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Assessment of Flood Frequency Pattern in a Complex Mountainous Terrain Using the SWAT Model Simulation †

Nada Joumar [1],*, Amal Markhi [2], Jamal Eddine Stitou El Messari [1] and Lahcen Benaabidate [3]

[1] Laboratory of Applied and Marine Geosciences, Geotechnics and Geohazards (LR3G), Abdelmalek Essaadi University, Tetouan, Morocco; email1@email.com
[2] GEOHYD Laboratory, Faculty of Sciences Semlalia, Cadi Ayyad, Marrakech, Morocco; email2@email.com
[3] Laboratory of Functional Ecology and Environment Engineering, Faculty of Sciences and Techniques, University of Sidi Mohamed Ben Abdellah, 30000 Fez, Morocco; email3@email.com
* Correspondence: nada.joumar@etu.uae.ac.ma

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Abstract: Understanding the relationship between rainfall and runoff is one of the requirements and necessities in flood modeling, predicting and recording annual runoff contributions. This study aimed to evaluate the use of hydrological modeling and flood frequency analysis (FFA) in studying the extent and occurrence of floods in complex mountain basins and the impact of dams on downstream flooding. increase. The N′fis Subbassin, the study area is located in the High Atlas Mountains of Morocco, drains a total area of 1700 km^2 and is characterized by an arid to semi-arid climate in the plains and a subhumid climate in the mountains. Flood modeling in this catchment is very difficult due to the lack of sufficient spatial and temporal flood data available for FFA. Therefore, SWAT (Soil and Water Assessment Tool), a physics-based continuous model, was used to simulate and reproduce the hydrological behavior upstream of N′fis. The model parameters were calibrated and validated using data collected from 2000 to 2016 and performed well with Nash-Sutcliffe statistics with a calibration period of 0.52 and validation of 0.69. Finally, using the daily flood data (1982–2016), we performed FFA using the L-moments method (Gumbel Normal and Log Pearson III). Furthermore, a comparison of the goodness of fit of the Gumbel, GEV and LP3 distributions to the flood frequency analysis in the N′fis basin highlights that the GEV distribution gives good results and appears to be the more appropriate one. increase. This research will enable better assessment of floods and help water managers and decision makers to better plan and manage flood mitigation.

Keywords: flood frequency analysis; SWAT; flood forecast; high Atlas; Morocco

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1. Introduction

Morocco's rainfall distribution is very varied in both spatial and temporal scales. It can reach more than 800 mm at high altitudes, but hardly more than 300 mm on the plains [1]. The Moroccan high Atlas has seen some of the most destructive flood occurrences in history, such as the 1995 Ourika flood, which killed 732 people and cost 80 million dirhams in economic damage [2]. The use of flood frequency analysis in dry and semi-arid environments, particularly in developing nations, can be tremendously beneficial for better assessing and planning flood risk and reducing the disastrous effects of this phenomena [3]. The N′fis watershed was studied since it is located in the High Atlas area, which is prone to flooding [4]. This area is marked in particular by substantial spatiotemporal variability of precipitation and relative irregularity of surface runoff [5].

Many studies have been carried out in N′fis Wadi watershed. [6] for instance investigated the relative performance of the Snowmelt Runoff Model (SRM) to simulate streamflow in five sub-catchments of the High Atlas Mountain range, this study found that

Snowmelt contribution to surface runoff in N'fis watershed is lower compared to neighboring mountainous catchments, and the hydrological model tends to underestimate peak flows due to their absence in the input weather data [7]. On the other hand, first developed a water erosion risk map of the watershed by digital processing of various satellite products, this study indicated that more than three quarters of the catchment area located at south-east and west of the sub-basin is subject to moderate risk, high and very high risk of water erosion. This work was followed by [8] who applied the RUSLE and the SEDD model over two periods to analyze the impact of land use change on potential erosion as well as the suspended sediment yield SSY, this study revealed that in general there is a decrease in spatial annual average erosion rate and subsequently the sediment delivery ratio over the years due the significant changes experienced by the land uses in the area. Similarly, but using a different approach [9] used SWAT model (Soil and Water Assessment tool) to estimate potential soil erosion and sediment yield in the semi-arid N'fis basin, this study determined soil loss within each hydrological response unit in the watershed and indicating a high yield rate (123 t Ha^{-1} for an average annual rainfall of 315 mm yr^{-1}).

