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Modelling rainfall runoff relations using HEC-HMS in a semi-arid region: Case study in Ain Sefra watershed, Ksour Mountains (SW Algeria)

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Abstract

Ain Sefra is one of the Algerian cities that had been experienced several devastating floods during the past 100 years. The purpose of this study is to simulate runoff in the semi-arid region of Ain Sefra watershed through the employing of the Hydrologic Engineering Center – Hydrologic Modelling System (HEC-HMS). In this paper, the frequency storm is used for the meteorological model, the Soil Conservation Service – curve number (SCS-CN) is selected to calculate the loss rate and Soil Conservation Service 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 0.95, indicates that the hydrological modeling results are satisfactory and accepted for simulation of rainfall-runoff. The peak discharges obtained for the 10, 50, 100 and 1000 year storms are respectively 425.8, 750.5, 904.3 and 1328.3 $m^3 \cdot s^{-1}$.

Key words: *Ain Sefra, floods, frequency storm, HEC-HMS, hydrological modelling, semi-arid climate*

INTRODUCTION

The report compiled by the UN Office for Disaster Risk Reduction (UNISDR) and the Belgian-based Centre for Research on the Epidemiology of Disasters (CRED), says that between 1995 and 2015, there were 3062 flood disasters, which accounted for 47% of all weather-related disasters and 43% of all natural disasters combined, which also includes geophysical hazards such as earthquakes and volcanoes. The floods are ranked first in the disaster world, causing nearly 32 million people, or 33.2% of the total number of people affected by natural disasters [GUHA-SAPIR *et al.* 2015]. In Algeria, the floods have marked as one of the most frequent natural disasters and the most destructive. The flood of November 10th, 2001 at Bab El Oued district of Algiers is the deadliest with 772 deaths [GUENIFI 2004]. These exceptional phenomena are well-studied under temperate climate however arid and semi-arid areas have received little attention [WHEATER *et al.* 2008]. This study interest in Ain Sefra which is situated in the western part of Ksour Mountains, in the junction of wadis Breidj and Tirkount (Fig. 1). As it belongs to a semi-arid climate, it already suffers the problem of flash flooding during the last 100 years. The most recent flood was in 2014, which caused losses of live and destruction to properties and infrastructures.

The flood damages will be increased over the years due to population growth and socio-economic development, and the climate change due to the global warming effect. Therefore, it is necessary to define

Fig. 1. Junction of wadis Breidj and Tirkount in Ain Sefra city (01.10.2014); source: own elaboration

methodology to predict the flash floods in this region, to protect the city against inundations. The widely used approach to determine flash flood occurrence and the relationships between rainfall and runoff data is the hydrological modelling which accommodate the hydrological process to estimate streamflow over river basins and assist forecasters in making a comparison between simulated streamflow and observed flooding, to predict and understand the hydrologic process. Hydrological studies are often aimed at establishing rainfall-runoff relationships [Shah *et al.* 1996]. Rainfall-runoff models can be categorized according to the model type. According to Clarke [1973] and Ambroise [1998], the hydrological models can be classified in to four main categories: determinist or stochastic, global or semi-distributed, kinematic or dynamic and finally empirical or conceptual. The selection of the model depends on the watershed and the objective of the hydrological forecast in the watershed. In this study, the conceptual approach is adopted for the hydrologic modelling, we use a semi distributed hydrologic model of HEC-HMS (Hydrologic Engineering Center-Hydrologic Modelling System) was developed by US Army Corps of Engineers, in order to investigate the rainfall-runoff interactions in the semi-arid Ain Sefra watershed of southwestern Algeria. It is applicable in diverses geographic areas for solving the widest possible of problems. Many scientists have conducted important hydrologic studies using HEC-HMS model, which proved its ability to simulate and forecast streamflow. As example: Sintayehu [2015] used HEC-HMS model employing Snyder unit hydrograph and exponential recession method to simulate the runoff of upper Blue Nile River Basin. Norhan *et al.* [2016] modelled rainfall-runoff relations using HEC-HMS in arid environment at Wadi Alaqiq, Madinah, Saudi Arabia. Sampath *et al.* [2015] modelled the rainfall-runoff relations using HEC-HMS in tropical catchment in Sri Lanka. Meiling *et al.* [2016] employed the HEC-HMS to simulate runoff in the semi-arid region of northwestern China. Laouacheria and Mansouri [2015] used HEC-HMS model by employing frequency storm to simulate the runoff in a small urban catchment in the North-East of Algeria. Mokhtari *et al.* [2016] modelled the rain-flow by HEC-HMS in watershed of Wadi Cheliff-Ghrib in the North of Algeria. Skhakhfa and Ouerdachi [2016] used HEC-HMS for estimating floods of short duration in Wadi Ressoul watershed in the North-East of Algeria. Wałęga [2013] reconstrued a flood event in an uncontrolled basin by using HEC-HMS model. This paper presents a methodology of rainfall–runoff model by using HEC-HMS program integrated with DEM data as an input for basin model in semi-arid environment to simulate the pick discharges for 10, 50, 100 and 1000 year (average recurrence interval – *ARI*) in Ain Sefra watershed and its sub-catchment.

MATERIALS AND METHODS

DATA

Rainfall time series data are collected from Algerian Meteorological Office (Fr. Office National de la Météorologique – ONM) from the only meteorological station in the region that of Ain Sefra (for 1980–2014), and flow data are collected from the National Agency of the Hydraulic Resources (Fr. Agence Nationale des Ressources Hydrauliques – ANRH) from the unique gauging station in the region that of Ain Hadjadj (for 1978–2008) – Table 1.

Table 1. Characteristics of rainfall and runoff stations in Ain Sefra watershed

Station name	Gauge type	Longitude	Latitude	Elevation m	Selected period
Ain Sefra	rainfall gauge	32°45'08.44"N	0°35'39.02"W	1 084	1980–2014
Ain Hadjadj	runoff gauge	32°38'33.74"N	0°22'17.92"W	933	1978–2008

Source: own elaboration.

Also, spatial data was downloaded from USGS [undated] in the form of ASTER (Advanced Spaceborn Thermal Emission and Reflection Radiometer) type Global Digital Elevation Model GDEM with 30 m resolution. We adopted the DEM to define Ain Sefra watershed and its physical characteristics.

METHODS

Our objective is to examine the rainfall-runoff relationship in Ain Sefra watershed, in order to propose effective solutions to protect the city against inundations. The methodology is based on meteorological and physical data processing in the geospatial environment and on data editing using remote sensing and GIS techniques. Our methodology can be separated into six main stages:

- description and geographic location of the study area;
- DEM processing, defining stream network, topography, and watershed characteristics, using the extension ArcHydro tools in ArcMap;

- define geological and soil characteristics of the watershed, to compute the runoff curve number (CN);
- importing the catchment physical characteristics data to HEC-HMS model;
- run the rainfall/runoff simulation, and compare compute and observes flows;
- calibration and validation of the model.

