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Integrated spatial and hydrological approaches for sustainable management of semi arid watersheds: A case study

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ABSTRACT

The integration of geographical information system (GIS) and hydrological modelling appears to be an essential approach for efficient management of water resources, especially in contexts where data is scarce. The objective of this study is to carry out a hydrological modelling of rain-flow in the basin of 'cedra isser' by integrating the hydrologic engineering center – hydrologic modeling system (HEC-HMS) model and the GIS. This approach will simulate the basin's hydrological response to various rainfall events. To assess the flood risk of this river, the HEC-HMS model was combined with the HEC-GeoHMS extension in ArcGIS. Based on 23-year rainfall data and the HEC-HMS hydrological model, we simulated a 24-hour rain corresponding to a 100-year return period. Runoff volume was estimated using the curve number method., then converted to a flood hydrogram using the soil conservation service (SCS) unit hydrogram method. This approach has made it possible to simulate the excess of rainwater and its runoff path through the watershed. The results indicate that the fast and intense flows of the centenary flood of the river of 'cedra isser' is 698.9 m^3/s with 60.96 mm loss volume; The results showed that the observed and simulated hydrographs were highly correlated with a coefficient of 0.879, The performance of the model was evaluated using an NSE coefficient that equals 0.816, Results indicate that the model is suitable for hydrological needs simulations in the cedra isser basin,This study contributes to better management of water resources for the purpose of flood control.

Keywords: flood, water resources management, HEC-HMS, hydrological model, GIS.

INTRODUCTION

Surface runoff estimation based on rainfall is one of the prerequisites for planning and execution of water resource projects (Majidi and Shahedi, 2012; Masoud, 2015). Estimating the volume of runoff caused by rainfall is critical for accurately calculating the quantities needed to store water in reservoirs and determining the likelihood of flooding (Hamdan et al., 2021). Accurate runoff estimation is crucial for effective water resource management, encompassing flood control, irrigation planning, and the design of drainage networks (Cheddad et al., 2025).

Shortage of water in most of the water scarce region is not only caused by low or unpredictable rainfall pattern but also due to the lack of capacity to conserve and manage the available rainwater in a sustainable manner (Ibrahim-Bathis and Ahmed, 2016). However, the scarcity and unreliability of hydrological data in many Algerian watersheds pose significant challenges for hydrologists and water resource managers (Cheddad et al., 2025). Hydrological modeling is a commonly used tool to estimate the basin's hydrological response due to precipitation. It allows to predict the hydrologic response to various watershed management and to have a better understanding of the impacts of these practices (Choudhari et al., 2014).

Several studies have used the model of hydrologic engineering center – hydrologic modeling system (HEC-HMS) in different regions (soils and different climatic conditions) (Chu and Steinman, 2009). The HEC-HMS model has also been used to simulate rainfall-runoff process with geo-informatics and atmospheric models for flood forecasting and early detections in different regions of the world (Arekhi et al., 2011; Majidi and Shahedi, 2012; Yener et al., 2012; Yusop et al., 2007). Also, it has been used for management of watersheds in different regions (Zilé et al., 2015; Benkirane et al., 2018; Moumen et al., 2017; Remini B., 2016).

Geographical information system (GIS) technology is very effective tools nowadays in the field of water resources to extract data from satellite image. It is widely used by many researchers in their research work (Gautam,.et al., 2000). Many researchers have developed the use of GIS in hydrological modelling (Kovar and Nachtnebel, 1996). The integration of GIS with hydrological models is an essential tool for integrated water resources management. By integrating spatial data, GIS optimizes these models and provides a powerful visualization of the results obtained.

This study aims mainly to develop a hydrological modelling methodology for the 'cedra isser' watershed located in Tlemcen in western Algeria, exploiting the HEC-HMS model and integrating remote sensing data such as the DEM via the HEC-Geo-HMS tool and a GIS, to accurately simulate rain-water processes and characterize the flow.

The geomorphological characteristics of the Isser Cedra watershed were established using GIS tools, including ArcGIS 10.8. This data was then used to analyze the runoff behavior in the area under study. The precise watershed delineation was obtained from DEM data. In addition, the estimation of extreme floods was carried out using HYFRAN-PLUS software, a frequency analysis model specifically designed for extreme values.

The HEC-HMS model was used to simulate runoff volume using loss methods, including the soil conservation service – curve number (SCS-CN) method. This method is one of the most widely used in the world to estimate losses and direct runoff from a given rain event. By combining HEC-Geo-HMS with GIS, the results were imported into the hydrological model HEC-HMS, which should lead to a significant improvement in the management of the Isser Cedra basin, its hydraulic structures (regulation, drainage, etc.) and management of flood risks and their impacts.

MATERIAL AND METHODS

Presentation of Isser Cedra basin

The Isser Cedra watershed is situated in northwestern Algeria. It is one of the watersheds of the Tafna River, which belongs to the Oranie-Chott Chergui hydrographic region. It covers an area of 1119.65 square kilometers and has a maximum altitude of 1611 meters. Its principal wadis are:

- The Isser River which drains in its upstream part the carbonate formations of the Jurassic