Additionally, a previous study carried on the Ourika watershed by [3] comparing 12 frequency models using the maximum likelihood method and the criteria to guide the selection of the most appropriate model, showed that the most suitable method is the GEV law. Another study tackled the regional flood frequency analysis in the catchments (N'Fis, Rheraya, Ourika, Zat and R'dat) [10], using the Generalized Extreme Value (GEV) model. However, there were no studies done comparing the statistical probability distributions, such us Generalized Extreme Value (GEV), Log-Pearson type 3 (LP3), and Gumbel (EV1) in the N'fis watershed, which constitutes an important aspect of flood modeling and forecasting. These statistical probability distributions are used generally to estimate the magnitude and probability of occurrence of extreme events and to obtain accurate results [11]. The data series required to proceed with the FFA generally exceeds 50 years [12]. Due to data-scarcity, the hydrological modeling is required step to acquire long-term flood time series. The SWAT model (Soil and Water Assessment Tool) was used, which is a physically based, continuous model. Major model components include weather, hydrology, soil temperature and properties, land use etc. [13]. The choice of this model comes from the ability to take into account the different important factors that impact the floods especially in a rural area, which is the case for N'fis wadi watershed, and the proven good performance of this model in different watersheds in Morocco [9,14–16]. The overarching goal of this paper is to, first generate a long time series of Flow using SWAT model, and second applying flood frequency analysis to these data series and compare the three common statistical distributions used in FFA, and investigate the goodness of fit of the three distributions methods selected.

2. Materials and Methods

2.1. Study Area

The Tensift watershed is located in west-central Morocco, it covers a total area of 24,000 km^2 and includes the seven prefectures and provinces, such as Marrakech and Al Haouz and Al Youssoufia (Figure 1). The study area is the largest subbasin of the Tensift watershed which is N'fis that drains a total area of 1700 km. This complex terrain watershed is characterized with an elevation that ranges from 583 m to 4102 m and a mean elevation of 1868 m. The watershed is 96% rural land and only 6% urban [17]. The land use consists mostly of forested areas (44%) and the dominant soil type is zonal brown soils on shale socle which explains the impermeable nature of the basin (79.3%) [18]. The basin's climate is semi-arid, the climate is characterized by hot (max: 46°) and dry summers then cold (min: −7.4 °C) humid winters [19]. The annual rainfall ranges from 254.1 mm in low altitude to 796.9 mm in high altitudes.

