^2}{P - I_a + S} \tag{1}$$

Where Pe is the excess precipitation, P the total precipitation, I_a the initial losses and S the maximum retention potential. In the SCS method, the initial losses are given by the relation

$$I_a = 0.2S \tag{2}$$

The retention potential S is related to the CN, which in turn can be estimated by tables describing the different soil types (USDA-SCS, 1985) or by calibration with observed data:

$$S = \frac{254000 - 254}{CN} \tag{3}$$

The CN (or S) parameter can indeed be linked to different soil moisture indicators, measured in the field (Huang et al., 2007; Brocca et al., 2009; Tramblay et al., 2010), from models (Marchandise and Viel, 2009) or from satellite data (Brocca et al., 2010).

The CN map for Wadi Mekerra (Fig. 7) is obtained from the GCN250 map of global gridded curve numbers for hydrological modelling and design (Jaafar et al., 2019).

For a sub-catchment an average CN can be established by the zonal tool in ARC-GIS

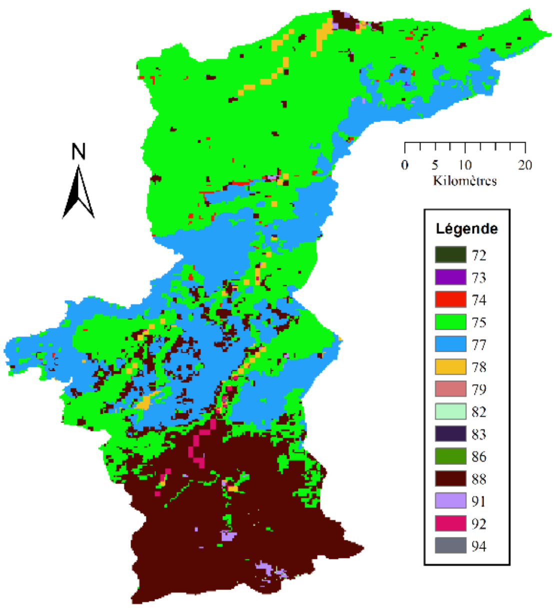

Figure 7: The CN map for Wadi Mekerra.

Transfer function

Once the excess rainfall is known, it is transformed into direct runoff. The runoff is modelled in HEC-HMS using the unit hydrograph method. The model used is the SCS unit hydrograph.

The unit hydrograph by the (SCS) method is based on the transformation of rainfall into flow with the use of the response time (or delay) (T_{lag}), which is the time difference between the centre of the rainfall mass and the peak of the unit flood hydrograph. It is considered from the numerous experimental data that:

$$T_{lag} = 0.6\ Tc \tag{4}$$

with;
Tc is the time of concentration obtained from equation:

$$T_c = \frac{0,571 \cdot l^{0,8} \left(S+1\right)^{0,7}}{y^{0,5}} \qquad \text{(in h)} \tag{5}$$

Where

l: length of the sub-catchment (Km) ;

S: is the maximum retention potential.

Y: Slope of the sub-basin (%)

The results of the application of these formulas are shown in the table

Table 4: Model parameters in the transfer function

Sub-basin	CN	l (km)	Y (%)	Tc (h)	T_{Lag} (min)
Subbasin1	75.55	64.47	6.77	16.90	608.37
Subbasin2	77.21	73.76	12.43	13.23	476.20
Subbasin3	85.57	32.67	5.53	7.89	284.05
Subbasin4	83.91	62.97	8.16	11.63	418.73
Subbasin5	75.98	33.88	7.21	9.67	348.03

For initial losses and impermeability are initially taken to be zero

Weather modelling

Various methods are proposed for modelling a rainfall event, known or unknown. However, we have the hypothetical rainfall based on frequency (Frequency storm). For each frequency we have calculated the corresponding rainfall amounts at different time steps (15min, 1, 2, 3, 6, 12, 24, ...). The results are presented in Table 5, which represents the meteorological data used in the HEC HMS model:

Table 5: Rainfall data for each frequency

Time (hours)				0.25	1	2	3	6	12	24
Freq (%)	10	Precipitation (mm)	46.52	14.51	20.67	24.67	27.36	32.66	38.98	46.52
	20		50.82	15.85	22.58	26.95	29.89	35.67	42.58	50.82
	50		55.88	17.43	24.83	29.63	32.86	39.22	46.82	55.88
	100		59.39	18.52	26.38	31.49	34.93	41.69	49.76	59.39
	1000		69.78	21.76	31.00	37.00	41.04	48.98	58.46	69.78

River flow modelling

The river flow models included in the HEC-HMS allow the calculation of a hydrograph downstream of the catchment area, knowing the upstream hydrograph. All these models use the continuity and momentum equations. River flow modelling is done using the Muskingum-Cunge method. The following table summarises the parameters used in this method

Table 6: Parameters of the Muskingum-Cunge model

Section	Length (m)	Slope (m)m)	Manning
Section 1	32111	0.00498	0.035
Section2	39016	0.00498	0.035
Section3	39261	0.00492	0.035

Cross-sections from the study by Atallah et al, 2016 were used.