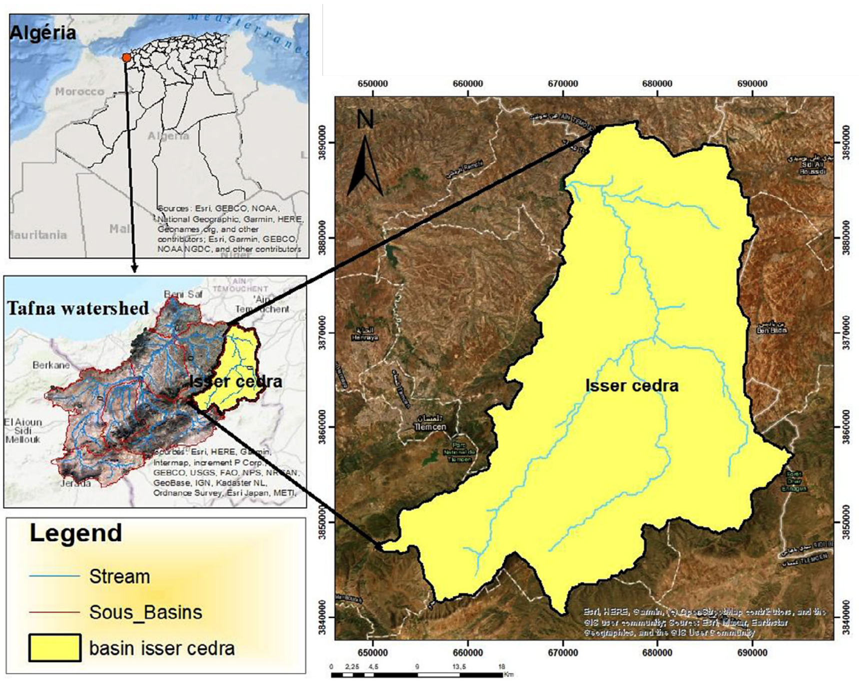


Figure 1. Geographic location of Isser Cedra basin (Arc Gis 10.8)

up to Ouled Mimoun. Beyond that, he cuts a deep throat in the marl Miocene (Adjim, 2004; Ketrouci, 2014).
- The choulyriver which flows lower into Oued Isser thus constituting its main tributary (left bank tributary). It originates in the Tlemcen mountaim of altitude, it drains the North slope of these mountains, its valley is overlooked by a series of massifs (Bouanani, 2004).

The analysis of climate data

Hyfran Plus

Hyfran Plus is one of the statistical analysis programs used to compute the maximum depth of rainfall for different return periods, including 2, 5, 10, 20, 50, and 100 years. It is also used to compute the intensity and intensity curves of rainfall (IDF Curve), providing a precise calculation of the amount of precipitation that fell on the drainage basin (Asaad et al., 2022).

Analysis of the Isser Cedra basin climate data reveals an important spatio-temporal variability in annual flows. To predict exceptional floods (return periods of 10 to 100 years) at Sidi Aissa station, the HYFRAN statistical model suggests the use of a statistical law of gamma. These results are in agreement with those found by (Bouanani, 2004; Ketrouci, 2015) on this region. Table 1 summarizes these results (Figure 2).

HEC-HMS model description

The hydrologic engineering center – the hydrologic modeling system is a physically based distributed model, designed to simulate the rainfall-runoff processes of dendritic watershed systems (Scharffenberg et al., 2010). The US Army Corps of engineers developed this model and is widely used to simulate and forecast stream flow in humid, tropical, subtropical and arid watersheds (Ibrahim-Bathis 2016). The model can simulate both flood events and precipitation across continuous time steps, ranging from instantaneous to daily intervals (Scharffenberg et al., 2010). It has been widely used and validated in various catchments with contrasting climates around the world (Abood, 2012; Motevalli, 2012; Moumen et al., 2017).

SCS-CN model for rainfall runoff

Assuming that the ratio of actual direct runoff to maximum possible runoff is equal to the ratio of actual infiltration to potential maximum retention and that the amount of initial abstraction is a fraction of the potential maximum retention, the SCS-CN method (NRCS, 2008) is a popular rainfall-runoff model that is based on the water balance calculation. This method is given by Equations (1), (2), and (3) (Dahdouh and Ouerdachi, 2018):

Table 1. Maximum daily flow characteristics at Sidi Aissa station (Isser Cedra basin)

Years	10	20	50	100
Frequency	0.9	0.95	0.98	0.99
Q max	295.95	396.66	531.88	635.24
Standard deviation	74.56	110.16	171.28	223.65

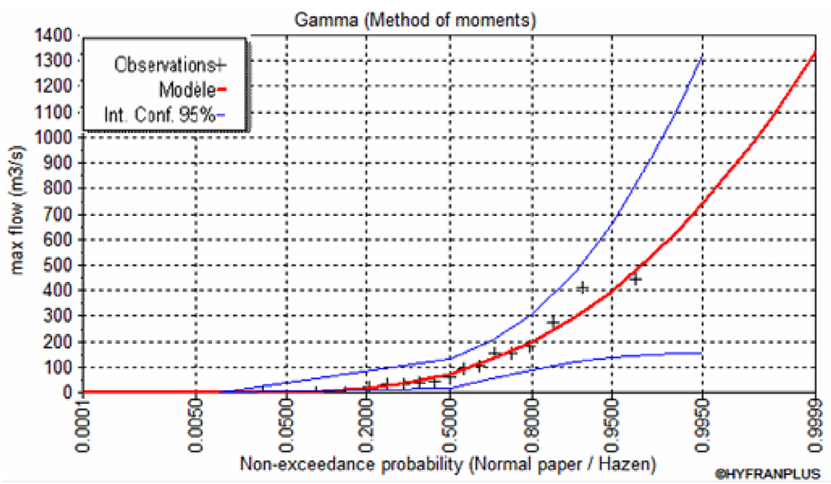


Figure 2. Adjustment for Sidi Aissa station (Isser Cedra basin)

$$P_e = \frac{(P-I_\alpha)^2}{P-I_\alpha+S} \quad (1)$$

$$I_\alpha = 0.2S \quad (2)$$

where: P_e – excess precipitation, P – the total accumulated precipitation at time t, I_α – initial losses, S – the maximum retention potential.