DESCRIPTION OF STUDY AREA

Ain Sefra watershed has an area of 1957 km^2; it's situated in the SW of Algeria in the region called Ksour Mountains (Fig. 2). It is located between longitudes (1°0'0" and 0°03'00" W) and latitudes (32°30'22" and 33°00'00" N). The watershed is as a landlocked basin surrounded by mountains, dominated south by a marked relief of Mekther Mountain (2035 m), the South West by Mir El Djebel (2109 m) and the Mzi Mountains (2206 m), north by Aissa Mountain (2236 m) and the north west by Morghad Mountain (2136 m) and Bouamoud Mountain (2116 m).

With 67 km of length, the longest flow path run southwestward from its origin in the north side of Morghad Mountain, and receive the valley of Sfissifa, together they forms the valley of Breidj, and they pursues the same direction to meet the valley of Tirkount that drains the waters of Morghad Mountain and Aissa Mountain and has 29.6% of Ain Sefra watershed area. These two valleys (Breidj and Tirkount) meet at downtown Ain Sefra to form the valley of Ain Sefra that's run to the south at downstream of the study area while receiving other valleys as Tiout and Sam, to become at the end the Namous valley that is lost in the great western Erg in the Algerian Sahara at 370 km from its origin. The network is quite dense and branched which allows easy collection of rainwater to lead them to the outlet [DERDOUR *et al.* 2013].

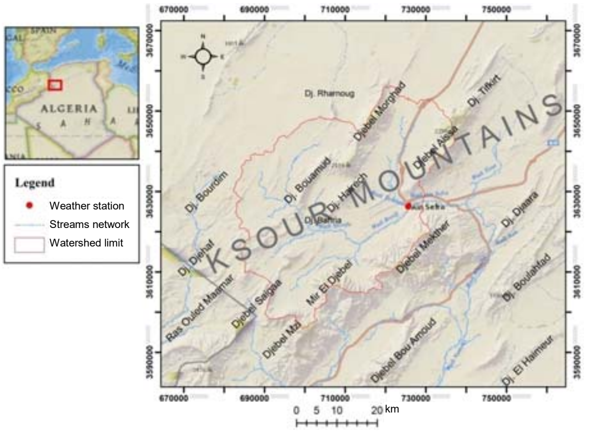


Fig. 2. Location of Ain Sefra watershed in Algeria (ASTER, 30 m resolution, Map datum: UTM WGS 84); source: own elaboration

TOPOGRAPHY OF AIN SEFRA WATERSHED

The morphometric characteristics are extracted from digital elevation model (DEM). The most common altitudes are between 1200 and 1400 m representing 57% of the total area of Ain Sefra watershed. The altitudes below 1100 m represent only 2% of the total area (Fig. 3). Ain Sefra watershed is characterized by relatively steep slopes upstream, the slope decreases downstream from the confluence of Wadi Sfissifa with Wadi Breïdj. The mean elevation is 1334 m and the mean basin slope is 5.8 m·km^{-1}.

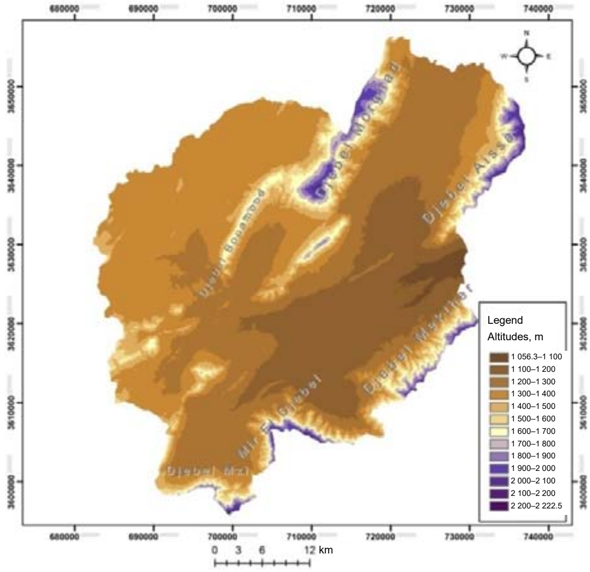


Fig. 3. Hypsometric map of Ain Sefra watershed (Map datum: UTM WGS 84); source: own elaboration

There are three types of slopes (Fig. 4):

1) a relatively low slope between (0 and 6%) at low altitudes (1058–1400 m), where the presence of a deep valley in the area of El Hendjir, and Ain Sefra, occupying 79% of the total area of the watershed;
2) a moderately steep slope between (6 and 25%) at moderate altitudes (1400–1600 m), where the presence of an intermediate hill in the foothills of Djebels: the area occupied is about 12%;

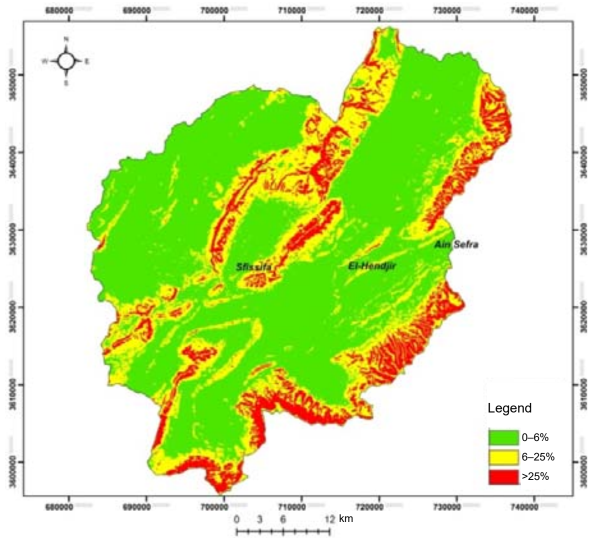


Fig. 4. Map of slopes of Ain Sefra watershed (Map datum: UTM WGS 84); source own elaboration

3) a very steep (over 25%) at altitudes (1600–2213 m) explaining the presence of mountains that occupy 8% of the total area of the basin, these slopes give the river a violent and torrential type.

GEOLOGY OF AIN SEFRA WATERSHED

The watershed is composed of different geological constituents from the Triassic formation to the Quaternary with a predominance of the Mesozoic formations. According to KACEMI [2014] the formation of Tiout belonging to the Cretaceous is the largest with a thickness of 1065 m. More than 46.4% of the area is covered by Jurassic formation, 19.4% of Mio-Pliocene formations, and 18% of Cretaceous formations. The other percent (16.2%) filled with, alluvium, colluvium, and Quaternary formations. The Figure 5 shows the geological map of Ain Sefra watershed extracted from the geological map of Algeria [CORNET, DELEAU 1951]. The facies that largely dominate the Ksour Mountains are the sandstone formations (Jurassic and Cretaceous), but they are usually clayey interspersed by marl or compact quartz, their permeabilities are generally very low, except for the Albian sandstone which constitute the most important groundwater aquifer in the region which is characterized by confined to semi-confined conditions [RAHMANI 2010]. The Quaternary formations are very thick but they cover large areas in the basin; they are known by their high permeability [DOUIHASNI 1976; GALMIER 1970], as the case of the wadis Breidj and Tirkount that left their banks significant alluvial deposits that contain a alluvial watertables exploited by many wells.

