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APPLICATION OF THE CROSS-SIMULATION METHOD TO THE ANALYSIS OF THE RAIN-FLOW RELATIONSHIP FROM THE GR2MMODEL: CASE OF THE TAGHJIJT SUB-BASIN (GUELMIM- MOROCCO)

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ABSTRACT

The study of the relationship between precipitation and run-off is very interesting especially, in arid and semi-arid regions, and in watersheds where flow data are scarce. The case of the Taghjijt basin, which has an area of 1400m^2, is a case study for our research using the monthly model of rural engineering with two optimizable parameters X1 and X2 (GR2M), consisting of the application of the method of cross-simulations and the evaluation by the criterion of NASH-SUTCLIFFE during the period of calibration and validation. The model performance evaluation criteria, numerical and graphical, yielded satisfactory results in calibration and validation, including the correlation coefficients between observed and calculated flows. The monthly model showed better results for the calibration in comparison to the validation. This is due to the drought in the region, which has significantly affected the surface flows. In addition, tectonics, lithology, and Geographic Information Systems (GIS) are used to represent the general characteristics of the studied watershed. The data of the period from 1986 to 2016 of the station of Taghjijt are used and results show the performance of the estimation model GR2M for the period of calibration as well as in the period of validation, in the prediction of floods, even if it applies only two parameters. The phase shift between observed and simulated flows and precipitation is explained by lithology and tectonics. The creation of a significant real flow is dependent on the lithology and tectonics of the superficial rocks, similarly, these two factors can explain the observed mismatches between observed and simulated flows. The results of this study are useful for the adequate management of water resources, for the prediction of floods, and finally for a better adaptation of semi-arid territory to climate change.

Keywords: rainfall-flow modeling, GR2M model, taghjijt sub-basin, guelmim.

1. INTRODUCTION

The hydraulic basin of Guelmim is located in the South of Morocco (Figure-1). The hydrographic network in the basin of Guelmim is constituted by rivers with temporary flows, which are generally done towards the WSW, and the majority of the rivers are not very deep and average vast. This could be attributed to the hydric-erosion and the facies of the rivers which harden by place, with certainly the change of the beds of rivers over time. These three temporary rivers are deduced from the DTM map (Figures 2 and 3): Oued Seyyad, Oued Aourioura, and Oued Bouissaffen [8, 39] (Figures 3 and 4).

The basin of Guelmim belongs to the geological domain of the western Anti-Atlas. These are folded formations like lacustrine, limestone, dolomites, marls, and sandstone; which are oriented along a NE-SW direction. The massifs of the Precambrian Anti-Atlas are very eroded and often have a lower altitude than the Paleozoic terrain that covers them and outcrop in the Buttonholes, in the Guelmim Basin they outcrop in the Jbel Taissa. Modeling rainfall/flow is very useful in our region because it is subject to catastrophic floods, including that of 1985 and 2010, 2014 [39]. Belonging to a semi-arid area, it increases the risk of hazardous water, due to extreme precipitation [7], which forecasts the flows in a useful way for better management of the resource.

This study aims to identify trends in rainfall/run-off on monthly conceptual modeling in the sub-basin of Taghjijt located in the northeast of the basin of Guelmim. For that purpose, we apply this model on a monthly time basis (GR2M).

2. BASIN OF GUELMIM

2.1 Geographical Situation of the Guelmim Basin

The hydraulic basin of Guelmim is located in the South of Morocco. It has an elongated shape and is superimposed with the province of Guelmim with a total area of about 10.200 km^2 [4]. It is bordering to the North by the hydraulic basin of Souss Massa and to the West by the Atlantic Ocean over a length of about 120 km of coastline. The border remains underlined by the Hydraulic basin of Draa towards the South and the East.

2.2 Hydrology of the Guelmim Basin

Previous studies [4, 8, 39] have shown that the three main rivers in the Guelmim Basin are:

The Oued Seyyad River: is the main river of the Hydrological basin of Guelmim. Its source reaches 1,200 m altitude on the slopes of the Anti-Atlas (Figure-1 sub-basin Taghjijt), flowing almost in the East-West direction over 152 km and reunites with many tributaries, especially on the right bank. A dam is built in the Fask region

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downstream of the Taghjijt station, to improve the recharge of the Guelmim water table according to two variants [4]:

- By spreading the regulated water downstream on the river of Oued Seyyad;
- By infiltration at the level of the catchment fields of potable water for Guelmim.

The Bouissafene River: has a length of 82 km and a catchment area of 1,964 km². The river beds are few, as this river delimits the sub-basin of Bouissaffen;

The Aourioura river: is 56 Km long, and covers an area of 1,036 Km².

The Table-1 summarizes the physical characteristics of the three sub-water sheds of Guelmim:

Table-1. Physical parameters of the three sub-watersheds of Guelmim [8, 39].

Sub-basin	Surface area (Km^2)	Perimeter (Km)
Seyyad	6,896	699
Bouissafen	1,932	356
Aourioura	1,048	292

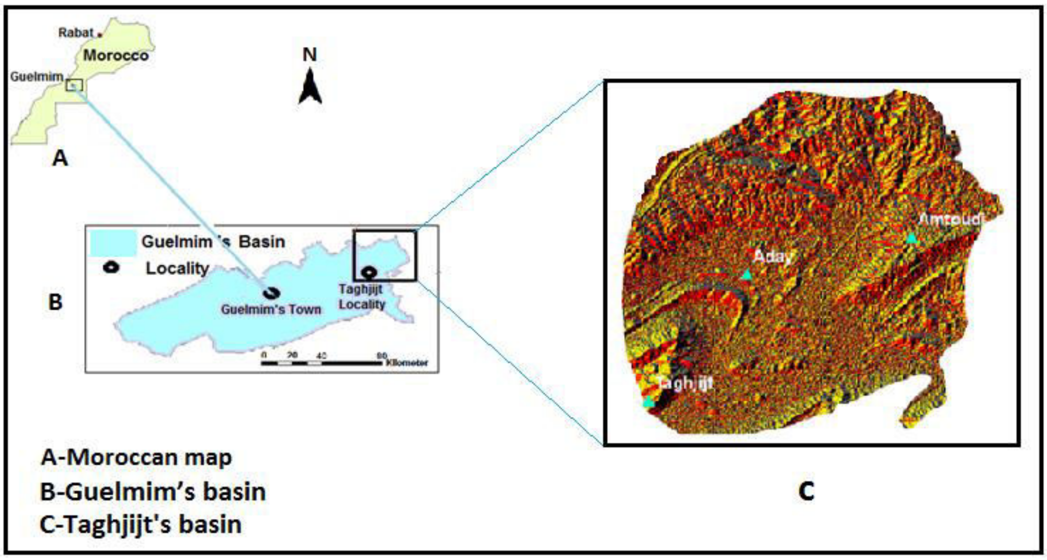

Figure-1. Location of Taghjijt sub-basin and Guelmim basin in Moroccan map. This shows the location of Guelmim basin in southwestern Morocco And which shape appears to be elongated.

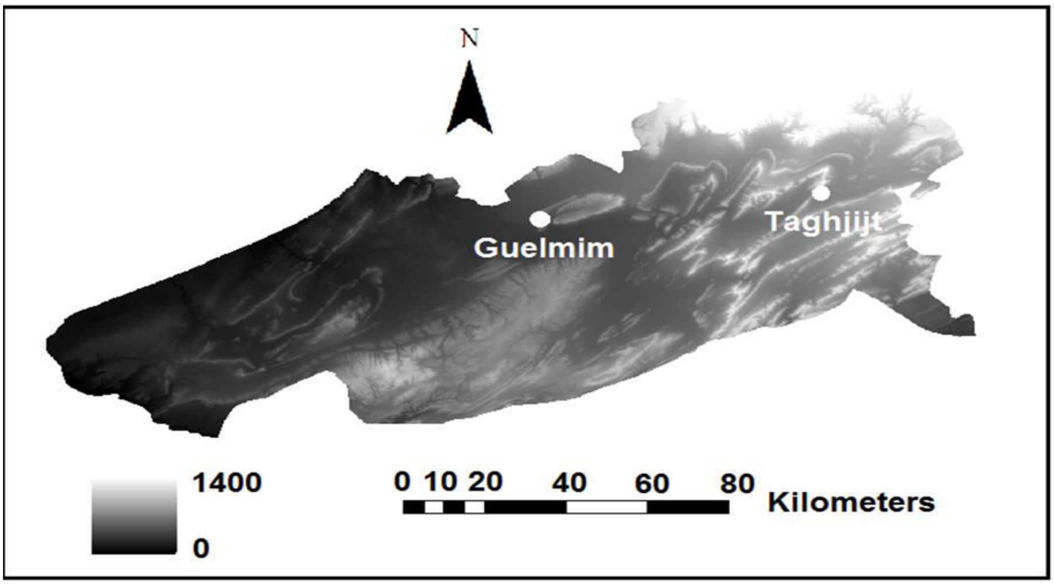

Figure-2. MNT of the basin of Guelmim: The altitudes vary between 0 and 1,400 m in the Guelmim Basin, Low altitudes are situated in the coastal zone, whereas high altitudes are mainly located in the eastern zone (Western Anti-Atlas).