The maximum retention potential and the characteristics of the watershed are linked via the curve number (CN) by:

$$S = \frac{25400-254CN}{CN} \quad (3)$$

Statistical analysis

Nash-Sutcliffe efficiency (NSE) was used to assess the goodness-of-fit between the simulated and observed discharge data. NSE values can range from negative infinity to 1, where 1 is a perfect match of simulated to observed data. Correlation coefficients (R) ranging from 0.7 and 0.9 indicate the variables which can be considered highly correlated. NSE and R are calculated using the following formulas:

$$NES = 1-\frac{\sum_{i=1}^{N}(Q_{i,obs}-Q_{i,sim})^2}{\sum_{i=1}^{N}(Q_{i,obs}-\bar{Q}_{obs})^2} \quad (4)$$

$$R = \frac{\sum_{i=1}^{N}(Q_{i,obs}-\bar{Q}_{obs})(Q_{i,sim}-\bar{Q}_{sim})}{\sqrt{\sum_{i=1}^{N}(Q_{i,obs}-\bar{Q}_{obs})^2(Q_{i,sim}-\bar{Q}_{sim})^2}} \quad (5)$$

RESULT AND DISCUSSION

Data preparation and sub-watershed creation

The methodology employed consists of several key stages. It begins with data collection and preparation, which includes the extraction of the SRTM image, acquisition of a digital terrain model (DTM), and gathering other relevant data, such as land use. Next, ArcGIS version 10 is utilized to automatically delineate the basin contours such as fill, flow direction, flow accumulation, basin, basin polygon. The physical characteristics of the basin, including slope, surface area, and hydrographic network, are then extracted using GIS software. Finally, this data is integrated into HEC-HMS to simulate the basin's hydrological behavior under various rainfall events (Figure 3).

Slope of Isser Cedra basin

Slopes play a crucial role in the runoff process within a watershed. Assessment of this topographical parameter is essential to address problems related to erosion, transport and sediment deposition (Mashauri et al, 2023). To better understand the sub basin topography, slope was calculated with the slope tool in Arc Gis 10.8 software. Then, these slopes were reclassified by categories as shown in Table 2. The slope categories are chosen according to the classification proposed by Hagerty and Kingston 1992 (Cheddad

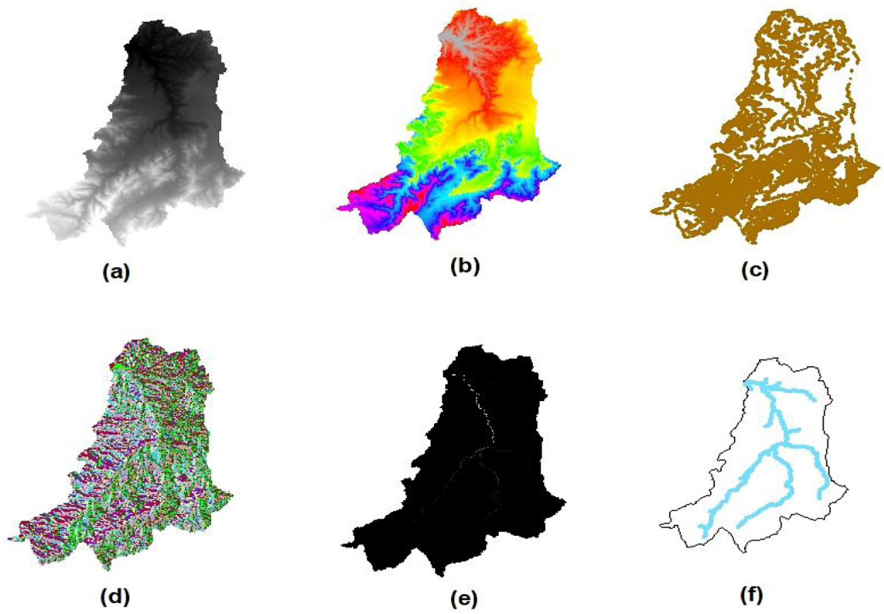


Figure 3. Pre-processing and spatial modeling with ArcGis software: (a) raw digital elevation model, (b) fill sinks, (c) elevation curve, (d) flow directions, (e) flow accumulation, (f) hydrographic network

Table 2. Slope category

Classes	Slope degree	Description	Area, km^2	Pct, %
1	0-2	Plat - almost plat	2.29	13.9
2	2-9	Very slight slope - slight slope	153.05	43.2
3	9-15	Medium slope	157.74	28.5
4	15-30	Steep slope	313.946	14.3
5	30-45	Very steep slope	476.75	0.21