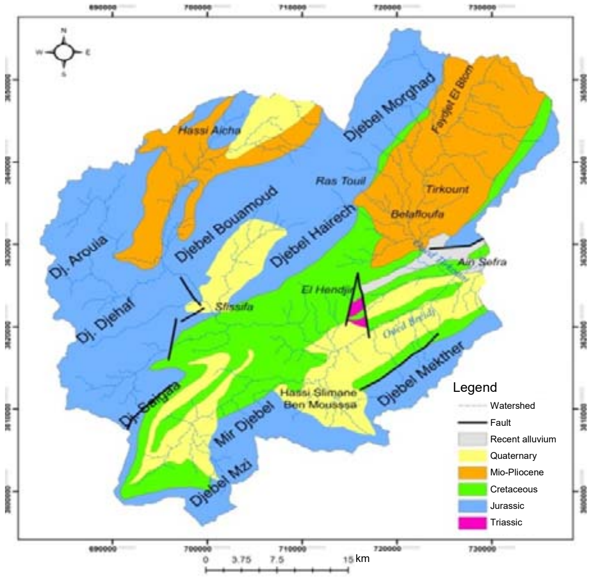


Fig. 5. Map of geology of the studied zone (Map datum: UTM WGS 84); source: own elaboration

LAND USE AND SOIL TYPE OF AIN SEFRA WATERSHED

The land use data was provided from the General Directorate for Forestry of Algeria (Fr. Direction Générale des Forêts Algérie – DGF). The total area of the basin covers about 1957 km^2. The main dominant lands in the basin are the grasslands (56.2%), the forest land (29.2%), bare areas (6.6%) and outcrop lands (4.4%). The rest are in minor proportion: agricultural lands (1.8%), sand lands (1.6%) and urban areas (0.3%) – Figure 6.

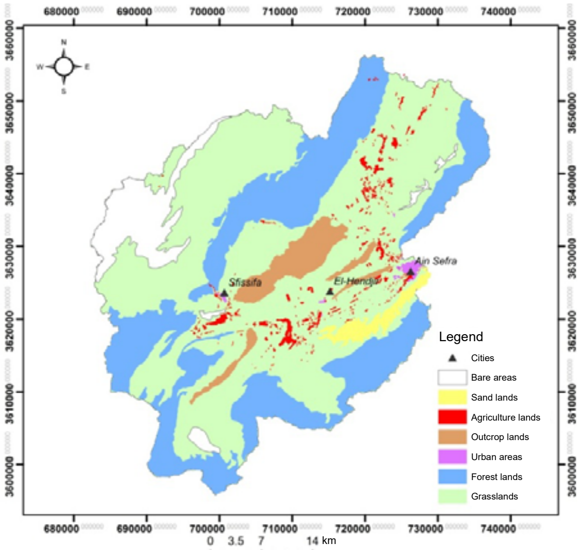


Fig. 6. Land use of Ain Sefra Watershed (Map datum: UTM WGS 84); source: own elaboration

The other major factor of the basin property is the soil type. Soil types and their distribution are extremely related to the nature of geomorphic unites. According to the researches of: BENSAID [2007], DJEBAILI [1984], POUGET [1977] and GORDO [2014], four soil types are distinguished in the basin of Ain Sefra: The calci-magnesi soils, the mineral soils, the poorly graded soils and the saline soils.

HYDRO CLIMATIC CHARACTERISTICS AIN SEFRA WATERSHED

The region is characterized by a semi-arid climate, with dry and hot summers where rainfall is almost absent and with high evaporation. Winters are

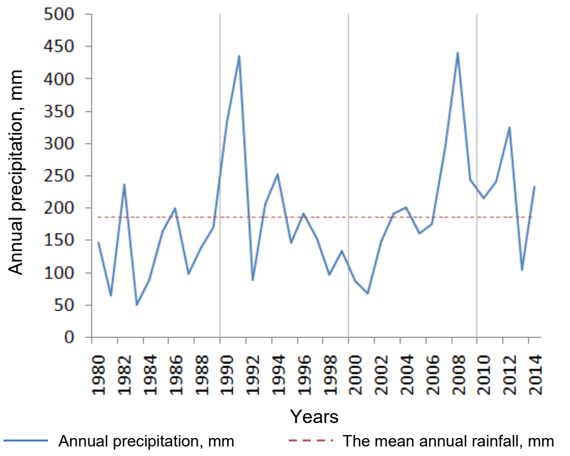


Fig. 7. The total annual rainfall depth at the rain gauge of Ain Sefra city; source: own study

cool and sometimes very cold, with often rain intensities in autumn. The series of data available from 1980 to 2014 in the only weather station in the region that of Ain Sefra, shows that the study area receives annual rainfall between 50.3 mm and 439.8 mm with an average of 185 mm (Fig. 7). The region rainfall is characterized by high temporal and spatial irregularity. The average monthly rainfall is 30.64 mm for the wettest month (October), and 3.92 mm for the driest month (July). The durations of rainfall events in Ain Sefra wetershed vary from storm to storm but they are generally short with a high intensity. The annual average temperature is around 17.5°C.

The maximum, minimum, and average temperatures show that the lowest temperatures occurs in November, December, and January and the highest records are in June, July, and August. Only 1.3% of the rainfall infiltrates and percolates into the saturated zones, which is comparable with other arid and semiarid regions [DERDOUR 2010].

The mean annual runoff of the basin is 0.7 $m^3 \cdot s^{-1}$, with high temporal and spatial variability. Ain Sefra watershed floods are highly variable and irregular, short and stormy, with very high peak discharges. The morphology of the basin helps boost peak discharges observed at the outlets. The peak discharges of the Wadi Ain Sefra vary from a few $m^3 \cdot s^{-1}$ to 750.84 $m^3 \cdot s^{-1}$. The maximum peak discharges is recorded in 1st October 2014. Floods are characterized by a very fast rise, leading severe damages in Ain Sefra city, and a slow decline followed by a prolonged dry period. Autumn is reported as risky season. After having tested several statistical methods employed in flood frequency analysis (FFA) (exponential, GUV, gamma, Gumbel, normal, log-normal), peak discharges of Wadi Ain Sefra during 32 years fits well with the Gumbel approach (Fig. 8). This statistical methods employed allow us to estimate the peak discharges ($Q_{\max}$) for different average recurrence interval (Tab. 2).