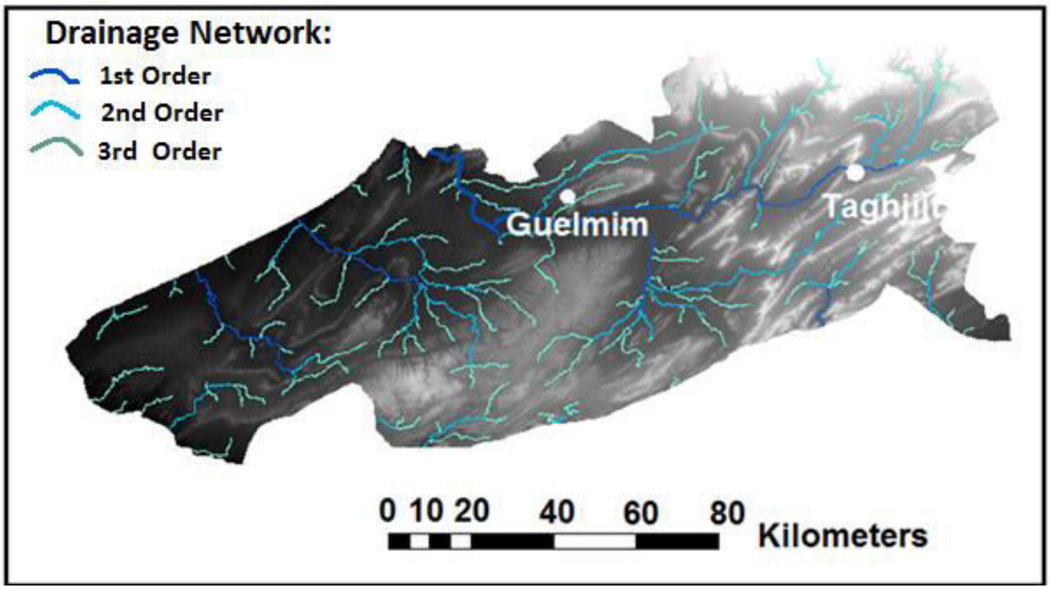

Figure-3. Hydrographic network of the basin of Guelmim, showing the location of Guelmim and Taghjijt; and the three main rivers effluents on each other.

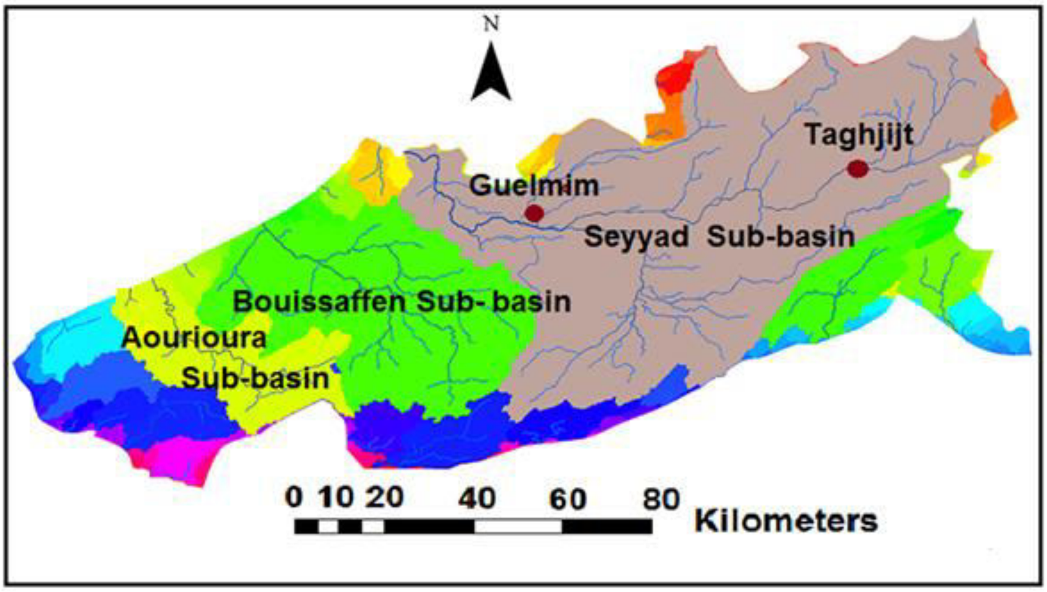

Figure-4. Map of the three sub-basins of the Guelmim Basin: The hydrographic network extracted from the DTM map of Guelmim , consists of 3 three main rivers [8, 39].

2.3 Geology of the Guelmim Basin

2.3 A Regional lithostratigraphy

The region of Guelmim corresponds to a vast synclinal basin-wide of 25 Kilometers, centered on the Mountain of Tayert located on the synclinal axis surrounded by the quartzite bars of the terminal Acadian, locally called " internal Fieja "[4,28,59]. The layers of the region are affected by spectacular folds. The direction of the folds is NNE/SSW. The anticlines are often pinched while the synclines are wide. The fillers on either side of these landforms consist of plio-quaternary cover deposits overlying the bedrock Acadian Shale [28, 59]. The outcrops of the "Paradoxid Shale" of the Fask Hills show a marked schistosity due to the passage of an important tectonic phase.

The Bouizakarne region is tectonically more complex, with narrow sub-meridian folds affecting the Cambrian and Adoudonnian carbonate series. The folds show a clear incubation and, their orientation WSW/ENE at Guelmim changing to NNE/SSW near Bouizakarne [59].

In Figure-5, a synthetic log describes the different geological formations encountered in the area of the Western Anti-Atlas, according to previous studies conducted in the region [24, 28, 59], and the succession of land from bottom to top is as follows in the basin of Guelmim:

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The Precambrian: constituted by Rhyolites and andesites that outcrop in the southern slope of Ifni massif, testifying an important volcanic activity in it. All layers of these formations are compact in their mass; however, they still provide important superficial cracks and zones of alteration or detrital accumulation.

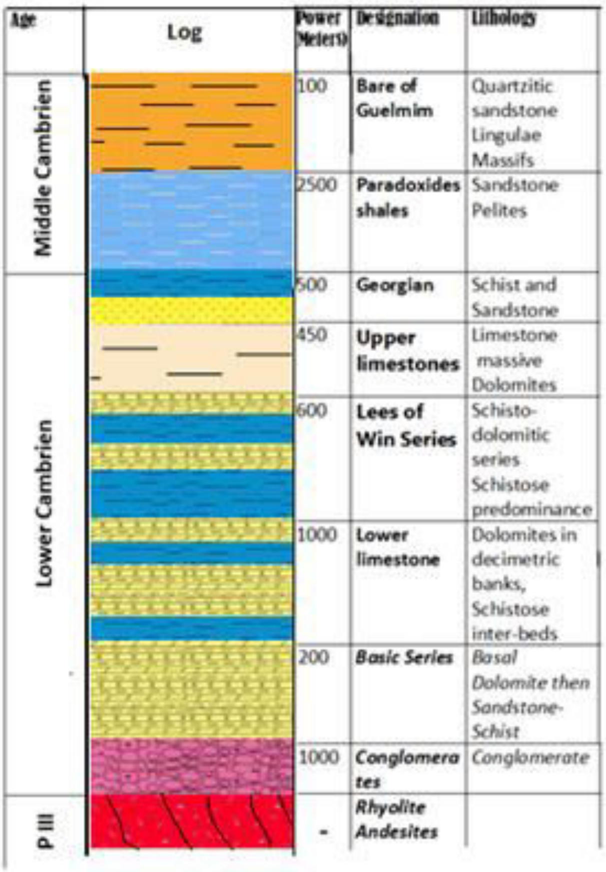

Figure-5. Schematic lithostratigraphy column from the Guelmim basin [74].

The Infracambrian: constituted from Bottom to Top by [4]:

- The basic series formed by the crystalline formations of the Precambrian transgressed by coarse conglomerates with eruptive elements, surmounted by the schistose series of the base. These formations are attributed to the lower Adoudounien;
- The "lower" dolomitic limestones and dolomites, with some schistose intercalations, are attributed to the Talwinian and constitute a soft zone in the morphology. They are of lower Adoudonnian age;
- The "wine lees series" alternates Schist and limestone banks. This series tightens towards the South and the East and is loaded by schistous deposits;
- The upper limestones of the Adoudounian;

The Georgian "Upper Limestone": formed by a Schisto-limestone series;

The Acadian: characterized by green shales at the base and sandstone and quartzite at the top (Guelmim bar);

The Ordovician: constituted by Schists and Quatzite, outcropping in the East of the Basin, which is organized in a sharp mountainous ride;

The Pliocene: formed of lumachellic sandstones, constituting with the Quaternary the filling of the plain of Guelmim;

The villafranchian: represented by encrusted dune formations;

The Quaternary: Is characterized by a great variation of facies: marine and fluvial terraces, crusts, regs, scree, alluvial fans, lacustrine limestone, dunes, travertines and salt deposits.

The Seyyad basins is the main one of the Hydrological basin of Guelmim, it takes its source at 1,200 m of altitude on the slopes of the Anti-Atlas; and its flow is almost in the East-West direction on 152 km and receives numerous tributaries, in particular on the right shoreline.

The study area (sub-basin Taghjijt) is located NE of the Seyyad sub-basin (Figure-8), between X = 108.437 and Y = 235.535 at an altitude of 1,050m NGM (Amtoudi Mountain) and extends over an area of 1,400 km2, its shape is oval.