Model calibration

Calibration is a systematic process of adjusting the model parameters until it faithfully reproduces the observed data. It was therefore possible to calibrate certain parameters to the flood by entering the flow curve at the outlet during the rainfall event. For each parameter to be optimised, we can enter a starting value and limit values that must not be exceeded. We also have the choice between four convergence criteria, two of which have given satisfactory results in terms of flood volume. The historical event selected for the calibration corresponds to the flood of September 29 to October 2, 1994, measured by the National Agency of Hydraulic Resources (ANRH) which records a peak flow (215 m^3 /s). In our case and for the calibration of the model, we have chosen the parameters CN, T_{Lag} , the initial losses and the Manning's coefficient. Tables 7 and 8 show the parameters corresponding to the calibration for each sub-catchment.

Table 7: Values of all optimised parameters for the sub-basins.

Sub-basin	CN		Initial losses (mm)	
	Before chocking	*After calibration*	*Before chocking*	*After calibration*
Subbasin1	75.55	41.52	0	0.59
Subbasin2	77.21	19.20	0	0.69
Subbasin3	85.57	27.81	0	0.25
Subbasin4	83.91	21.91	0	0.26
Subbasin5	75.98	9.57	0	0.80

Table 8: The values of all optimised parameters for the sections.

Section	Manning's coefficient	
	Before chocking	*After calibration*
Section 1	0.035	0.089
Section2	0.035	0.089
Section3	0.035	0.089

After calibration, we obtained Fig. 8 which illustrates the difference between the simulated and observed hydrographs at the outlet of the Wadi Mekerra catchment. Fig. 8 shows that the simulated hydrograph is very close to the observed hydrograph. The simulated peak flow and the observed peak flow are respectively 203.5 and 215 m^3/s.

The performance of the HEC-HMS model is evaluated using the Nash-Sutcliffe efficiency coefficient (NSE) (Nash, Sutcliffe 1970), given by equation (6), which ranges from negative infinity to 1.0. An NSE value of 1.0 means a good agreement between the observed and predicted hydrographs (Moriasi et al. 2007). After calculating the NSE, we concluded that the simulated hydrograph obtained using the HEC-HMS model matches the observed hydrograph perfectly with a Nash-Sutcliffe coefficient value of 0.869.

$$NSE = 1 - \frac{\sum_{i=1}^{N}\left(Q_{i,obs} - Q_{i,sim}\right)^2}{\sum_{i=1}^{N}\left(Q_{i,obs} - \overline{Q}_{obs}\right)^2} \tag{6}$$

Where: $Q_{i,\mathrm{sim}}$ = the simulated flow at time t = i; $Q_{i,\mathrm{obs}}$ = the observed flow at time t = i; $\overline{Q}_{obs}$ = the average observed flow; N = the number of observations.

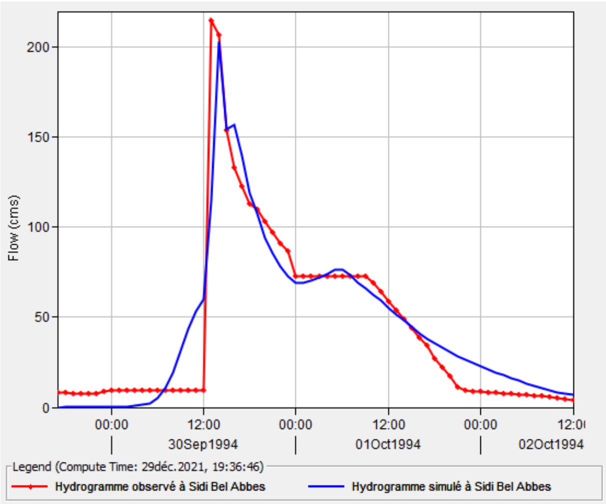

Figure 8: Observed and simulated hydrographs at the outlet of the Wadi Mekerra watershed in HEC-HMS after calibration.

USE OF THE MODEL

After calibration of the model, we simulate different hypothetical rainfall events for different average return periods (10, 20, 50, 100 and 1000 years) to obtain their corresponding hydrographs. We find that the simulated peak flows obtained by HEC-HMS are close to those derived from Gumbel laws. The results are presented in Table 9 and Fig. 9. The calibrated HEC-HMS model was also used to estimate the direct runoff volume of the Wadi Mekerra catchment area for different average return periods (10, 20, 50, 100 and 1000 years).