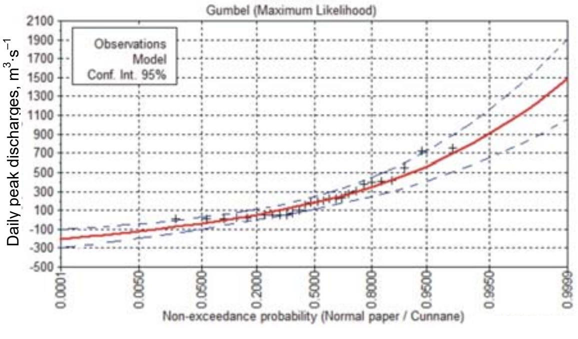


Fig. 8. Peak discharges adjusted with Gumbel statistical method; source: own elaboration

Table 2. Peak discharges with Gumbel approach

Flow ($m^3 \cdot s^{-1}$) when average recurrence interval (years)				
10	20	50	100	1000
463	580	731	845	1 120

Source: own elaboration.

HEC-HMS MODEL

MODEL DESCRIPTION

The Hydrologic Engineering Center's Hydrologic Modeling System (HEC-HMS) is designed to simulate the precipitation-runoff processes of dendritic watershed systems. It is designed to be applicable in a wide range of geographic areas for solving the widest possible range of problems [SCHARFFENBERG, FLEMING 2016]. Hydrographs produced by the program are used directly or in conjunction with other software for studies of water availability, urban drainage, flow forecasting, future urbanization impact, reservoir spillway design, flood damage reduction, floodplain regulation, and system operation [SCHARFFENBERG, FLEMING 2016]. HEC-HMS model setup consists of four main model components: basin model, meteorological model, control specifications, and input data (time series, paired data, and gridded data). An assortment of different methods is available to simulate infiltration losses (deficit and constant, exponential, Green and Ampt, initial and constant, SCS curve number, Smith Parlange and Soil Moisture Accounting – SMA). Seven methods are included for transforming excess precipitation into surface runoff (Clark unit hydrograph, kinematic wave, ModClark, SCS unit hydrograph, Snyder unit hydrograph, user specified graph and user specified unit hydrograph). Six methods are included for routing model (kinematic wave routing, lag routing, modified puls routing, Muskingum routing, Muskingum–Cunge routing and Straddle Stagger routing). For the meteorological model eight methods are included (frequency storm, gage weights, gridded precipitation, inverse distance, HMR52, SCS storm, specified hyetograph, standard project storm).

MODEL STRUCTURE

In this study, SCS curve number (CN) loss method will be used to determine the hydrologic loss rate, the SCS unit hydrograph (HU) method will be used to calculate the runoff rate, and the simulating process is done by using frequency storm for the meteorological model.

CATCHMENT MODEL

The catchment model represents the physical watershed. In order to increase for better performance of modelling, in this study, the catchment is sub divided into two major sub basins (Breidj and Tirkount) to use the model as semidistributed. The representation of these sub-catchments within the watershed is shown in Figure 9. The hydrological parameters of sub--catchments of Ain Sefra watershed are shown in Table 3.

Table 3. Hydrological parameters of sub-catchments of Ain Sefra watershed

Catchment	Area km^2	Perimeter km	Channel slope %	Stream length km
Tirkount	579.55	143.34	9.56%	44.51
Breidj	1373.44	269.2	9.31%	67.00

Source: own elaboration.

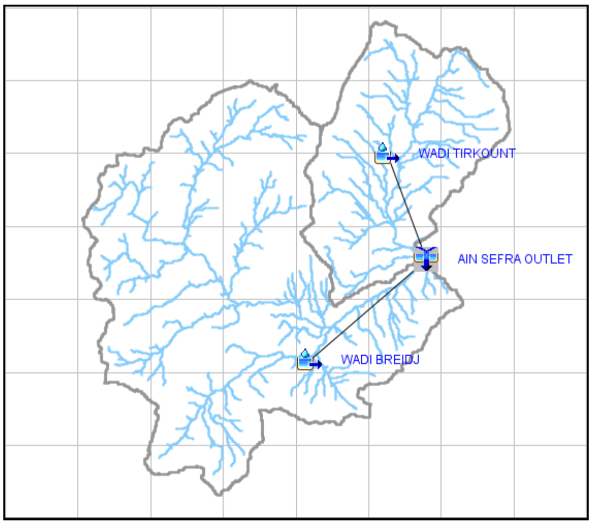


Fig. 9. The schematic representation in Hydrologic Engineering Center's-Hydrologic Modelling System of Ain Sefra watershed; source: own elaboration

LOSS METHOD

In this study, SCS curve number (*CN*) loss method is used to determine the hydrologic loss rate. The Soil Conservation Service (now the Natural Resources Conservation Service) curve number method implements the curve number methodology for incremental losses. Originally, the methodology was intended to calculate total infiltration during a storm. The *CN* for a watershed can be estimated as a function of land use, soil type, and antecedent soil moisture, using tables published by the SCS. *CN* values range from 100 (for water bodies) to approximately 30 for permeable soils with high infiltration rates [SCHARFFENBERG, FLEMING 2010]. The SCS CN model is given by Equation (1):

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

Where: Q = runoff value (mm); P = precipitation (mm); I_a = initial abstraction (mm); S = potential maximum retention is given by Equation (2):

$$S = \frac{254000 - 254}{CN} \tag{2}$$

The runoff curve number *CN* is a function of land use, treatment and condition; infiltration characteristics of the soils; and antecedent moisture condition. MCCUEN [1982] discusses the use of the SCS runoff model in detail. The hydrological soil classification system developed by the Soil Conservation Service was used for classifying soils into different hydrological soil groups. In this classification system, soils are classified as A, B, C or D hydrologic soil group depending on their properties: Soil group 'A' has low runoff potential and high infiltration. Soil group 'B' has low to moderate runoff. Soil group 'C' have flat infiltration rate, so the runoff is quite higher. Soils group 'D' has high runoff potential and very low infiltration rate [NRCS 2007]. For this purpose the hydrologic soil groups were defined based on the geological map of Ain Sefra watershed. The results are listed in Table 4.

Table 4. Soil type classification on Ain Sefra watershed

Geological formations	Infiltration type	Soil group
Quaternary	high infiltration	A
Mio-Pliocene	medium infiltration	B
Cretaceous	medium infiltration	B
Jurassic	flat infiltration	C
Triassic	flat infiltration	C

Source: own elaboration.

In this study, curve numbers (*CN*) are computed for the two sub-catchments (Tirkount and Breidj) are based on their land use/covers, soil types, and hydrologic soil groups by using appropriate approaches in watershed modelling system WMS [AQUAVEO 2012]. The *CN* values are listed in Table 5.