During this period, the rainfall has an irregular distribution with a predominance of the month of December, from May, rainfall becomes increasingly rare and during the months of June and July, rainfall is almost non-existent. The trend curve (Figure-10) shows a slight increase during the study period. The rainfall peaks coincide with the years of floods 1985, 2010, and 2014 (P_{max} =300mm) [39, 76]. From the 20th of November to the 1st of December rainfall in Taghjijt reached 208.5 mm, (according to ABH Guelmim 2015) which caused flooding.

From Figure-9 we find that:

- The rainfall has great variability according to the seasons;
- The rainy period extends from November to March.

Figure-11 shows that:

- Flows are highly variable by season;
- The period of high flows extends from November to March;
- From May onwards, the flows become increasingly low;
- During the months of May, June, and July, the flows are almost nil.

2.3 B Geology of the Guelmim Basin

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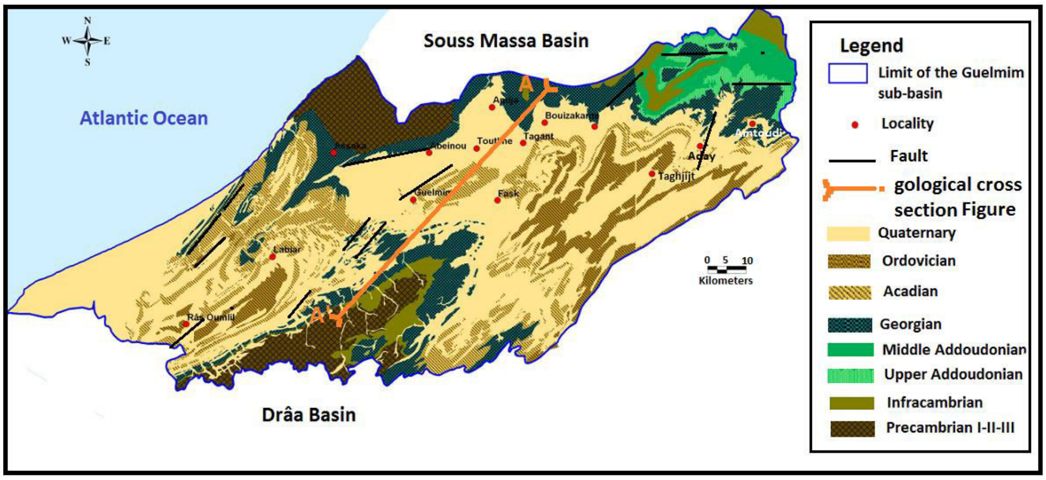

Figure-6. Geological map of the Guelmim basinSource: (Geological map of Foum El Hassane-Assa and Guelmim and Guelmim-Draà inferior at 1/200 000, [25]).

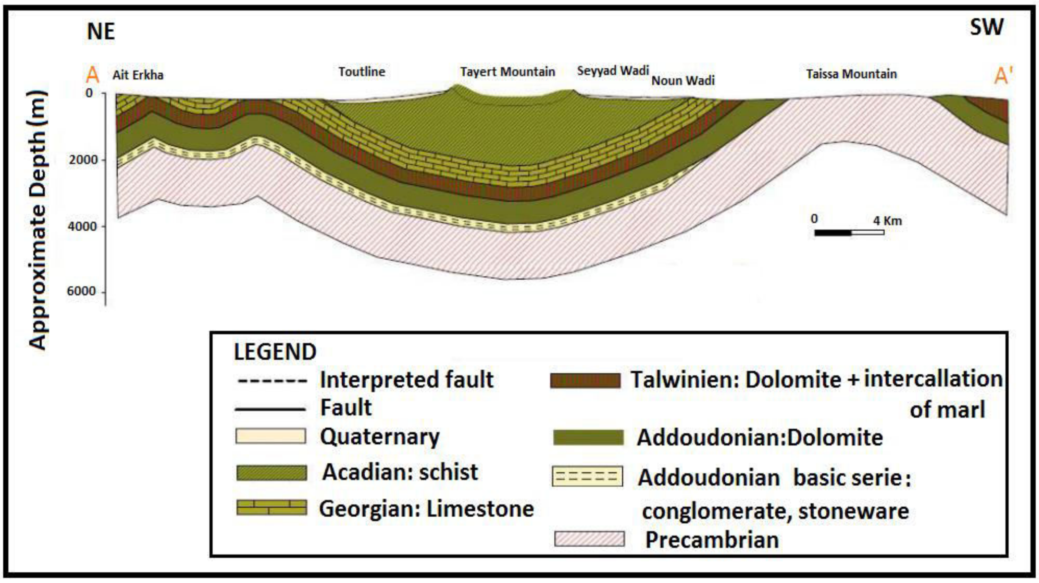

Figure-7. Geological section in the center of the Guelmim basin (Source: Agence du Sud Guelmim, 2006; Schéma régional d'aménagement du territoire Guelmim, 2006).

The nature of the soil in the Guelmim basin is much diversified and varies according to the proximity of the desert, the sea or the Anti-Atlas Mountains.

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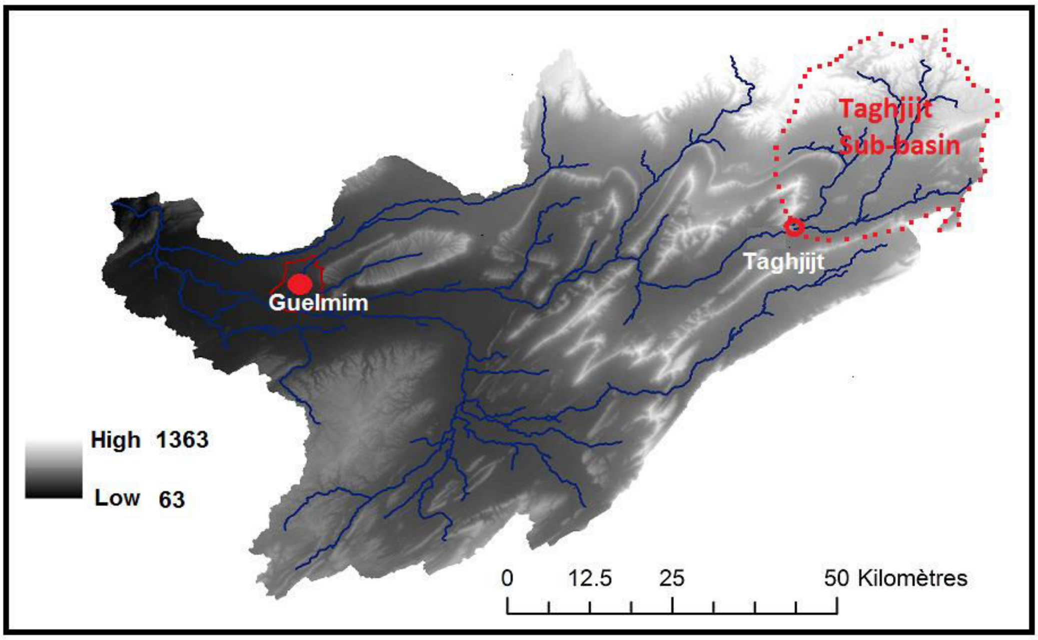

Figure-8. DEM of the Seyyad basin and hydrographic network, the Taghjijt sub-basin is delimited by dashed lines in red [42, 91].

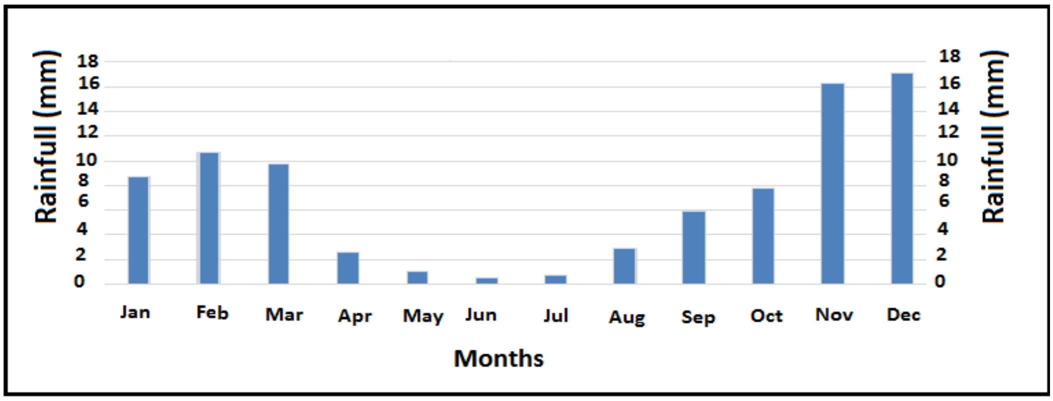

Figure-9. Monthly rainfall recorded in Taghjijt station (1937-2015)(Data source: KNMI Climate Explorer).