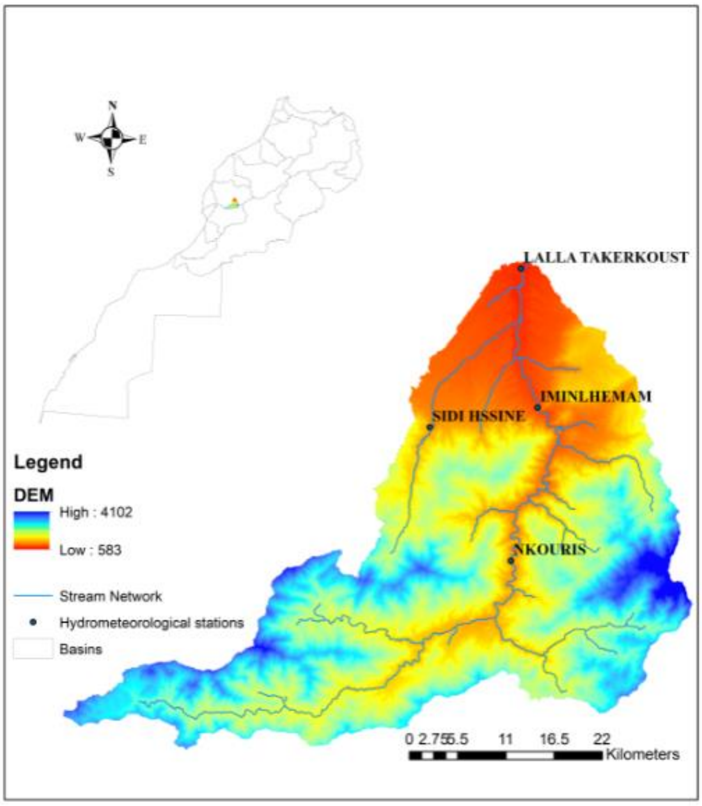

Figure 1. Location of N'fis watershed and the hydrometeorological stations (Lalla Takerkoust, Imin el Hemam, Nkouris, Sidi Hssine).

2.2. *SWAT Model*

The Soil and Water Assessment Tool (SWAT) is a widely used hydrological model that simulates the hydrological processes of watershed [13]. It is a comprehensive model that integrates various sub-models to simulate the water balance, erosion, sediment transport, nutrient cycling, and crop growth within a watershed. SWAT uses a semi-distributed approach to simulate the complex interactions between land use, climate, topography, soil properties, and vegetation in a watershed [20].

The mathematical equation of SWAT is based on the water balance equation [21], which is expressed as:

$$P = Q + S + E + G + A$$

where P is the precipitation, Q is the runoff, S is the soil water storage, E is the evapotranspiration, G is the groundwater flow, and A is the lateral flow. The SWAT model uses this equation to represent the water balance of the watershed and to simulate the various hydrological processes.

SWAT has been used in a variety of applications, including water resources management, land use planning, and climate change impact assessments [22]. Its flexibility, adaptability, and comprehensiveness make it a valuable tool for studying the interactions between land use, climate, and water resources in watersheds. The dataset used in the swat set up are presented in Table 1. The weather data inputs used in this study are daily precipitation, minimum, and maximum air Temperature. SWAT can simulate wind, solar and humidity data. The setup of SWAT was done for a period of 16 years, including 2 years warm-up (2000 and 2001) to ensure that the model is initialized, then calibration (2002–2012) and 4 years validation (2013–2016).

Table 1. Geo-spatial and hydrometeorological datasets.

Data	Source	Spatial Resolution	Temporal Resolution
DEM	STRM-United States Geological Survey (USGS) https://earthexplorer.usgs.gov/ (accessed on 16 June 2020)	30 m	-
Land use Map	(MODIS) Land Cover Type (MCD12Q1)	500 m	Yearly
Soil Map	Tensift Basin Hydraulic Agency (TBHA)	ArcInfo format (scale 1:100,000)	-
Soil Data	Field work [9]	ArcInfo format (scale 1:100,000)	-
Observed Hydrometeorology	Tensift Basin Hydraulic Agency (TBHA)	-	Daily

2.3. Model Calibration and Validation

Among various methods to perform calibration and uncertainty analysis is the widely used Sequential Uncertainty Fitting 2 (SUFI-2) approach with SWAT Calibration Uncertainty Procedure (SWAT-CUP) [23,24]. The SUFI-2 is a semi-automated approach that is used to perform parameterization, sensitivity analysis, uncertainty analysis, calibration, and validation of hydrologic parameters[25]. Sensitivity analysis in particular is necessary to understand which particular input parameter has a great impact on the model outflow [26]. Thus, the SUFI-2 algorithm was used to analyze 16 input parameters and further calibrate and validate the SWAT model. The model performance was evaluated using Nash-Sutcliffe efficiency (NSE) [27,28], percent of bias (PBIAS)[29] and rand root-mean-square error (RMSE) [30].