Table 5. Curve numbers values of the sub-catchments of Ain Sefra watershed

Sub-catchments	Curve number
Tirkount	75
Breidj	79

Source: own study/ own elaboration.

TRANSFORM METHOD

In this paper, the translation of excess precipitation to runoff is accomplished using the user-specified S-graph transform method. The SCS unit hydrograph method requires only one parameter for each subbasin "The lag time". The standard lag is defined as the length of time between the centroid of precipitation mass and the peak discharges of the resulting hydrograph [USGS 2012]. The transform method requires a lag time determination as an input. The SCS developed a relationship between the time of concentration (T_c) and the lag time (T_{lag}) given by Equation (3). The time of concentration is calculated by Giandotti's formula given by Equation (4) [GIANDOTTI 1934]. The time of concentration and lag time values for the Breidj and Tirkount sub-catchments are listed in Table 6.

$$T_{\text{lag}} = 0.6T_c \tag{3}$$

$$T_c = \frac{4\sqrt{A} + 1.5L}{0.8\sqrt{H}} \tag{4}$$

Where: T_{lag} = the lag time; T_c = the time of concentration; A = the watershed area (km^2); L = the length of the main channel (km); H = the difference between the mean basin elevation and the outlet elevation (m).

Table 6. The temps of concentration and lag times of Ain Sefra sub-catchments

Sub-catchment	T_c, min	T_{lag}, min	T_c, h	T_{lag}, h
Tirkount	295.4	177.24	4.9	2.95
Breidj	645.2	387.22	10.7	6.45

Explanations: T_{lag} = the lag time; T_c = the time of concentration.
Source: own study.

METEOROLOGICAL MODEL

In this study, frequency storm data are used for the HEC-HMS model. The frequency storm method is designed to produce a synthetic storm from statistical precipitation data. This method is designed to use data collected from the maps along with other information to compute a hyetograph for each sub-basin, and to accept partial or annual duration precipitation depth-duration data. The records from Ain Sefra rainfall station were obtained and analysed to establish the intensity-duration-frequency (*IDF*) curves based on extreme value, in order to evaluate the watershed reaction to a given rainfall event. In this study, it is assumed that the entire watershed would receive the same amount of design rainfall. The rainfall *IDF* results adopted for the area for various storm durations and average recurrence interval (*ARI*) are listed in Table 7. The storm durations of 1, 2, 3, 4, 5, 6 and 24 hours are used in the simulations.

Table 7. Design storm rainfall intensity for various duration

Average recurrence interval years	Rainfall intensity (mm·h^{-1}) when duration (h)							
	1	2	3	4	5	6	12	24
10	21.9	27.0	30.5	33.2	35.5	37.5	46.2	56.9
50	34.6	42.6	48.1	52.5	56.1	59.2	72.9	89.8
100	40.9	50.3	56.8	61.9	66.2	69.9	86.1	106.0
1 000	64.0	78.8	89.0	97.0	103.7	109.5	134.8	166.0

Source: own study.

RESULTS AND DISCUSSION

The selected historical event for the control was the flood of 24th October 2000, measured by the National Agency of Hydraulic Resources (ANRH) which records maximum peak discharges (750.84 m^3·s^{-1}), and that represent the flood of 50 year recurrence interval according to the frequency analysis with the statistical Gumbel method. After the first simulation with HEC-HMS, we obtained the Figure 10 that illustrated the difference between simulated and observed hydrographs for the event of 24th October, 2000. The figure indicates that the simulated hydrograph underestimates the peak discharge; it can be observed that simulated peak discharge is 622.5 m^3·s^{-1}; however the observed peak discharge is about 750.84 m^3·s^{-1}.

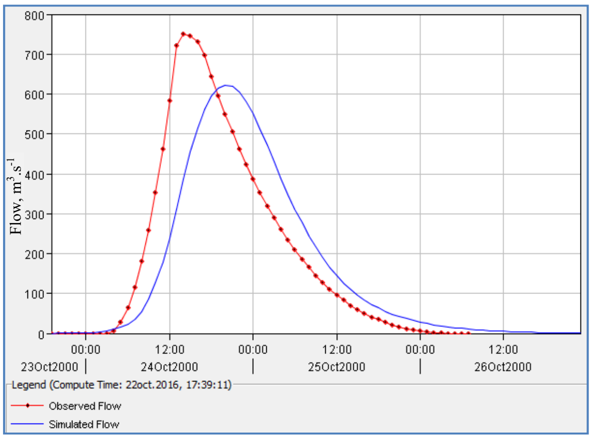


Fig. 10. Observed and simulated hydrographs for Ain Sefra watershed in Hydrologic Engineering Center's-Hydrologic Modelling System before calibration; source: own study

CALIBRATION

Model calibration is a systematic process of adjusting model parameter values until model results match acceptably the observed data. The precipitation-run-off models, this function measures the degree of variation between computed and observed hydrographs [CUNDERLIK, SIMONOVIC 2004]. The purpose of calibration is to identify the parameters whose variation causes significant changes in the outputs of the model. For the calibration of the generated simulation in the present study, the measured peak discharges of 750.84 m^3·s^{-1} is used to enhance the difference between the simulated and observed discharge hydrograph. In our case we have to choose the *CN*, impervious, and lag time parameters. Table 8 shows the corresponding parameters for calibration for each sub-catchment.

After the calibration, we obtained the Figure 11 that illustrated the difference between simulated and observed hydrographs at the outlet of Ain Sefra watershed. The Figure 11 indicates that the simulated hydrograph and are very close to the observed hydrographs. The simulated peak discharge and the observed peak discharge are 750.6, 750.48 m^3·s^{-1} respectively, noting that the peak discharge calculated by Gumbel approach is 731 m^3·s^{-1}. The performance of the HEC-HMS model is evaluated using the Nash–Sutcliffe efficiency coefficient (*NSE*) [NASH, SUTCLIFFE 1970], given by Equation (5), 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 discharge hydrograph obtained using the HEC-HMS model is perfectly matched by the observed discharge hydrograph with Nash–Sutcliffe coefficient value of 0.95.

$$NSE = 1 - \frac{\sum_{i=1}^{N}(Q_{i,\text{obs}} - Q_{i,\text{sim}})^2}{\sum_{i=1}^{N}(Q_{i,\text{obs}} - \overline{Q}_{\text{obs}})^2} \tag{5}$$

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

Table 8. Calibration parameters

Method	Parameter	Breidj	Tirkount
Loss method	curve number	85	86
Transform method	impervious, %	25	25
	lag time, min	645.2	295.4

Source: own study.