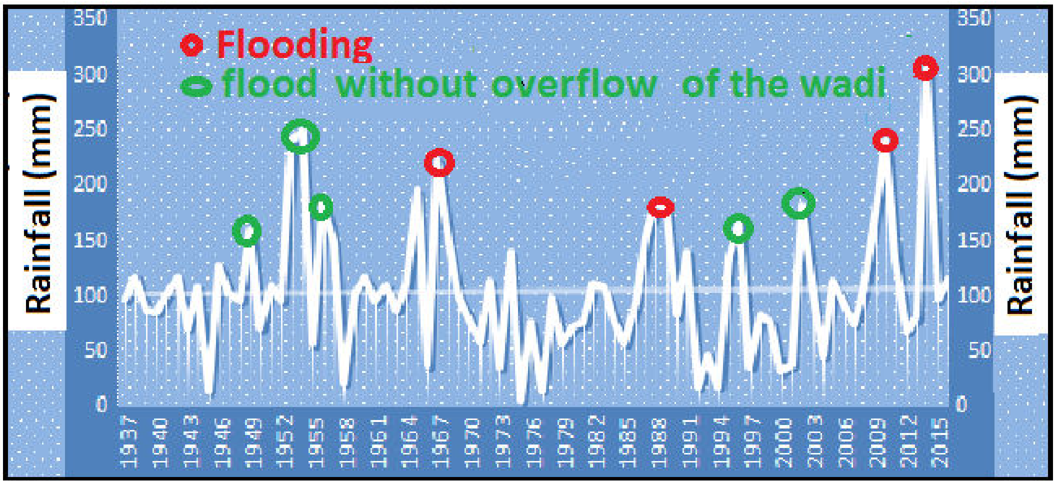

Figure-10. Annual rainfall recorded in Taghjijt station (1937-2015), and the rainfall peaks that caused flooding in the region. (Data source: KNMI Climate Explorer).

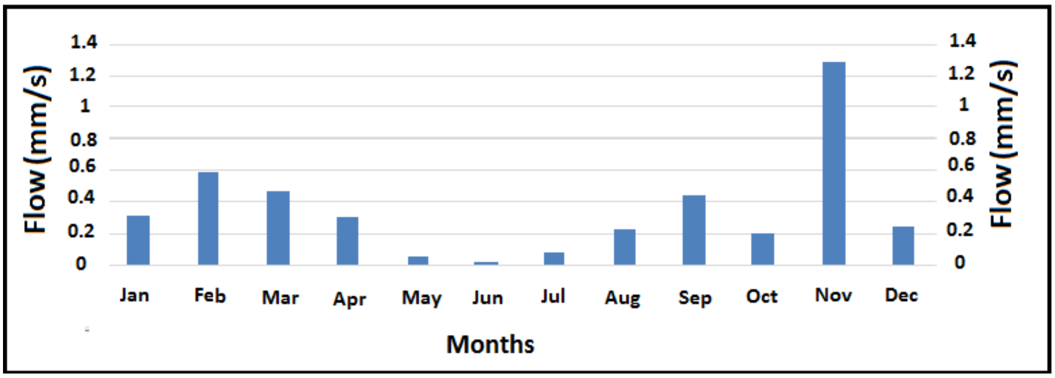

Figure-11. Variation of the average mean flow in the Taghjijt station (1986-2016) (Data source: Agence du basin hydraulique Souss Massa Deraa Agadir).

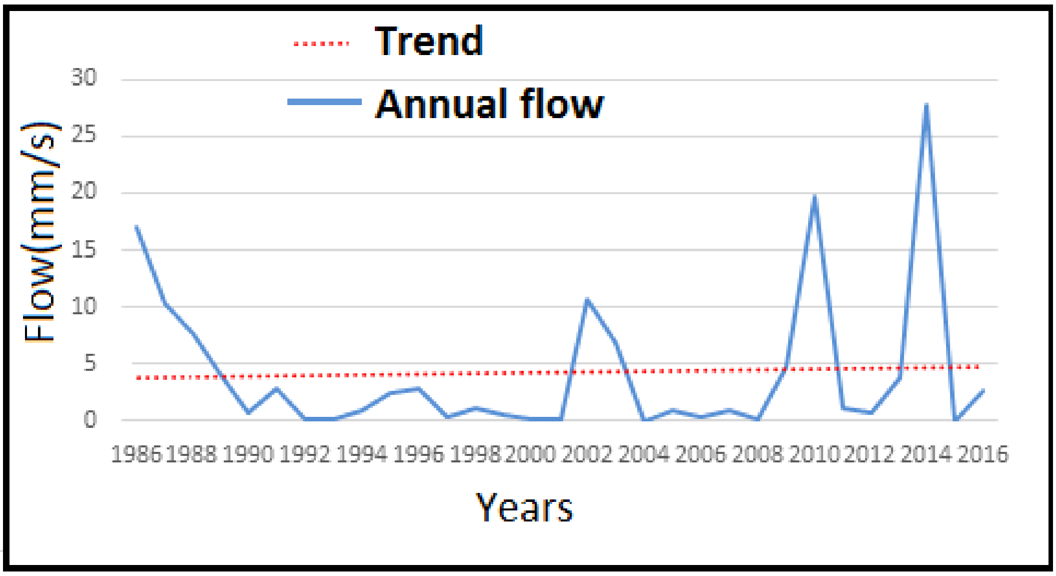

Figure-12. Variation of the annual average flows in the station of Taghjijt (Data source: Agence du basin hydraulique Souss Massa Deraa Agadir).

The contributions of the river of Seyyad on the hydrometric station of Taghjijt are very heterogeneous from one year to another (Figure-12). The Taghjijt region has a semi-arid climate with a bimodal distribution of annual rainfall [34]. With extreme events or rainfall exceeding 50 mm in 24 hours. The average annual precipitation is of the order of 125 mm, with a coefficient of variation of 0.45 [58]. The wind system is also bimodal [58], in the winter dominates the cold winds from the North, on the contrary in the summer the winds from the east and SE dominate and transport the dust to the lower altitudes [58]. Wind speeds and relative humidity measured at the Taghjijt station 1987/1998 vary from 1.42 to 4.70 m/s and from 25 to 63%, respectively. The region regularly experiences violent sandstorms. The average annual temperature is about 19.5°c with minimum values in January and maximum in August [58]. The insolation is very important and can reach more than 3500 hours/year in low altitude areas. The average annual ETP is 1500mm [58].

3. SUB-BASIN OF TAGHJIJT

3.1 The Geology of the Sub-Basin

The study area belongs to the Western Anti-Atlas which is part of the Anti-Atlas. The Anti- Atlas is located between the northern part of the West African craton, the High Atlas Mountains in the north, and the Tindouf basin in the south. The sub-basin of Taghjijt is constituted in narrow plains "internal Fieja" which are cleared in the shales and dominated by the crests of the synclinal perches of Bani which are armed with a large number of stones. The limestone plateaus are surrounded by schistosandstone outcrops Georgian [29]. At their foot, extend narrow plains of "fiejas", whose substratum is formed by Acadian shales generally masked by quaternary formations (silt, conglomerates, and screen). The geological formations of the center of Taghjijt are cut by the river Oued seyyad. The latter enters the Baní at Foum Taghjijt. Its temporary stream is well-incised and its bed is relatively narrow. The general flow is towards the West. The slopes of the Baní are made up mostly of low permeability rocks, the runoff can be quite high. The Baní folded in this area is formed by synclinal alignments oriented NE-SW alternating with narrow anticlines [29]. This zone corresponds to the formations of sandstone and quartzite Acadian and Ordovician of the Bani Fold, violently compressed by the folding of ejective type [29]. The relief is more or less high and the eroded structures, with an altitude varying from 0 to 1,455 m (in the region of Amtoudi). And the mountainous relief occupies more than half of the territory of the sub-basin of Taghjijt. At the level of the center Taghjijt, are the formations of the Ordovician (sandstone and Quartzite) which constitute the reliefs. Towards the east of the center, there exist shale and sandstone of Cambrian that mark the appointments within the quaternary formations [29]. The narrow Ordovician valley of Taghjijt is traversed by the Seyyad river, and constitutes the outlet (=Foum) for the sub-catchment area; the reason for which a hydrometric and metorological station is installed in this forum.

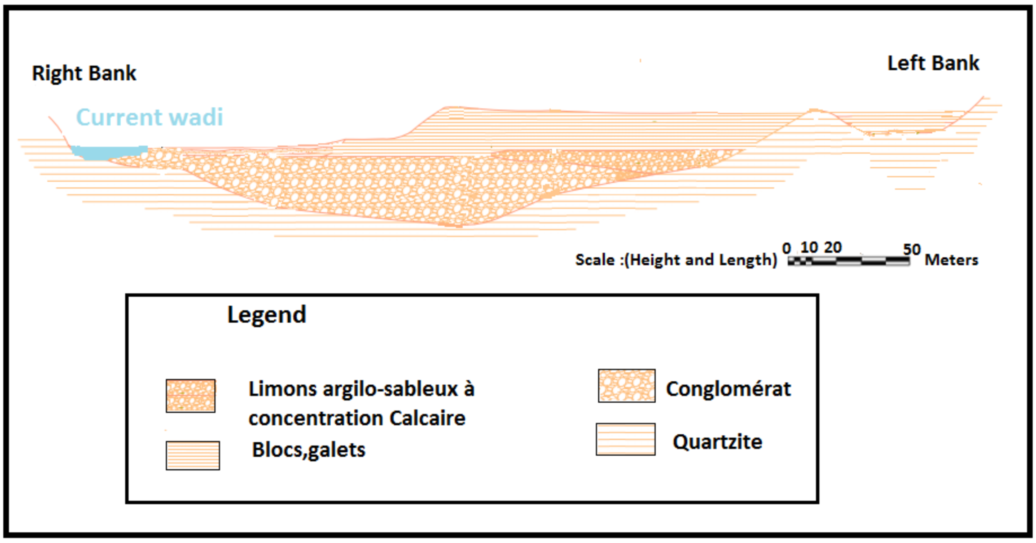

Figure-13. Section of the Foum-Taghjijt(according to the sections of the drillings carried out in 1956 by the company SOLETANCHE, [28]).