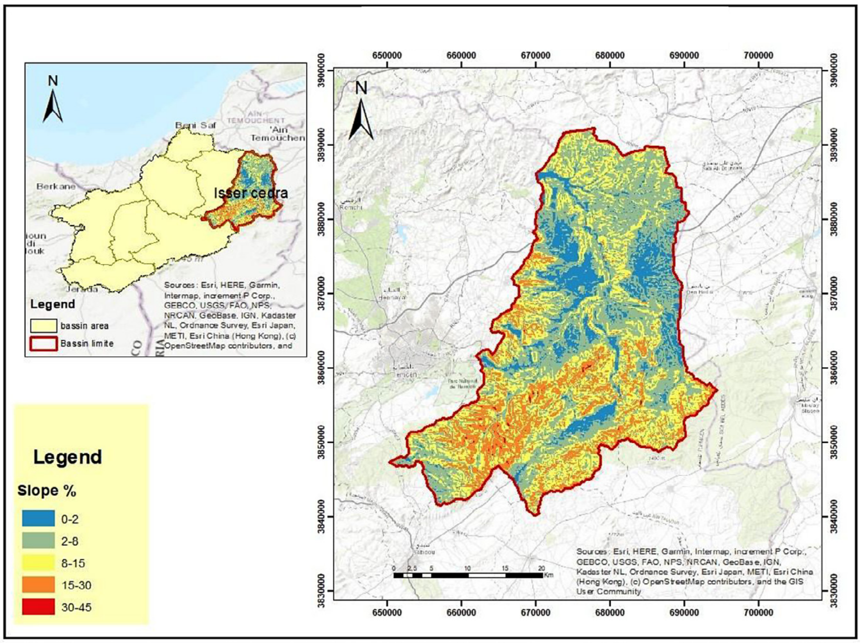


Figure 4. Slope map (Arc Gis 10.8)

et al., 2025). The result is presented in Figure 4. Each category's area, expressed in km² and percentage (Table 2).

Hypsometric curve

The hypsometric curve provides an overview of the slope of a watershed and, therefore, of the relief, according to (Boudhik et al., 2021). This curve illustrates the distribution of the watershed area by altitude and assess its age and degree of erosion. The hypsometric curve (Table 3 and Figure 5), indicates that the erosive potential of Isser Cedra basin is quite large.

The hypersonic map represents the surfaces between the different contour lines. It gives an idea of the slope and the aspect of the relief (Mashauri et al., 2023). The hypersonic map of Isser Cedar basin (Figure 6) shows that the distribution of altitudes is related to the watershed topography. The most dominant surface is between 600 and 700 m.

Soil map, land use/land cover map, soil classification map and hydrological soil group map

To obtain a land use map of the Isser Cedra watershed, the following steps must be followed – starting with the download of the raster file of the global soil type from the site: https://livingatlas.arcgis.com/landcoverexplorer/. Then the data was exported to ArcGis software 10. 8 to clip the study area and convert it from raster file to shape file. A symbology was subsequently performed (Figure 7).

To obtain a map of soil types and hydrological soil group of the Isser Cedra basin started first by downloading the raster file of the world soil type (digital soil map) from the site: https://www.fao.org/soils-portal/data-hub/soil-maps-and-databases/faounesco-soil-map-of-the-world/en/. Then the data was exported to ArcGis 10.8 software to extract soil type after several steps (Figure 8).

HSGs were derived from texture classes and described in the U.S. Department of

Table 3. Hypsometric distribution of the Isser Cedra watershed

Altitudes (m)	Partial areas		Cumulated areas	
	(km²)	(%)	(km²)	(%)
1611-1600	0.078	0.0	0.078	0.01
1600-1500	5.981	0.53	6.059	0.5
1500-1400	31.126	2.7	37.186	3.32
1400-1300	81.840	7.31	119.026	10.6
1300-1200	80.637	7.2	199.663	17.83
1200.1100	89.625	8	289.288	25.83
1100-1000	90.731	8.10	380.019	33.93
1000-900	96.778	8.64	476.797	42.57
900-800	91.018	8.13	567.816	50.70
800-700	98.190	8.77	666.006	59.47
700-600	163.943	14.64	829.948	74.11
600-500	131.936	11.78	961.884	85.89
500-400	124.590	11.13	1086.474	97.02
400-334	33.176	2.96	1119.651	100

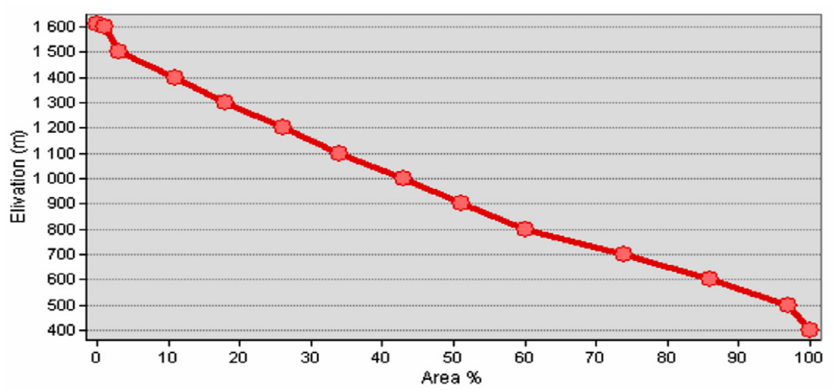


Figure 5. Hysometric curve (Arc Gis 10.8)