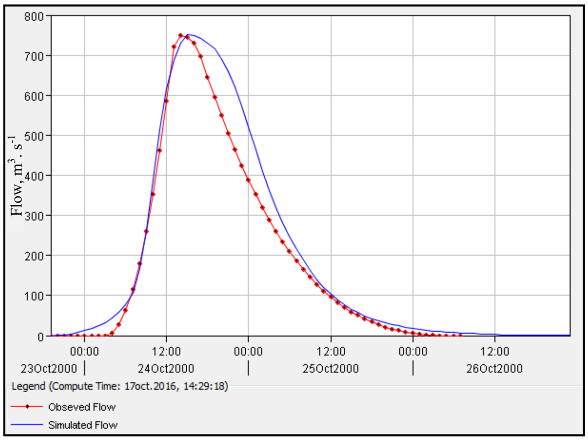


Fig. 11. Observed and simulated hydrographs for Ain Sefra watershed in Hydrologic Engineering Center's-Hydrologic Modelling System after calibration; source own study

EXPLOITATION OF THE MODEL

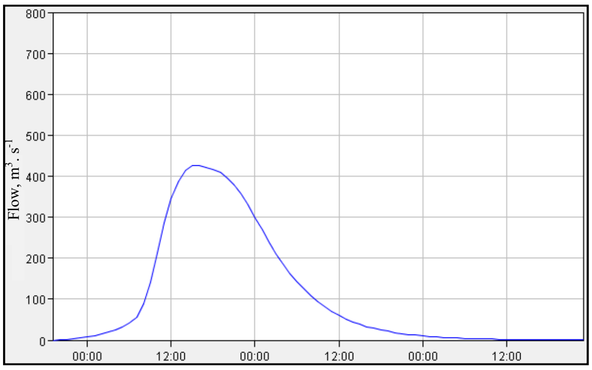
After the calibration of the model, we simulate various hypothetical storm events for various *ARI*'s (10, 50, 100 and 1000 years) to obtain their corresponding hydrograph. We note that the simulated peak discharges obtained by HEC-HMS were close with those derived by Gumbel approach. The results are listed in Table 9 and Figure 12.

The calibrated HEC-HMS model were also used to estimate direct runoff volume, and the peak discharges for the two ungauged sub-catchments (Breidj and Tirkount) of Ain Sefra watershed for various average recurrence intervals (10, 50, 100 and 1000 years).

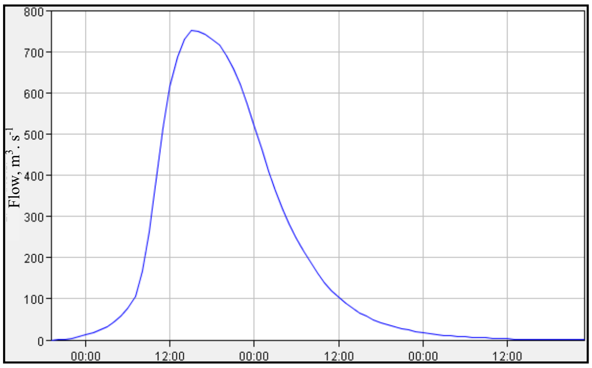
Table 9. Results of simulated and observed hydrographs for Ain Sefra watershed

Average recurrence interval years	Hypothetical storm mm	Simulated peak discharges (HEC-HMS) $m^3 \cdot s^{-1}$	Calculated peak discharges (Gumbel) $m^3 \cdot s^{-1}$
10	56.9	425.8	463
50	70.5	750.5	731
100	106	904.3	845
1 000	166	1 328.3	1 220

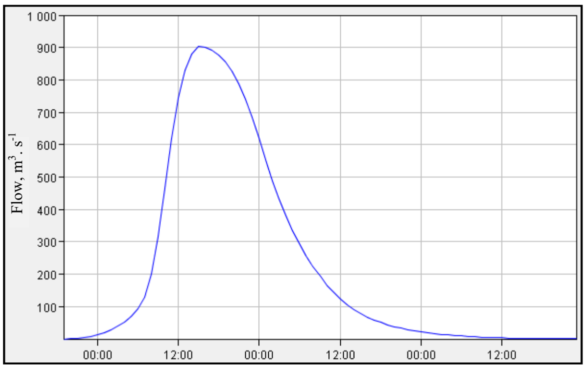
Explanations: HEC-HMS = Hydrologic Engineering Center's-Hydrologic Modelling System.
Source: own study.



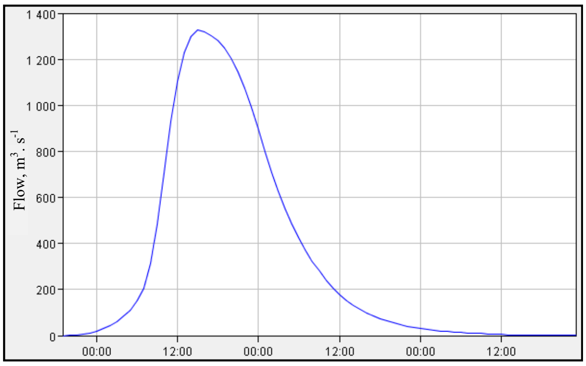
10 years



50 years



100 years



1000 years

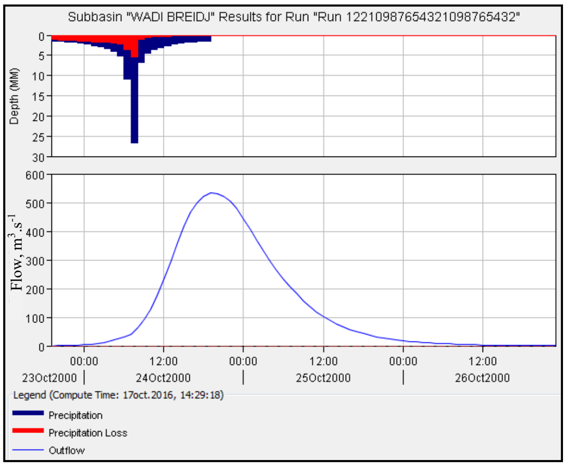
Fig. 12. Simulated hydrographs of Ain Sefra watershed of the 10, 50, 100 and 1000 return period; source: own study

The peak discharges ($m^3 \cdot s^{-1}$) and volumes (millions m^3) for the sub-catchments, are listed in Table 10. The Figure 13 shows the simulated hydrographs of

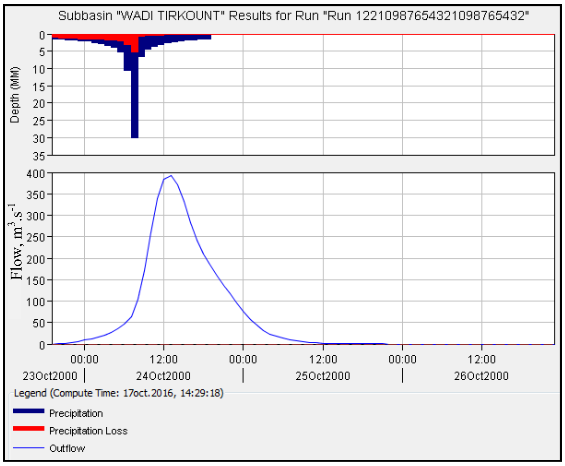
Table 10. Peak discharges ($m^3 \cdot s^{-1}$) and volumes (hm^3) for the sub-catchments

Average recurrence interval years	Parameters	Breidj sub--catchment	Tirkount sub--catchment	Outlet (Ain Sefra)
1 000	peak discharges	943.5	687.3	1328.3
	volume	62.51	26.97	89.48
100	peak discharges	641.9	473.0	904.3
	volume	42.52	18.52	61.04
50	peak discharges	532.8	393.2	750.5
	volume	35.42	15.51	50.93
10	peak discharges	301.1	227.0	425.8
	volume	20.11	8.9	29.01

Source: own study.