At the level of the forum(=Outlet) Taghjijt, we notice the displacement of the river towards the right bank with time, the conglomerate outcrops on the river and the quartzite outcrops on the river and on the right bank (Figure-14). So this forum (outlet) is very narrow, which threatens the locality of Taghjijt to the overflows of the river during the periods of rain.

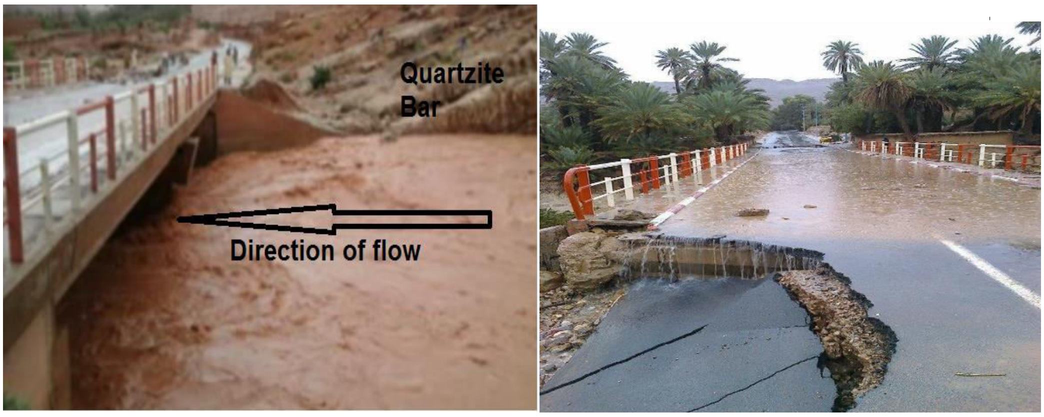

Figure-14. Lift: The Seyyad River near forum Taghjijt during the flood of November 28 and 29, 2014; right: road damage caused by the overflow of the Oued Seyyad at the same location.

3.2 Climate

The study area is characterized by severe aridity, due to the presence of the High Atlas mountain chain, which hinders rainy disturbances from the North. The region is characterized by frequent winds causing sandy accumulations of various forms throughout the year and which can reach 4.70 m / s. Two wind regimes are observed [62]:

- That of weak winds, generally from October to the end of March;

- Strong winds, from April to the end of September.

3.3 Exposure

The dominant exposure of the landforms is W-NW and S-SW (Figure-15).

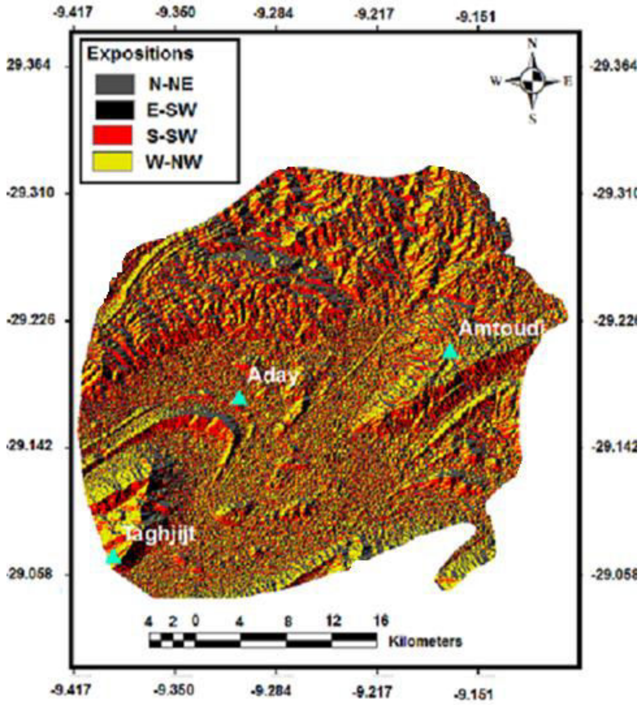

Figure-15. Map of exposures in the Taghjijt sub-basin.

3.4 Topography

We note high altitudes in the NE of the basin with a maximum altitude of 1350m, and about 60% of the land is located in medium to low altitudes (below 730m). The mountainous relief occupies almost half of the sub-basin, and its elevation varies between 600m and 1350m. (Figure-16).

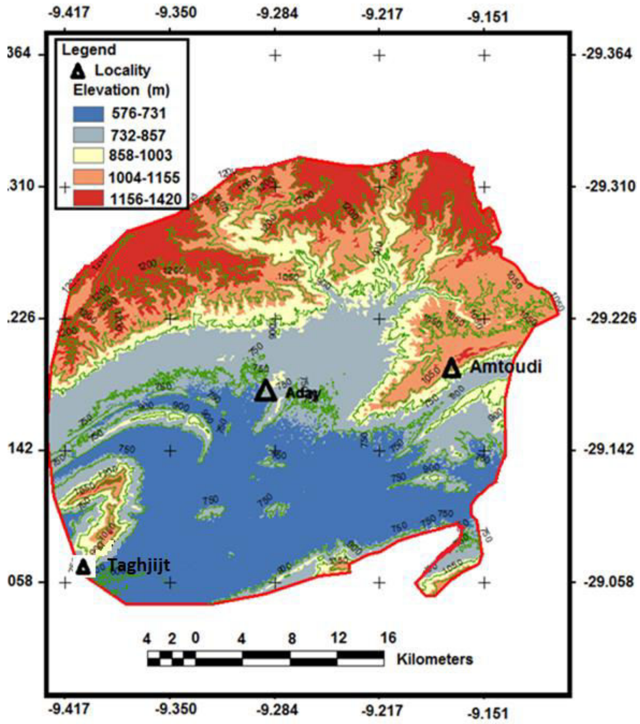

Figure-16. Map of the altitudes of the Taghjijt sub-basin.

3.5 Slopes

In the high altitude area (NE), we note strong slopes ranging from 16% to 56%, on the contrary in the plain we note weak slopes from 0.5% to 10% (center and SW). It is also noted that strong slopes exist in the Northern part of the basin and weak slopes are in the Southern part with a percentage of 50%, the slopes break abruptly in the middle part of the Taghjijt basin (Figure-17). We also note that the map of altitudes is united with that of slopes, so the strong slope in the sub-basin of Taghjijt is encountered in the high altitudes, which is explained by water erosion and the nature of the land that is uneven in the reliefs. Conversely, the strong slopes favor surface runoff.

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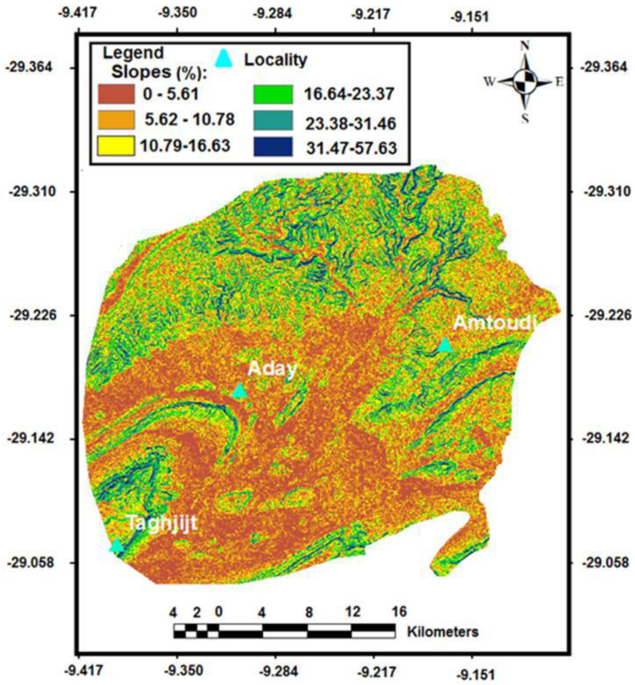

Figure-17. Map of the slopes of the Taghjijt sub-basin.

3.6 Hydraugraphic Network

The hydraugraphic network extracted from the DTM (Figure-18) delineates two sub-basins: Sub-basin Taghjijt-Aday and sub-basin Amtoudi (Figure-19), whose characteristics are mentioned in Table-2 and the hydrometric station is located at Foum- Taghjijt is the outlet of the sub-basin Taghjijt.

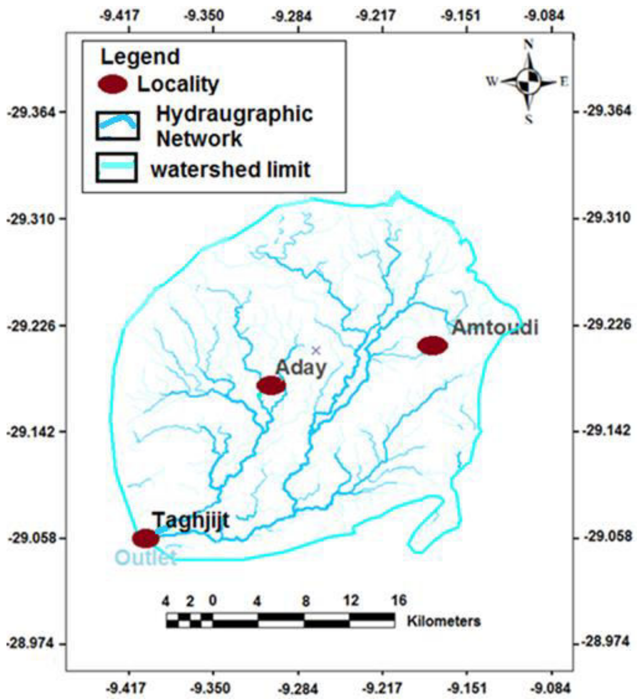

Figure-18. Map of the hydraulic network of the Taghjijt sub-basin.