2.4. Flood Frequency Analysis

Using the calibrated model output, 50 years of annual discharge (m3/s) (1966 to 1960) was simulated. and used for deriving the flood frequency curve by applying the commonly used probability distribution functions which are the Gumbel Distribution (EV), Log Pearson Type 3 and Generalized Extreme Value Distribution (GEV). These distributions are widely used for estimating extreme values of the available data sets [31]. Two methods were used to estimate the parameters of the distributions: First is the Method Of Moments MOM technique which is most used in Canada to estimate the parameters for EV1 (Gumbel) [32], as well as for the Pearson logarithm type III (log Pearson III) which is widely used in by U.S federal agencies for Flood Frequency Analysis [33], second is the Probability Weighted Moments (PWM) to calculate the Generalized Extreme Value Distribution (GEV) which is beginning to be accepted [32]. The GEV and LP3 and distributions include three parameters which are; location, scale, and shape while Gumbel and Normal distributions are two parameters, i.e., location and scale.

The probability density function for the three distributions presented in Table 2. The more mathematical details on the above-mentioned probability distributions can be found in the reference book [34]. Kolmogorov-Smirnov (K-S), Anderson-Darling (A-D), tests were used to assess the performance of each distribution.

Table 2. Probability density function equations.

Name	Equation	Symbols
Log Pearson III	$f(x) = \frac{1}{\alpha * x * \Gamma(\beta)} * \left[\frac{ln(x) - \gamma}{\alpha}\right]^{\beta-1} * e^{-\left\{\frac{ln(x)-\gamma}{\alpha}\right\}}$	α = shape parameter ($\alpha > 0$) β = scale parameter (β ≠ 0) γ = location parameter

		Γ(β) = The Gamma distribution function for the parameter β.
Gumbel (EV I)	$f(x) = \frac{1}{\sigma} * exp\left[-\left(\frac{x-\mu}{\sigma}\right) - e^{-\left\{\frac{x-\mu}{\sigma}\right\}}\right]$	μ = shape parameter (−∞ < α < ∞) σ = scale parameter (β > 0)
Generalized Extreme Value Distribution (GEV)	$f(x) = \frac{1}{\sigma} * \left[1 - k * \frac{x-\mu}{\sigma}\right]^{1/k-1} * e^{-\left[1-k*\frac{x-\mu}{\sigma}\right]^{1/k}}$	σ = scale parameter (σ > 0) k = shape parameter μ = location parameter

3. Results and Discussion

3.1. SWAT Model Performance

The model was calibrated over the period 2002–2012 at gauge both Imin Lhemam and Nkouris gauging stations and validated over the period 2013–2016. The effect of melting snow was taken into account during the calibration stage.

Figure 2a,b show the results of the calibration and verification of the model, as the hydrographs of measurements and modeling for the calibration and verification periods, while Table 3 shows the respective results of the statistical indicators. The results of NSE were >0.5 and are considered satisfactory for both the calibration and validation period (Table 3). For the indicator PBIAS, and RMSE for both stations (Iguir Nkouris and Imin lhemmam) present a good performance. Observing the hydrographs, the surface runoff is overestimated for a number of years e.g., 2009 and it cannot be reduced because it will affect the base flow. however, the model generally underestimates the runoff. A study done by [35] explained that this underestimation is due to the limited number of the meteorological stations or an inadequate description of the rainfall input.