Breidj sub-catchment



Tirkount sub-catchment

Fig. 13. Simulated hydrographs of sub-catchments of Ain Sefra watershed for the event of 24.10.2000; source: own study

sub-catchments (Breidj and Tirkount) for the 24th October 2000 flood event. The peak discharges and volumes for the sub-catchments Breidj and Tirkount are respectively: 532.9 and 393 $m^3 \cdot s^{-1}$, 35.4 and 15.5 mln m^3. This difference is due mostly to topography condition and the catchment area (Tirkount sub-catchment area – 579.55 km^2, Breidj sub-catchment area – 1 373.44 km^2).

CONCLUSION

In this study Digital Elevation Model (DEM) data of 30 m resolution was used for Ain Sefra watershed delination and catchment characteristics using the extension ArcHydro in Arc GIS. Geological, soil and land use data used to well-understand the nature the watershed. The HEC-HMS hydrologic modeling software was applied to Ain Sefra watershed located in southwestern Algeria to predict the surface runoff. The SCS curve number loss method was used to determine the hydrologic losses from the study area and SCS unit hydrograph method was used for effective rainfall transformation. The model parameters were calibrated against measured runoff event of 24th October, 2000. The daily Nash and Sutcliffe efficiency (*NSE*) was used to estimate the goodness of fit between the observed stream flow and modeled stream flow. The results obtained are very satisfactory. Therefore, runoffs generated from frequency storm method will be invaluable for the next study of flood hazard and risk assessment in Ain Sefra city using HEC-RAS.

As there are plenty of ungauged rivers located in the semi arid zone in Algeria, the presented methodology could be allowed an acceptable estimation of the runoff in areas with similar conditions.

REFERENCES

AMBRSOISE B. 1998. La dynamique du cycle de l'eau dans un bassin versant. Processus, Facteur, Modèles [The dynamics of the water cycle in a watershed. Process, factor, models]. Bucarest. H.G.A. ISBN 973-98954-2-5 pp. 206.

AQUAVEO 2012. WMS 9.1 Tutorial. Watershed modeling – Time of concentration calculations and computing a composite CN. Provo. Utah pp. 14.

BENSAID A. 2007. SIG et télédétection pour l'étude de l'ensablement dans une zone aride: le cas de la Wilaya de Naama (Algérie) [GIS and remote sensing for the study of silting in an arid zone: The case of the Wilaya of Naama (Algeria)]. PhD Thesis. Grenoble. Joseph Fourier University pp. 319.

CLARKE R.T. 1973. A review of some mathematical models used in hydrology with observations on their calibration and use. Journal of Hydrology. Vol. 19 p. 1–20.

CORNET A., DELEAU P. 1951. Carte géologique au 1/500.000 [Geologic card of Algeria scale 1/500.000]. Algiers, Algeria. Le service de la Carte Géologique d'Algérie.

CUNDERLIK J.M., SIMONOVIC S. P. 2004. Calibration, verification, and sensitivity analysis of the HEC-HMS hydrologic model. CFCAS project: Calibration, verifycation, and sensitivity analysis of the HEC-HMS hydrologic model. Project report IV. London, Canada. The University of Western Ontario pp. 113.

DERDOUR A. 2010. Modélisation hydrodynamique de la nappe des grès Crétacé de Remtha. Monts des Ksour [Hydrodynamic modelling of the cretaceous sandstone watertable of Remtha's Synclinal. Ksour Mountains]. MSc Thesis. Tlemcen. Unversity of Tlemcen pp. 101.

DERDOUR A., BOUANANI A., BABAHAMED K. 2013. Utilisation d'un SIG pour l'évaluation des caractéristiques physiques d'un bassin versant et leurs influences sur l'écoulement des eaux (Bassin versant d'Ain Sefra, Sud-Ouest Algérien) [Use of GIS for the assessment of the physical characteristics of a watershed and their influences on water flow (case of Ain Sefra watershed, S-W of Algeria]. Séminaire sur le développement des sciences, de la vie et de l'univers. 14–15.05.2013, Tlemcen p. 227–230.

DJEBAILI S. 1984. Steppe Algérienne phytosociologie et écologie [Algerian steppe phytosociology and ecology]. Alger. Office des publications universitaires pp. 178.

DOUIHASNI M. 1976. Etude géologique de la région d'Ain Ouarka-Bousemghoun (partie centrale des Monts des Ksour). Stratigraphie et analyse stucturale [Geological study of the region of Ain Ouarka-Bousemghoun (central part of Ksour Mountains). Stratigraphy and structural analysis]. Thèse 3éme cyc. Oran. Univesity of Oran pp. 272.

GALMIER D. 1970. Photogéologie de la région d'Ain Sefra (Atlas Saharien, Algérie) [Photogeology of the region of Ain Sefra (Saharian atlas, Algeria)]. PhD Thesis. Paris pp. 320.

GIANDOTTI M. 1934. Previsione delle piene e delle magre dei corsi d'acqua [Forecast of floods and lean waters]. Istituto Poligrafico dello Stato. Vol. 8 p. 107–117.

GORDO B. 2014. Contribution à l'analyse phytoécologique de la région d'Ain Sefra (Naama) [Contribution to the phytoecological analysis of the region of Ain Sefra (Naama)]. MSc Thesis. Oran. University of Oran pp. 141.

GUENIFI D. 2004. Gestion risque inondation: Application réglementaire pour la sauvegarde des personnes et des biens [Flood risk management: Regulatory application for safeguarding people and property]. Actes des journées techniques des risques naturels: Inondation, prévision, protection. 15–16.12.2004 Batna, Algeria. University of Batna p. 58–62.

GUHA-SAPIR D., HOYOIS P., BELOW R. 2015. Annual disaster statistical review 2014: The numbers and trends. Brussels. CRED pp. 50.

KACEMI A. 2014. Evolution lithostructurale des Monts des Ksour (Atlas Saharien, Algérie) au cours du Trias et du Jurassique: Géodynamique, typologie du bassin et télédétection [Lithostructural evolution of Ksour Mountains (Saharian Atlas, Algeria) during the Trias and Jurassic periods: Geodynamics, basin typology and remote sensing]. PhD Thesis. Tlemcen, Algérie. Université Abou BakrBelkaid pp. 249.