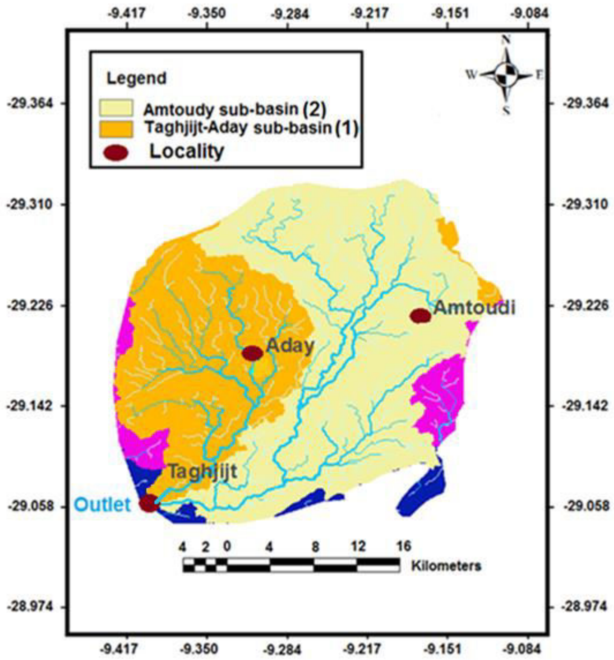

Figure-19. Map of the hydraulic network of the Taghjijt sub-basin showing two main sub-basins.

Table-2. Main characteristics of the two sub-catchments of Taghjijt.

Name	Area (km^2)	Perimeter (m)	Max altitude (m)
Taghjijt-Aday Sub-basin	500	60	1,209
Amtoudi Sub-basin	700	98	1,350

3.7 Pedology

The pedology of the sub-basin is characterized by the predominance of raw mineral soils, stony desert sands on limestone, or eruptive rock that develop on the Paleozoic formations of the Western Anti-Atlas.

3.8 Winds

The dominant winds are Gharbi (NW/SE. Oceanic origin) and Chergui (E/W. desertique origin). Wind speeds and relative humidity measured at the station Taghjijt 1987/1998 vary respectively from 1.42 m / s to 4.7 m / s and from 25 to 63% [93]. The region regularly experiences violent sandstorms.

3.9 Erosion, Desertification

This region is very sensitive to erosion and desertification due to several factors: The topography of the Taghjijt sub-basin, accidental in some places, the lithological diversity, the semi-arid climate, the proximity of the desert and the strong winds, and the low density of vegetation cover [4].In the sub-basin of Taghjijt, the phenomenon of water erosion is related to the dynamics of water in the various facies, and also wind erosion because

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of strong winds coincide with periods of severe drought [4,79].

3.10 Evapotranspiration in Taghjijt

The monthly evapotranspiration in Taghjijt is according to the seasons, and varies from 2.7 mm/day in December and July 9.8mm/day in July (Figure 20).

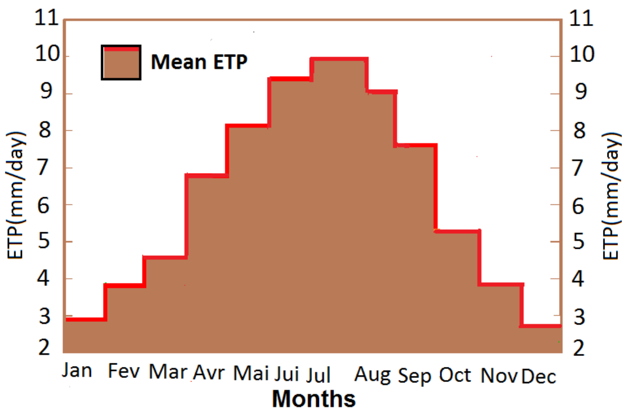

Figure-20. Monthly evapotranspiration in Taghjijt (Source: KNMI Climate Explorer).

3.11 Irrigation

The irrigated perimeters are located at the level of oases, the sub-basin of Taghjijt has several oases whose main are three: Taghjijt, Aday, and Amtoudi. The land occupation is characterized by the presence of plantations: olive trees, and palm trees with crops in underfloors [62].

Table-3 summarizes the main irrigated palm groves in the Taghjijt sub-basin. [4]

Table-3. Location and importance of palm groves [62].

Locality	Nombre de palmiers	Superficie (Ha)
Taghjijt	50,000	600
Aday	35,000	350
Amtoudi	04,000	50
Total	89,000	1,000

Data sources: Données de la DPA selon: Actualisation de l'étude du Shéma d'aménagement integer des ressources en eau du basin de Guelmim, Demande en eau agricole, CACG/ADI, Mars 2006.

4. METHODOLOGY

4.1 Choice of the GR2M Model

Edijatno *et al* (1999) wrote:" our ambition is to arrive at a not very disappointing simulation by using the simplest possible representation of the rainfall/flow process, dependent on a very small number of parameters, which will remain to be adjusted to fit the river we want to study".

The rainfall/flow models used must be robust to take into account the quantity and density of measurement points, and must not require a lot of data [81]. The step of swept space is 1400 Km^2. As for the step of time that is monthly. We worked from the monthly version GR2M of the rural engineering model, developed by Makhloufe in 1994.

4.2 Data Used

The GR2M rainfall/flow model cannot be tested or function without the contribution of hydrometeorological data: rainfall and evapotranspiration data as input to the model and hydrometric data as output from the latter (for the calibration period). The observed flows during the period 1986-2016 come from the ABHSMD (Agence du bassin hydraulique Souss Massa Drâa) and the data concerning rainfall and evapotranspiration are available online (KNMI Climate Explorer). The evapotranspiration is calculated by the Thornthwaite method over the period 1986-2016. The Taghjijte station is representative to translate significantly the hydrological behavior of the sub-basin Taghjijte since it is built on the outlet of the sub-catchment.

4.3 Description of the GR2M Model (Mouelhi Version 2003)

The GR2M model (rural engineering model with two monthly parameters) is a rainfall flow model capable of transforming, at the watershed scale, the two signals of precipitation and evapotranspiration into a single signal: flow at the watershed outlet [6, 44, 60]. Thus, the rest of the input signals are reduced in the timing of X1 and X2. This global model has two parameters. Its development was initiated at IRSTEA in the late 1980s, with application objectives in the field of water resources and low water flows [47, 48, 54, 67]. Although its structure is empirical, it resembles conceptual models of the reservoir, with a procedure of monitoring the state of moisture of the basin that seems to be the best way to take into account past conditions and ensure good functioning. The structure of the Continuous model combines a production reservoir and a routing reservoir as well as an opening to the outside, other than the atmospheric environment. Three functions are used to simulate the hydrological behavior of the basin [10]. The GR2M model consists of a production reservoir, which governs the production function that reflects the more or less good ability of the watershed to produce flows, and which is characterized by its maximum capacity; and a "gravity water" reservoir that governs the transfer function (routing). This monthly water balance model is governed by two parameters to be calibrated (X1 and X2): The first parameter (X1) represents the maximum capacity of the "soil" reservoir; the second parameter (X2) represents the subsurface exchange parameter at the "gravity water" reservoir (Figure-21). According to [67, 72], a number of two free parameters in a global conceptual model during a learning period in which the observed flows and those calculated are compared, is sufficient to represent the rainfall-flow relationship by monthly time step [67]. The

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model has demonstrated its performance and robustness in several watersheds, notably in West Africa and Algeria. The input data for the GR2M model are rainfall and evapotranspiration and the output data are flows. We were motivated to adopt the GR2M model for three reasons:

- Its simplicity by requiring a relatively small number of these parameters (rainfall and evapotranspiration) and the observed flows in monthly time steps to calibrate and validate the model;
- The availability of monthly data;
- Its adaptability to semi-arid areas.

The correct calibration of the model is estimated from the NASH criterion [71]. On different parameters but also graphically (superposition of observed and calculated flows).

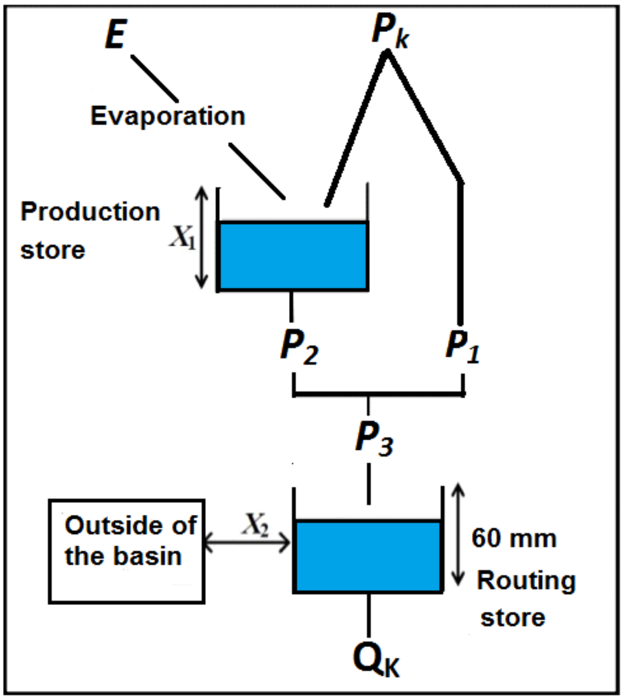

Figure-21. Diagram of the structure of the GR2M model, Adapted from [67].