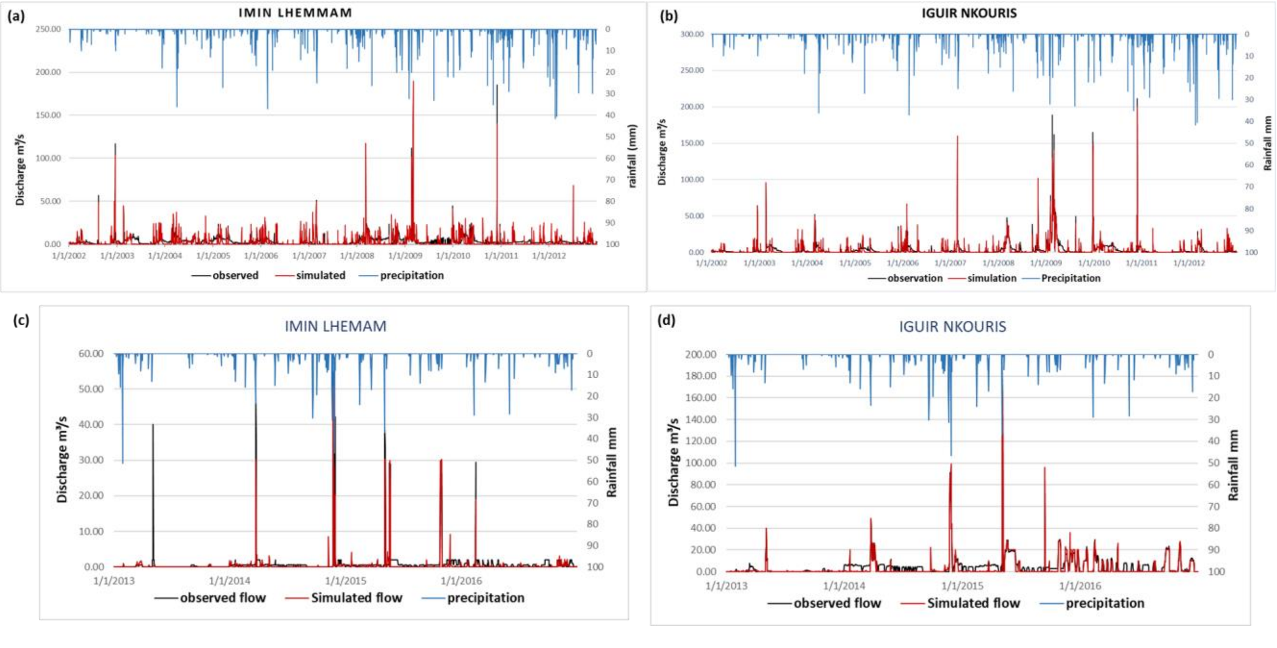

Figure 2. (**a**) Daily simulated and observed discharge (m^3/s) for the period (2002–2012) Imin lhemmam station, (**b**) Daily simulated and observed discharge (m^3/s) for the period (2002–2012) Iguir Nkouris station, (**c**) Daily validated discharge (m^3/s) for the period (2002–2012) Imin Lhemmam station, (**d**) Daily validated discharge (m^3/s) for the period (2002–2012) Iguir Nkouris station.

Table 3. results of statistical evaluation for calibration.

Parameter	Imin Lhemam		Nkouris		Condition
	Calibration	Validation	Calibration	Validation	
NSE	0.51	0.56	0.54	0.62	satisfactory > 0.5
PBIAS	16.4	15.3	22.9	21.03	satisfactory 25%

RMSE	4.00	3.25	3.72	3.12

3.2. Flood Frequency Analysis

The results of the return period of the LPIII, and GEV are given in Table 4. The distributions were able to give maximum discharge for return periods between 2–100 years. It appears that the GEV was the most appropriate to estimate the occurrence probability of N’fis floods. The value of decennial return period was 303.09 m3/s. and the 100-year flood reached 949.5 m^3/s. These quantiles are very high compared to the mean discharge (5.3 m^3/s).

Table 4. return period results for the GEV, Log Pearson III and EV1.

T	log Pearson III	Gumbel	GEV
2	82.3	114.8	78.5
4	187.5	231.4	163.2
8	304.4	333.2	264.9
10	343.4	364.6	303.0
20	466.0	460.1	442.7
40	588.3	553.7	623.6
80	707.5	646.5	859.2
100	745.0	676.2	949.5

The GEV distribution better approximates the relationship between return period and discharge Figure 3. Also, GEV achieved good results in both tests, while as shown in Table 5, it is very close to the Log Pearson III. The Gumbel distribution deviates from the normality based on the Anderson-Darling test and at the same time gives the lower flow values for long return periods, therefore it lags behind the other two and is considered unequable. It is noticeable that the 95% confidence interval in long return periods is extended for the Pearson III and GEV log distributions unlike for the Gumbel.