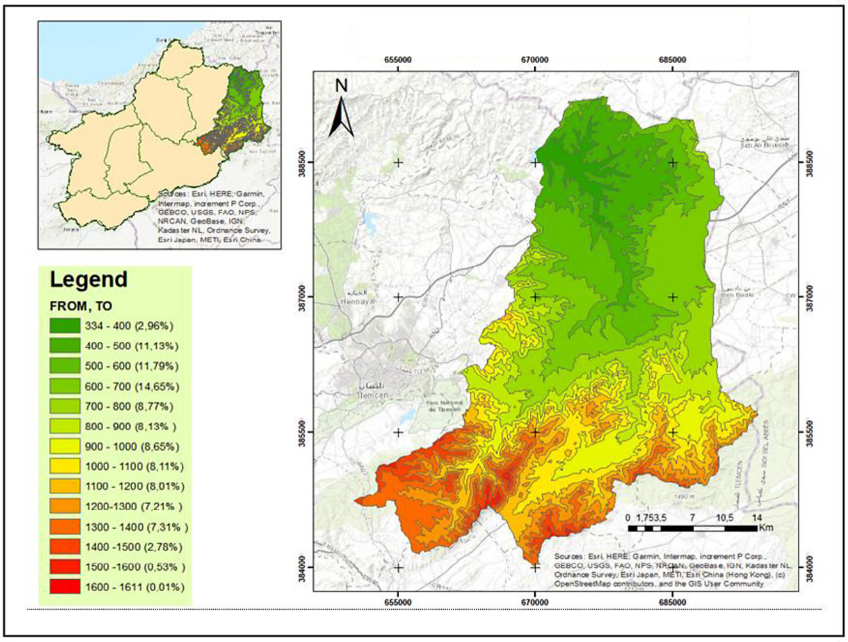


Figure 6. Hypsometric curved map (Arc Gis 10.8)

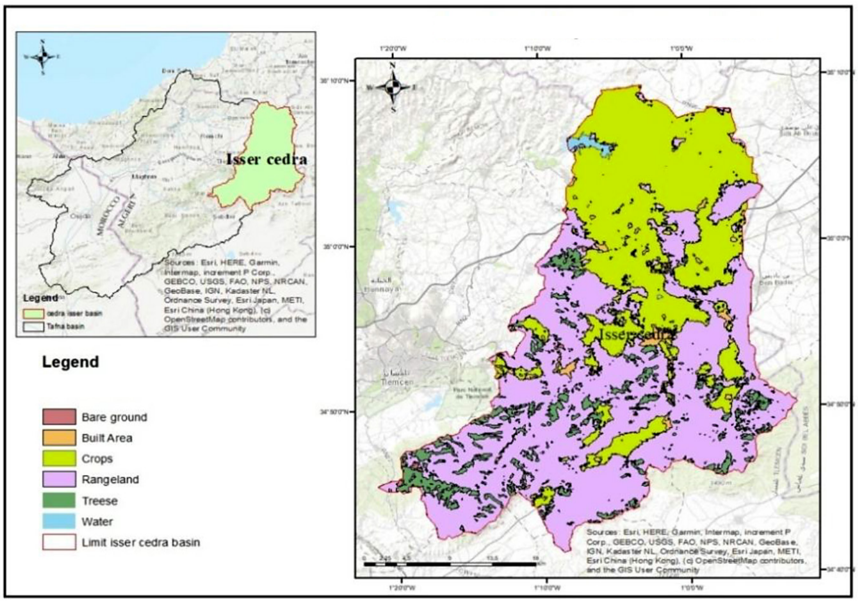


Figure 7. Land use map Isser Cedra basin

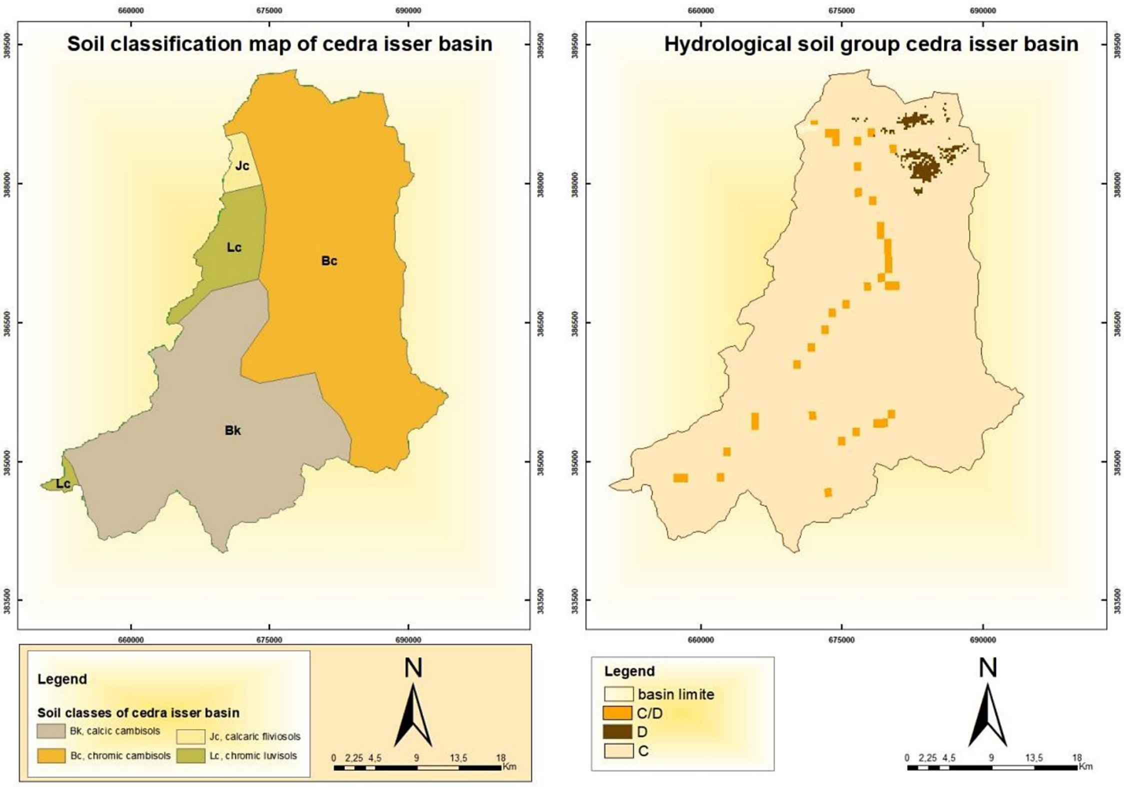


Figure 8. Soil classification map and hydrological soil group map Isser Cedra basin (Arc Gis 10.8)

Agriculture-Natural Resources Conservation Service (USDA-NRCS) National Engineering Handbook (USDA, 2009). The resulting data product (HYSOGs250m) represents general soil runoff potential suitable for regional, continental, and global scale analyses and is available in a gridded format at a spatial resolution of 250 m.