The production function of the model is based on a soil moisture reservoir. A part Ps of the rainfall P_k will be added to the content S_k in the reservoir at the beginning of the time step

$$\mathbf{P_s} = \frac{x_1\left[1-\left(\frac{S_k}{x_1}\right)^2\right]\tanh\left(\frac{P_k}{x_1}\right)}{1+\frac{S_k}{x_1}.\tanh\left(\frac{P_k}{x_1}\right)} \tag{1}$$

X_1parameter that represents the capacity of the reservoir; it is positive and expressed in mm. The excess rainfall $P_1$is given by:

$$P_1=P-Ps' \tag{2}$$

and the content of the tank S'is updated:

$$S'=S_k-P_s \tag{3}$$

Due to evapotranspiration, an amount E was withdrawn from the reservoir:

$$\mathbf{E_s} = \frac{S'\left[2-\left(\frac{S'}{x_1}\right)^2\right]\tanh\left(\frac{E}{x_1}\right)}{1+\left(1-\frac{S'}{x_1}\right).\tanh\left(\frac{E}{x_1}\right)} \tag{4}$$

E is the average potential evapotranspiration for the calendar month under consideration of the level S' becomes S"

$$S''=S'-E_S \tag{5}$$

The percolation function is defined by the soil moisture monitoring tank which then drains according to a P2 percolation

$$\mathbf{P_2} = \mathbf{S''}.\left\{\mathbf{1}-\left[\left(\frac{S''}{x1}\right)^3\right]\right\}^{-\frac{1}{3}} \tag{6}$$

And its levelSK+1, ready for the next month's calculations, is then given by
SK+1=S"-P2 (7)

And the routing is the exchange with the non-atmospheric exterior symbolized by the total amount of water P3 reaching the routing tank, is given by

$$P3=P1+P2 \tag{8}$$

The level RK in the tank then becomes R'

$$R'=RK+P3 \tag{9}$$

A groundwater exchange term F has been imposed by the data from the many basins used. Ignoring this opening to the non-atmospheric exterior leads to a considerable decrease in the efficiency of the model. F is then calculated by:

F=(X2-1) R'
(10)

The parameter X2 is positive and dimensionless the level in the tank becomes:

$$R''=X_2R' \tag{11}$$

The tank, with a fixed capacity of 60 mm, can be emptied 9

$$\mathbf{Q_k} = \frac{\mathbf{R''^2}}{\mathbf{R''+60}} \tag{12}$$

The content of the tank is finally updated by:

RK+1=R'–QK (13)

The optimized parameters X1 and X2 represent respectively the capacity of the production reservoir and the underground exchange coefficient.

4.4 Mathematical Criterion for Optimizing the Model (Nash Sutcliffe Criterion)

In the first step, the choice of the model is based on the performance. After the performances of the competing models for each time step are very close. The optimization criterion used in our study is the Nash-Sutcliffe criterion (Eq 14) [71]. This dimensional criterion allows to evaluate of the quality of the fit and facilitates the comparison of the fits on different basins whose flows correspond to different orders of magnitude, it is defined by Equation 14:

$$\mathbf{Nash-Sutcliffe} = \mathbf{100}\left[\mathbf{1} - \frac{\Sigma(Q_o^i - Q_c^i)^2}{\Sigma(Q_o^i - Q_m)^2}\right] \quad (14)$$

Where

Q_o^i: Observed monthly flows

Q_c^i: Calculated monthly flows

The value of the Nash-Sutcliffe criterion [71] varies between - ∞ and 100%. The model is considered to perform well when the estimated flows are close to the observed flows, that is to say when the value of the Nash-Sutcliffe criterion is close to 100%. Thus, a performance greater than or equal to 50% can be considered satisfactory, and it is considered that the result is logical [52, 73]. The performance in terms of the Nash Sutcliffe criterion reflects the image of the adequacy of the model and set of parameters calculated to the basin studied.

Table-4. Evaluation criteria (Nash) of simulations [63].

Nash	Performance Assessment
N≤50%	Insufficient
50%<N≤65%	Satisfactory
65%<N≤75%	Good
75%<N≤100%	Very good

Q_m: Average observed flows over the entire observation period without gaps.

5. RESULTS AND DISCUSSIONS

5.1 Optimization of the Calibration Parameters of the GR2M Model

The GR2M model is programmed on an Excel sheet, and the series of observations are divided into two periods, one for the calibration of the model and the second for its validation while keeping a common period between the rainfall and flow. The parameters of the model are optimized until obtaining a Nash value close to 100% and a better fit between the observed flows and 5.2 flows calculated by the model

The application to the Taghjijt basin was based on monthly data from January 1992 to December 2011 for calibration and January 1996 to December 2016 for validation, according to the principle of split-sample test which consists in calibrating a part of the sample of available data and validating the remaining third and vice versa [80]. For the calibration of the model, we proceeded manually to change the values of the parameters X1 and X2 several times until obtaining the optimal values of the coefficient of the quality criterion of Nash-Sutcliffe and the coefficient of correlation between the calculated flows and those observed (Table-5).

Table-5. Performances in phases of calibration and validation of the GR2M model at the station of Taghjijt, expressed in value of the criterion of Nash-Sutcliffe and the correlation coefficient between the observed and simulated flows: (X1:Production capacity (mm); X2: Exchange parameter (mm);r: correlation coefficient).

Calibration period	Validation period	X1	X2	Period nature	Nash	√Nash	Ln (Nash)	Bilan	r
1992-1995	1996-2016	3.52	0.54	Calibration	82.9	43.3	-74.1	97.2	0.92
				Validation	72.5	48.2	7.4	100.5	0.91
1992-1999	2000-2016	3.55	0.55	Calibration	60.8	32.2	-15.8	91.2	0.83
				Validation	63.8	41.4	8.6	87.9	0.91
1992-2003	2004-2016	3.85	0.72	Calibration	21.3	34.1	4.5	91.6	0.5
				Validation	27	33.5	-31.7	153.9	0.95
1992-2007	2008-2016	3.8	0.65	Calibration	22	36.8	8.3	77.4	0.49
				Validation	56.1	44	-20.8	130.4	0.95
1992-2011	2012-2016	3.5	0.6	Calibration	14	34.8	13.3	92.9	0.80
				Validation	54.4	57	-4.1	131.9	0.97

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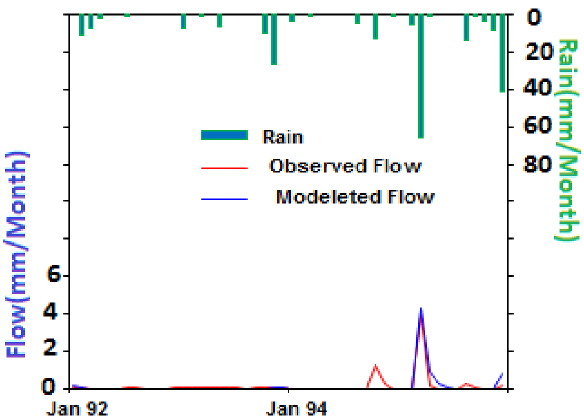
The results of Table-5 concerning the different values of X1 and X2, the Nash-Sutcliffe criterion, the correlation coefficient between the observed and simulated flows, and the good superposition of the two curves, of the simulated and calculated flows, make it possible to say that the model is well calibrated. For the validation of the model, the precipitation and evapotranspiration data corresponding to the period following the calibration years and which were not used during the latter are introduced. The calculation is done by taking the optimized values for the parameters X1 and X2 during the calibration. The values of the results are then compared to the observed values by simple linear correlation (Figures 22, 24, 26, and 28), with an average correlation coefficient of 0.82. The results decrease as long as we move to the validation phase, which is generally observed in this type of test [30]. The analysis of Table-5 shows that the variation of the calibration period has no significant influence on the two parameters X1 and X2. The Nash criteria are average, they evolve from 14 to 82.9 for Nash (Q), from 32.2 to 57 for, and from-74.1 to 13 for Nash (LnQ). The best Nash criteria obtained are those based on four years (1992-1995) which represents 17% with a validation period of 20 years (1996-2016) which represents 83%, this is the variant that gives the best modeling. The analysis of the scatter spots (Figures 22B, 23B, 24B, and 25B), shows a good correlation between the observed and simulated flows. The average correlation coefficient is equal to 0.70 in the calibration phase and 0.93 in the validation phase. The average correlation coefficient is equal to 0.70 in the calibration phase and 0.93 in the validation phase, and for the same simulation periods.