Table 5. Goodness-of-fit test result for Imin lhemmam.

T	log Pearson III	Gumbel	GEV
Kolmogorov-Smirnov	0.978	0.179	0.141
Anderson-Darling	−8.009	4.524	2.763

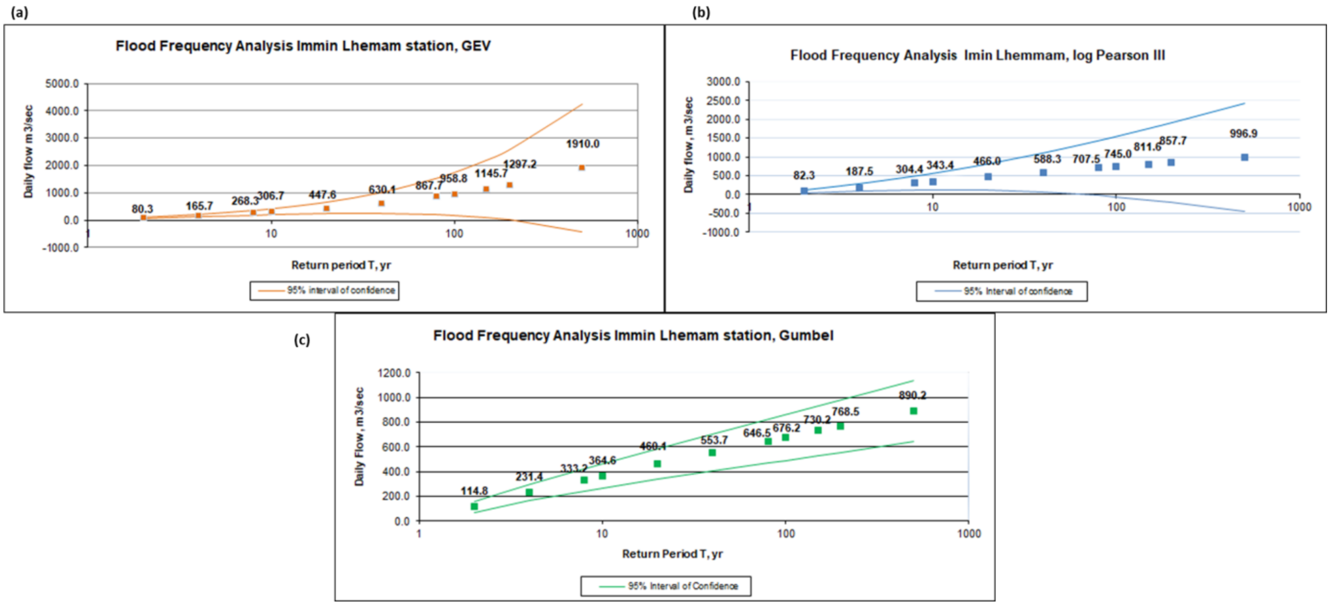

Figure 3. (**a**) Flood frequency analysis GEV, N′fis watershed using data from Imin lhemam station of the period 1966–2016, (**b**) Flood frequency analysis log Pearson III, of the period 1966–2016, (**c**) Flood frequency analysis Gumbel (EVI), of the period 1966–2016.

4. Conclusions

This study main finding is that SWAT (Soil and water assessments tool) model managed to simulate adequately the ungauged watershed N′fis watershed. The predicted values showed a quite good agreement with the observed data, based on statistical criteria. The calibration process needs a long time to provide as many cases as possible to reach the best scenario. Another problem for SWAT model is not being able to simulate the single events and reach the high peaks of flow during dry period. These high peaks affect the values of Nash Sutcliff and RSR.

Comparing the goodness-of-fit log-normal, Gumbel, GEV and LP3 distributions for flood frequency analysis in N′fis watershed, the GEV distribution shows good results and appears to be the more suitable one.

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