LAOUACHERIA F., MANSOURI R. 2015. Comparison of WBNM and HEC-HMS for runoff hydrograph prediction in a small urban catchment. Water Resources Management.Vol. 29 p. 2485–2501. DOI 10.1007/ s11269-015-0953-7.

MCCUEN R.H. 1982. A guide to hydrologic analysis using SCS methods. Englewood Cliffs, N.J. Prentice-Hall. ISBN 0133702057. pp. 145.

MEILING W., LEI Z., THELMA D. 2016. Hydrological modeling in a semi-arid region using HEC-HMS. Journal of Water Resources and Hydraulic Engineering. Vol. 5 Iss. 3 p. 105–115. DOI 10.5963/JWRHE 0503004.

MOKHTARI E.H., REMINI B., HAMOUDI S.A. 2016. Modelling of the rain–flow by hydrological modelling software system HEC-HMS – watershed's case of wadi Cheliff-Ghrib, Algeria. Journal of Water and Land Development. No. 30 p. 87–100. DOI 10.1515/jwld-2016-0025.

MORIASI D.N., ARNOLD J. G., VAN LIEW M. W., BINGNER R.L., HARMEL R.D., VEITH T.L. 2007. Model evaluation guidelines for systematic quantification of accuracy in watershed simulations. American Society of Agricultural and Biological Engineers. Vol. 50(3) p. 885−900.

NASH J.E., SUTCLIFFE J. 1970. River flow forecasting through conceptual model. Part 1: A discussion of principles. Journal of Hydrology. Vol. 10. Iss. 3 p. 282–290.

NORHAN A., SAUD T., FAHAD A., KAMARUL A. 2016. Arid hydrological modeling at wadi Alaqiq, Madinah, Saudi Arabia. Jurnal Teknologi p. 51–58. DOI 10.11113/jt.v78.4516.

NRCS 2007. National Engineering Handbook: Part 630 – Hydrology. Chapter 7. USDA Natural Resources Conservation Service. Hydrologic Soil Groups pp. 14.

POUGET M. 1977. Cartographie des zones arides. Note explicative Office de la Recherche Scientifique et Technique Outre-mer [Arid zone mapping. Explanatory note Office for Scientific and Technical Research Overseas]. Paris. ORSTOM. ISBN 2-7099-0435-7 pp. 101.

RAHMANI A. 2010. Apport des S.I.G dans la caractérisation hydrodynamique et hydrochimique de la nappe du crétacé inférieur de la région d'Ain Sefra (Atlas Saharien Occidental – Algérie) [Contribution of GIS in the hydrodynamic and hydrochemical characterization of the lower cretaceous aquifer of the region of Ain Sefra (Western Saharian Atlas – Algeria)]. MSc Thesis. Tlemcen. University of Tlemcen pp. 105.

SAMPATH D., WEERAKOON S., HERATH S. 2015. HEC-HMS model for runoff simulation in a tropical catchment with intra-basin diversions case study of the Deduru Oya River Basin, Sri Lanka. Engineer. Vol. 48. No. 01 p. 1–9. DOI 10.4038/engineer.v48i1.6843.

SCHARFFENBERG W., FLEMING M. 2010. Hydrologic modeling system HEC-HMS v3.5: Users manual. Davis, CA. USACE, Hydrologic Engineering Center. pp. 318.

SCHARFFENBERG W., FLEMING M. 2016. Hydrologic modeling system HEC-HMS v4.2: Users manual. Davis, CA. USACE, Hydrologic Engineering Center. pp. 614.

SKHAKHFA I.D., OUERDACHI L. 2016. Hydrological modelling of wadi Ressoul watershed, Algeria, by HECHMS model. Journal of Water and Land Development. No. 31 p. 139–147. DOI 10.1515/jwld-2016-0045.

SHAH S., O'CONNELL P., HOSKING J. 1996. Modelling the effects of spatial variability in rainfall on catchment response: Formulation and calibration of a stochastic rainfall field model. Journal of Hydrology. Vol. 175 p. 67–88.

SINTAYEHU L.G. 2015. Application of the HEC-HMS model for runoff simulation of Upper Blue Nile River Basin. Hydrology: Current Research. Vol. 6. Iss. 2: 199. DOI 10.4172/2157-7587.1000199.

USGS 2012. Estimating basin lagtime and hydrograph-timing indexes used to characterize stormflows for runoff-quality analysis. Scientific Investigations Report. Reston, Virginia. USA. U.S. Geological Survey pp. 58.

USGS undated. EarthExplorer [online]. [Digital elevation models and satellite data]. Available at: http://earthexplorer.usgs.gov/

WAŁĘGA A. 2013. Application of HEC-HMS programme for the reconstruction of a flood event in an uncontrolled basin. Journal of Water and Land Development. No. 18 p. 13–20.

WHEATER H., SOROOSHIAN S., SHARMA K. 2008. Hydrological modelling in arid and semi-arid areas. Cambridge UK. Cambridge University Press pp. 223. DOI 10.1017/CBO9780511535734.

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Modelowanie relacji opad–odpływ za pomocą HEC-HMS w regionie półsuchym: Przykład zlewni Ain Sefra w górach Ksour (południowozachodnia Algieria)

STRESZCZENIE

Ain Sefra jest jednym z algierskich miast, które doświadczyły kilku niszczących powodzi w ciągu minionych 100 lat. Celem badań prezentowanych w pracy było symulowanie odpływu w regionie o klimacie półsuchym w zlewni Ain Sefra z wykorzystaniem systemu modelowania hydrologicznego HEC-HMS. W pracy użyto częstotliwości opadów nawalnych do konstruowania modelu meteorologicznego, liczbę krzywych Służby Ochrony Gleb USA – ang. Soil Consevation Service (SCS-CN) wybrano do obliczenia tempa strat, a metodę jednostkowego hydrogramu Służby Ochrony Gleb USA użyto do symulowania szybkości odpływu. Po przeprowadzeniu kalibracji i walidacji modelu symulowane maksymalne odpływy były bardzo bliskie wartościom obserwowanym. Współczynnik wydajności Nasha–Sutcliffa równy 0,95 wskazuje, że wyniki modelowania hydrologicznego są zadowalające i mogą być przyjęte do symulowania relacji opad–odpływ. Uzyskane maksymalne odpływy dla 10-, 50-, 100- i 1000-letnich opadów nawalnych wynoszą odpowiednio 425,8, 750,5, 904,3 i 1328,3 $m^3 \cdot s^{-1}$.

Słowa kluczowe: *Ain Sefra, częstotliwość opadów nawalnych, HEC-HMS, klimat półsuchy, modelowanie hydrologiczne, powodzie*