During the calibration period 1992-1999 (Figure-22A), almost all rainfall generated a flow, and five out of ten peaks are almost superimposed. During the validation period 2000-2016 (Figure-25A), almost all rainfall generated a flow, and five out of ten peaks are almost superimposed, with some overestimation of the observed flows. We also note that sometimes rainfall only generates observed flows. The model was able to reproduce almost the same peaks with a slight time lag. Based on the presented simulation, conclusions can be drawn: According to the performance criteria, the model has the following characteristics:

- Overestimation and sometimes underestimation of flows;
- Precipitation is unable to generate flows or only generates the observed flows;
- Curves where the observed flows have the same shape as the simulated flows.



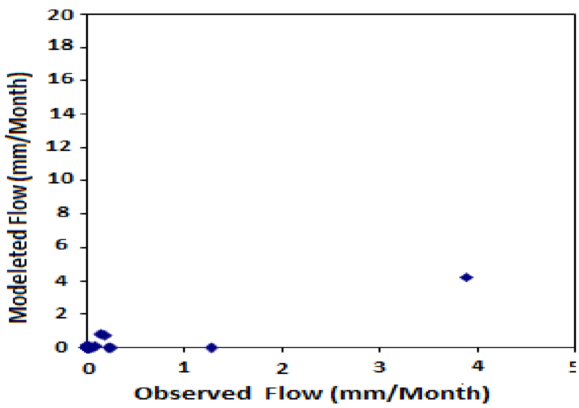


Figure-22. A. (Lift) Graphical presentation relating observed and simulated monthly rainfall-flow under GR2M, in Taghjijt station for the calibration period 1992-1989. B. (Right) Observed and simulated flows under GR2M, in Taghjijt station for the calibration period 1992-1989.

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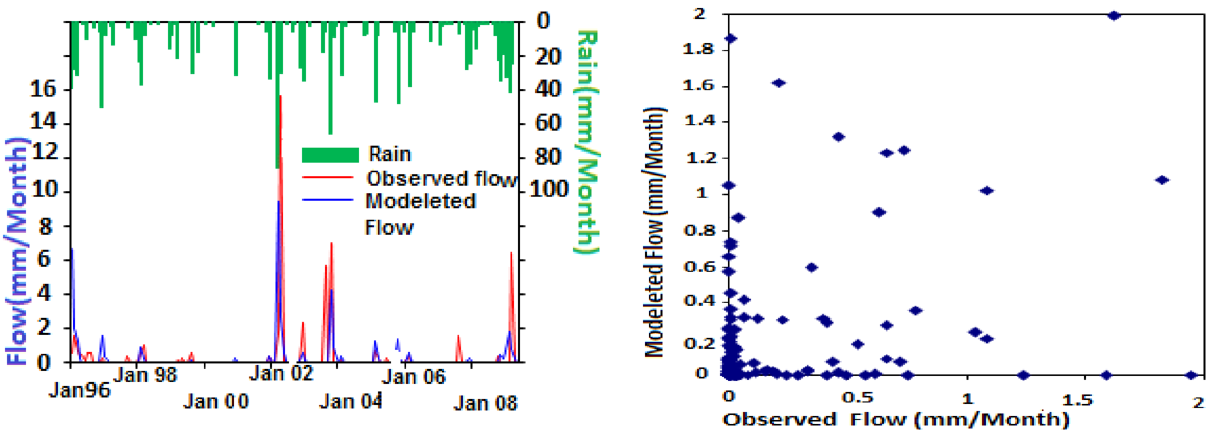

Figure-23. A. (Lift) Graphical presentation of the relationship between observed and simulated monthly rainfall-flow under GR2M, in the Taghjijt station for the validation period 1990- 2016. B. Observed and simulated flows under GR2M, in the Taghjijt station for the validation period 1990-2016.

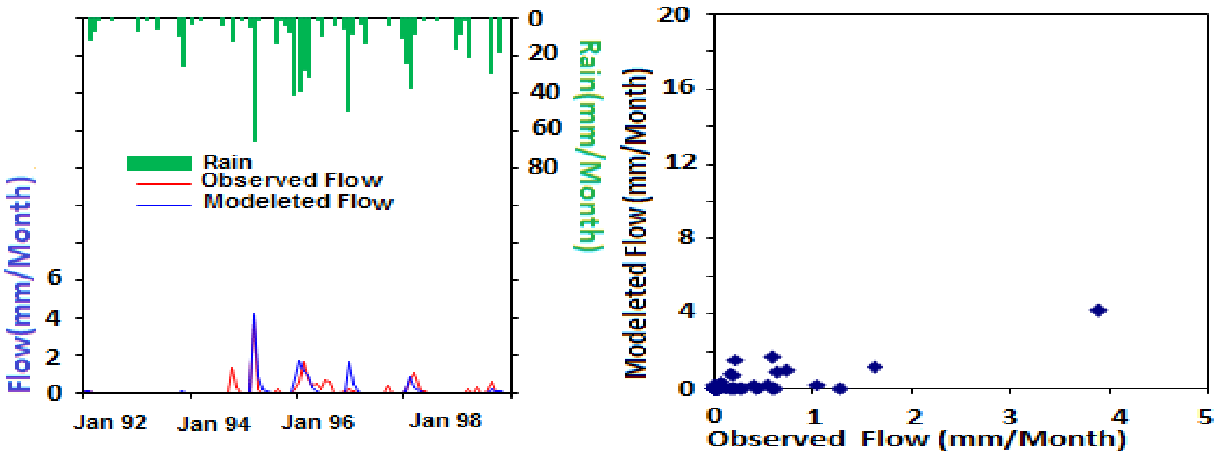

Figure-24. A. (Lift) Graphical presentation of the relationship between observed and simulated monthly rainfall-flow under GR2M, in Taghjijt station for the calibration period 1992-1999. B. (Right) Observed and simulated flows under GR2M, in Taghjijt station for the calibration period 1992-1999.

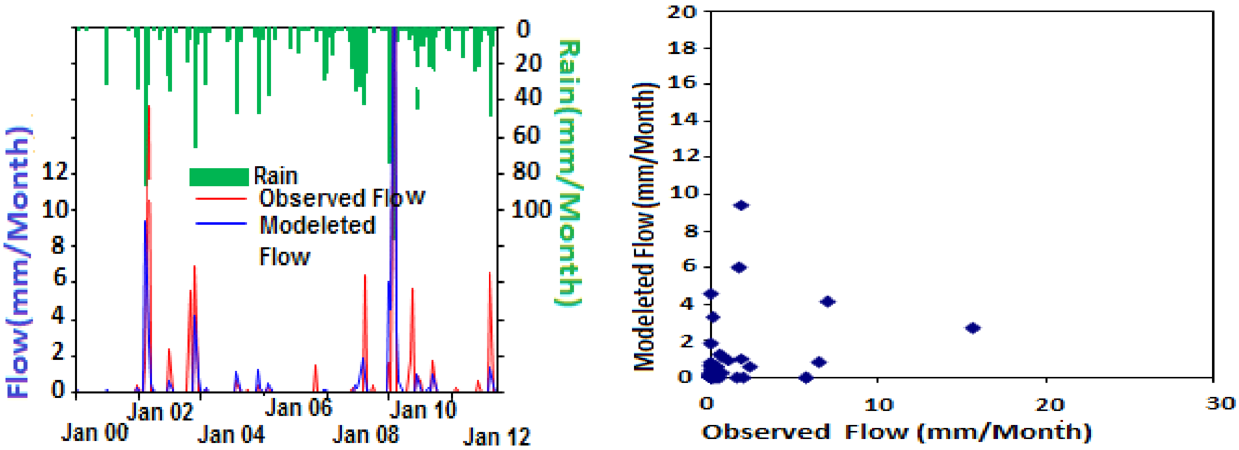

Figure-25. A. (Lift) Graphical presentation relating observed and simulated monthly rainfall-flow under GR2M, in Taghjijt station for the validation period 2000-2016.B. (Right) Observed and simulated flows under GR2M, in Oued Taghjijt station for the validation period 2000-2016.

5.2 Efficiency of the GR2M Model

The values of two parameters of the GR2M model were estimated for the Taghjijt watershed based on a calibration of part of the available observed data and validated on the remaining data. Several tests were performed to identify the best change of parameters, which optimizes the capacity of the production reservoir (X1) and the groundwater exchange coefficient (X2). The performances obtained remain globally above 50% and are therefore satisfactory in calibration and validation. These results show that the GR2M model is robust and efficient. It is therefore able to reproduce the behavior of the watershed in a satisfactory manner.

6. CONCLUSIONS

The Taghjijt sub-basin, with an ovoid shape, presents a mountainous zone with an essential limestone depot. It constitutes a light zone whose hydrographic network flows generally from North to South. These limestone mountainous formations are constituted by outcrops of schisto-sandstone Georgian. At their feet, there are narrow plains, whose substratum is formed by Acadian shales generally masked by the quaternary formations constituted by silts, conglomerates and screes. For mathematical modeling of rainfall/flow, a conceptual hydrological model was used, it is the model "with reservoirs" GR2M, with two parameters of setting, and at a monthly time step. The two calibration parameters X1 and X2 are used to calibrate and validate the simulated flows on the sub-basin of Taghjijt. The criteria for evaluating the performance of the model, numerical and graphical, have given satisfactory results in calibration and validation, including the correlation coefficients between observed and calculated flows. For the monthly model, the results are good for the calibration but less good for the validation. This is due to the drought in the region, which has significantly affected surface flows.

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