The results obtained with Arc GIS software indicate that the soil hydrological group of Cedra Isser basin is classified as C or D. According to Table 4, the group C has moderately high runoff potential (typically contains between 20 to 40% clay and less than 50% sand), than group D has highest runoff potential (typically contains more than 40%clay and less than 50% sand).

Table 4. Classification hydrologic soil groups (HSGs

HSG	Description
HSG-A	Lowest runoff potential (typically contains more than 90% sand and less than 10% clay)
HSG-B	Moderately low runoff potential (typically contains between 10 to 20% clay and 50 to 90% sand)
HSG-C	Moderately high runoff potential (typically contains between 20 to 40% clay and less than 50% sand)
HSG-D	Highest runoff potential (typically contains more than 40% clay and less than 50% sand).

Curve number map

Soil map and land use datasets were used to generate the curve number (CN) file, which is required to build the HEC-HMS model. CN values were used to determine the stream/sub-basin characteristics and to estimate the hydrological parameters used in the model (Tassew et al., 2019) (Figure 9). CN values range from 79 to 84 corresponding to impermeable soils with low infiltration rates.

Finally the digital model of the cedra isser basin, created using ArcGIS 10.8, was directly imported into HEC-HMS. This process enabled the seamless transfer of all necessary geographic and hydraulic information for simulations. Key data transferred included the basin's geometry, the hydrographic network, characteristics of the sub-basins, and the locations of hydraulic structure. The coupling of HEC-GeoHMS and HEC-HMS allows geographic data from a GIS to be transformed into hydrological information usable by HEC-HMS. This transformation involves creating a digital representation of the watershed using a digital terrain model (DTM) and calculating the hydrological characteristics of each element within the watershed.

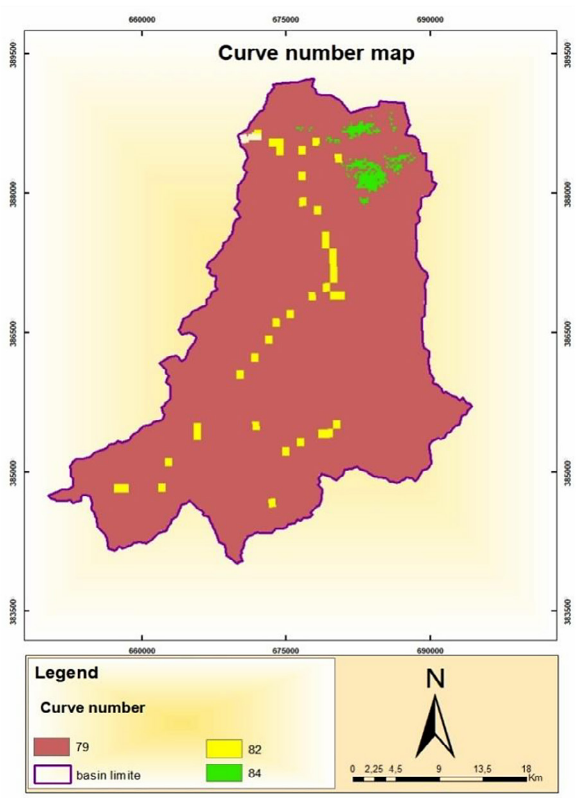


Figure 9. Curve number Map (Arc Gis 10.8)

The unit hydrograph

Figure 11 illustrates the simulated unit hydrograph for a 100-year return period. This hydrograph is obtained after configuring all the required parameters for the soil conservation service – curve number (SCS-CN) method, a method that allows for the determination of the sub-basin's direct runoff and peak discharge. A significant rainfall event, measuring 95.30 mm, resulted in a peak flow of 668.9 m^3/s. This high flow rate indicates the soil's low capacity for infiltration and highlights the prevalence of runoff in the area. Additionally, the lack of notable base flow underscores the basin's susceptibility to flooding (Figure 12). The rainfall event peaked at 6:30 am. The total measured rainfall was 29.57 mm, of which a portion, 19.8 mm, was absorbed by the soil. The remaining precipitation,