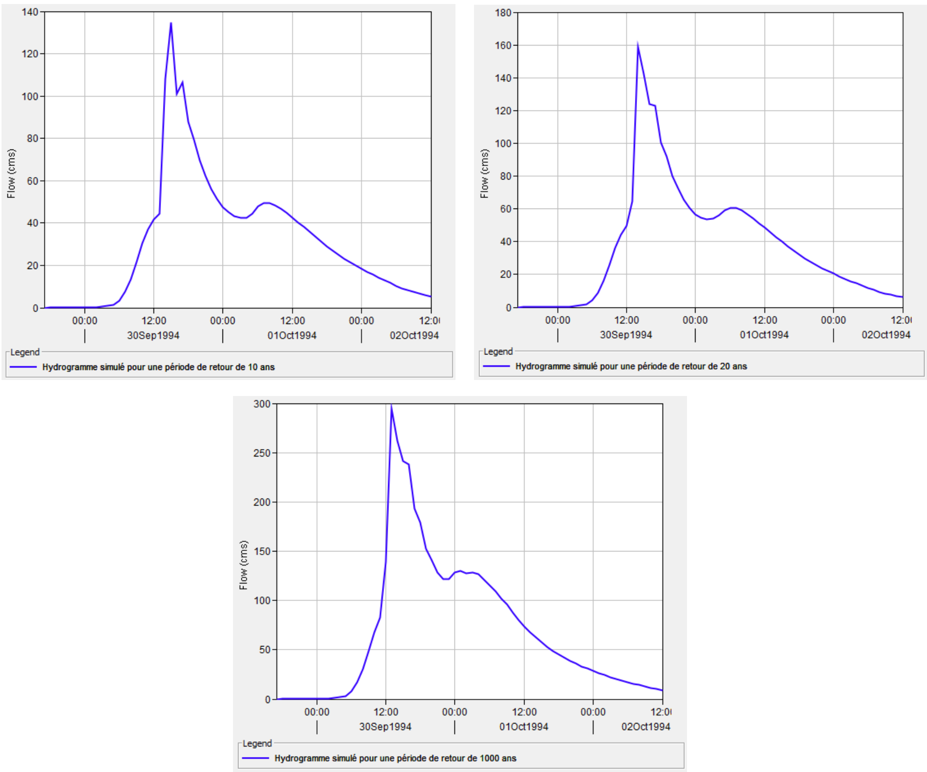

Figure 9: Simulated hydrographs of the Wadi Mekerra catchment area with return periods of 10, 20, 50, 100 and 100 years

Table 9: Results of simulated and observed hydrographs for the Wadi Mekerra catchment area.

Average return periods (years)	Hypothetical rainfall (mm)	Peak flow simulated by HEC-HMS (m /s)^{3}	Peak flow rate calculated by Gumbel laws (m /s)^{3}
10	46.52	134,7	132
20	50.82	158,7	166
50	55.88	203,5	210
100	59.39	223,6	244
1000	69.78	294,4	354

The peak flows (m^3 /s) and volumes (millions of m^3) for the catchment are shown in Table 10.

Table 10: Peak flows (m^3 /s) and volumes (hm^3) at the outlet of the Wadi Mekerra *catchment area*

Return periods	Peak flow (m /s)^3	Volume (hm)^3
10	134,7	7,62
20	158,7	9,06
50	203,5	10,90
100	223,6	12,25
1000	294,4	16,7

CONCLUSION

In this study, Digital Terrain Model (DTM) data with a resolution of 30 m was used for the delineation of the Wadi Mekerra catchment area. The average Runoff Curve Numbers (RCN) of the Wadi Mekerra sub-catchments were estimated from the GCN250 map of global grid curve numbers for hydrological modelling and design. The hydrological modelling software HEC-HMS was applied to the Wadi Mekerra catchment located in southwest Algeria to predict surface runoff. The curve number loss method SCS was used to determine the hydrological losses of the study area and the unit hydrograph method SCS was used for the effective transformation of rainfall. The model parameters were calibrated to the runoff event measured on 29 September to 02 October 1994. The Nash and Sutcliffe coefficient (NSE) was used to estimate the quality of the fit between the observed and simulated flow. The results obtained are very satisfactory. Therefore, the flows generated by the frequency-based hypothetical rainfall method will be very useful for the next flood risk study and risk assessment in the city of Sidi Bel Abbes using HEC-RAS.

As there are many ungauged wadis located in the semi-arid zone in Algeria, the presented methodology could allow an acceptable estimation of runoff in areas with similar conditions.

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