Figure 10. Hydrologic modeling system of the Isser Cedra basin by HEC-HMS

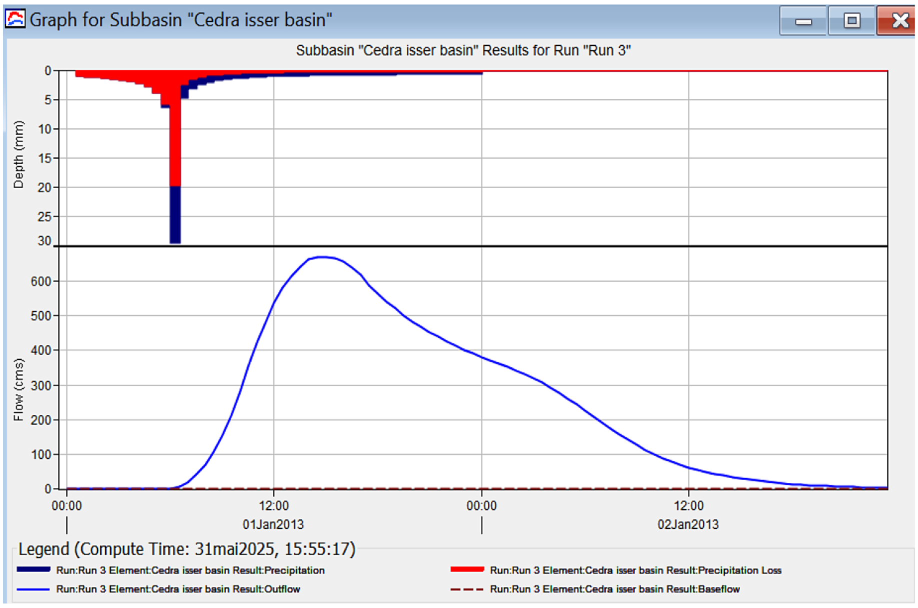
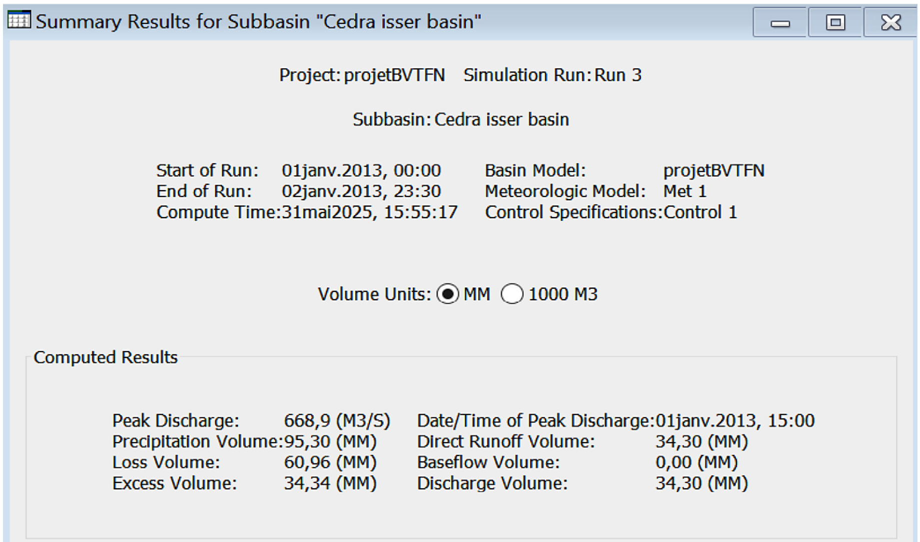


Figure 11. Flood hygrograph for a return period of 100 years (Isser Cedra basin)


Summary Results for Subbasin "Cedra isser basin"

Project: projetBVTFN Simulation Run: Run 3

Subbasin: Cedra isser basin

Start of Run:	01janv.2013, 00:00	Basin Model:	projetBVTFN
End of Run:	02janv.2013, 23:30	Meteorologic Model:	Met 1
Compute Time:	31mai2025, 15:55:17	Control Specifications:	Control 1

Volume Units: MM 1000 M3

Computed Results

Peak Discharge:	668,9 (M3/S)	Date/Time of Peak Discharge:	01janv.2013, 15:00
Precipitation Volume:	95,30 (MM)	Direct Runoff Volume:	34,30 (MM)
Loss Volume:	60,96 (MM)	Baseflow Volume:	0,00 (MM)
Excess Volume:	34,34 (MM)	Discharge Volume:	34,30 (MM)

Figure 12. Summary results for a return period of 100 years (Isser Cedra basin)

which was not absorbed, directly contributed to an increase in water flow, correlating with the intensity of the rainfall. After the rain stopped, the flow rate gradually decreased (Table 5).

Comparison of the simulated and observed hydrograph and validation of model

The simulated and observed hydrographs for the calibration period are shown in Figure 13 for both the simulated and observed hydrographs exhibiting nearly similar trends and shapes. However, the peak flow of the simulated hydrographs is 668.9 m^3/s. than the observed ones' is 635.24 m^3/s. The results of the model in this study showed an acceptable fit between the simulated values and observations. The trend and shape of the hydrograph seems compatible.

The correlations between simulated and observed runoff (Figure 14) give linear relationships with strong positive correlation coefficients ranging from 0.879. The Nash-Sutcliffe efficiency (NSE = 0.816229) which indicate very good model performance showing that the model effectively reproduces reliable for prediction and simulation.

Table 5. Simulated result of Isser Cedra basin

Date	Time	Precipitation (mm)	Loss (mm)	Exess (mm)	Total flow (m^3/s)
01janv.2013	05:00	2.74	2.74	0	0
01janv.2013	05:30	3.76	3.75	0	0
01janv.2013	06:00	6.35	5.87	0.48	0.3
01janv.2013	06:30	29.57	19.8	9.77	6.6
01janv.2013	07:00	4.76	2.38	2.38	20.7
01janv.2013	07:30	3.15	1.48	1.67	43.3
01janv.2013	08:00	2.44	1.1	1.34	71.8
01janv.2013	08:30	2.03	0.89	1.14	108.1
01janv.2013	09:00	1.75	0.75	1	154.2
01janv.2013	09:30	1.55	0.65	0.9	211.7
01janv.2013	10:00	1.4	0.57	0.83	280.1
01janv.2013	10:30	1.28	0.51	0.76	352.1
01janv.2013	11:00	1.18	0.47	0.71	420.7
01janv.2013	11:30	1.1	0.43	0.67	482.8
01janv.2013	12:00	1.03	0.4	0.63	537
01janv.2013	12:30	0.97	0.37	0.6	581
01janv.2013	13:00	0.95	0.35	0.59	614.8
01janv.2013	13:30	0.92	0.34	0.58	642.9
01janv.2013	14:00	0.9	0.33	0.57	661
01janv.2013	14:30	0.87	0.32	0.56	667.7
01janv.2013	15:00	0.85	0.31	0.55	668.9
01janv.2013	15:30	0.83	0.29	0.54	665.3
01janv.2013	16:00	0.82	0.29	0.53	656
01janv.2013	16:30	0.8	0.28	0.52	639.8
01janv.2013	17:00	0.78	0.27	0.51	616
01janv.2013	17:30	0.77	0.26	0.51	588.4
01janv.2013	18:00	0.75	0.25	0.5	562.5
01janv.2013	18:30	0.74	0.25	0.49	540.3
01janv.2013	19:00	0.72	0.24	0.48	520
01janv.2013	19:30	0.71	0.23	0.48	500.7
01janv.2013	20:00	0.7	0.23	0.47	482.9
01janv.2013	20:30	0.69	0.22	0.47	466.9
01janv.2013	21:00	0.67	0.22	0.46	452.4
01janv.2013	21:30	0.66	0.21	0.45	439
01janv.2013	22:00	0.65	0.21	0.45	426
01janv.2013	22:30	0.64	0.2	0.44	413.4
01janv.2013	23:00	0.63	0.2	0.44	401.6
01janv.2013	23:30	0.62	0.19	0.43	390.8
02janv.2013	00:00	0.61	0.19	0.43	381
02janv.2013	00:30	0	0	0	371.7

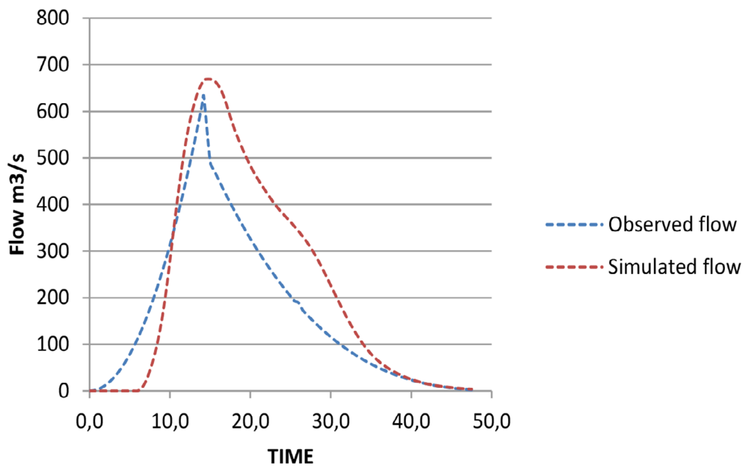


Figure 13. Comparison between observed and simulated runoff

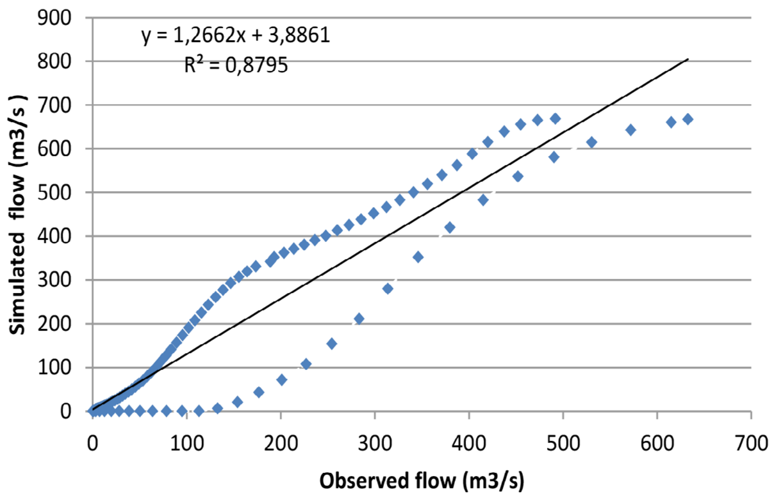


Figure 14. Correlation between simulated and observed stream flow

CONCLUSIONS

In order to better understand the hydrological dynamics of the Isser Cedra basin, we implemented a hydrological model using the HEC-HMS software. This model, combined with a geographic information system, allowed us to simulate runoff generated by precipitation. We used the SCS-CN method to estimate infiltration losses. A thorough calibration and validation process was conducted to ensure the accuracy and reliability of the simulation results.

Hydrological simulations were conducted using the HEC-HMS model, with the SCS-CN method to estimate infiltration, in order to analyze the hydrological responses of the Isser Cedra basin, under a rain event with a 100 year return period, This sub-basin has an infiltration capacity of about –60,96 mm. and a peak flow 668.9 m^3/s. With a correlation coefficient of 0.879 and NSE of 0,816 between simulated and observed runoff, the model confirms its satisfactory performance in capturing specific hydrological events such as peak flows and time to peak.

The results of this study represent an important initial step toward a better understanding of the hydrological dynamics in Algerian watersheds. To increase the practical application of these findings and enhance water resource management, further research is necessary. This research should focus on compiling more comprehensive databases and developing advanced hydrological models. By integrating these models with decision-support tools, we can simulate various land development scenarios and evaluate their impacts on the hydrological regime. This approach will aid in achieving more sustainable water resource management and provide better protection against flood risks.

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