Comparative study of two methods for modeling the runoff of surface water. Case of transboundary basin Tunisian-Algerian Wadi Sarrat

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Abstract.

This work has focused on the implementation of the method for calculating surface runoff developed by the Soil Conservation Service of the Agriculture Ministry of the United States, "The curve number method" called "SCS-CN" in a semiarid Tunisian-Algerian context (watershed Serrat) and comparing its results with the method of the simplified cofficient used by the software "Water Evaluation and Planning" (WEAP). It is also covered by this work evaluating the performance of the two methods compared with field observations.

The SCS-CN method involves the superposition of the land use and soil type maps. The new layer obtained by intersection consists of polygons representing the spatial variation of soil type and land use. Standard tables of the method used to determine the CN of each type of intersection. This gives CN spatial distribution for calculating the weighted CN for the study area, the basis for calculating the potential maximum retention (S) and the initial abstraction (Ia).

The study area is located in west-central Tunisia (Governorates of Kef and Kasserine), a bet up to the Algerian territory (wilaya Tbessa). Its area is about 2000 km^2 of flat terrain and relatively gentle slopes. The bioclimatic is semi-arid with annual rainfall ranging from 320 to 450 mm.

Results of six (6) studied rainfall events have shown that the SCS-CN method can give more accurate results than the simplified coefficient method which only depends on climatic conditions to calculate the crop needs.

The programming method in WEAP computing environment can be a rewarding prospect of development for hydrologists and water resource managers. This will require new features of WEAP oriented geographic information systems (GIS).

Keywords: Comparison, Modeling, SCS-CN, Simplified Coefficient, WEAP

1. Introduction

The comparison between two methods of calculation of rainfall-runoff compared to measured values on the main stream (Sarrat) aims evaluating the performance of each method. The method of the simplified coefficient used by the WEAP software only takes into account climatic factors to calculate ETP as not dribbled fraction.

The SCS-CN method is one of the best known methods for calculating runoff for a given rainfall event. This approach requires the use of a simple empirical formula and consultation tables and standard curves. One important value of a "Curve Number" (CN) corresponds to a high runoff and low infiltration (urban areas), by against a low CN value corresponds to a low runoff infiltration and strong (dry soils). CN is a number which depends on soil occupation and hydrological soil class (HSG). The SCS-CN method offers a quick way to estimate the runoff change resulting from a change of ground occupation (Shrestha 2003; Zhan and Huang, 2004).

The traditional method of calculating the CN made from tables and standard curves is tedious and slow. To overcome this difficulty, the GIS and the SCS-CN method are combined to facilitate the calculation of "Curve Number" compound (Zhang and Huang, 2004; Xu, 2006).

The latter was the subject of several research studies to evaluate its performance given the simplicity of its application. The methodology has been included in several hydrological models such as HEC-1 and HEC-HMS, WMS, SWAT (Arnold et al., 1996), EPIC (Williams, 1995), AGNPS (Young et al., 1989) and GLEAMS (Leonard et al., 1987).

In this study, GIS is used in the physical characterization of the watershed (automatic delineation, water system, slopes, morphological characteristics ...) as in the calculation of CN compounds that are the average (depending on the area) of CN for each sub watershed.

The automatic assignment of CN values for each combination of soil type and soil occupation is much easier using GIS which are then used to correct these parameters based on other (soil moisture conditions, slope ...).

To evaluate the performance of the two methods in question, we considered six different rainfall events and simulated results using both methods of calculation with the values measured by the gauging station and the errors were calculated and compared (deviation in %).

2. Study Area

The Watershed Wadi Sarrat as shown in Figure 1, is located in west-central Tunisia. It is a transboundary watershed partially belonging to governorates of Kef and Kasserine (Tunisia) and the Wilaya of Tebessa (Algeria). It is located between latitudes 35 ° 30 'and 36 ° North and longitudes 8 ° and 9 ° 15 East. The study area consists of a portion upstream Haidra drained by the river and its tributaries and a downstream part drained by the river and its branche Sarrat. Wadi Sarrat discharges into Wadi Mellegue which is the main branch of the river Medjerda who all have their sources in Algeria.

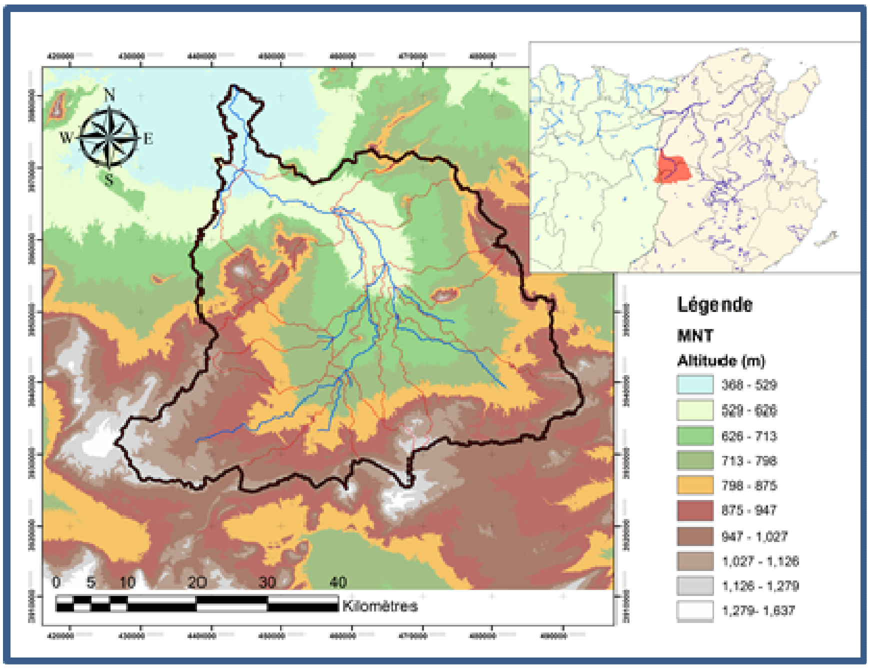


Figure 1. Limit of the watershed of Wadi Sarrat and river network.

The watershed of Wadi Sarrat belongs to the semi-arid bioclimatic. The river system is dense but temporary with the exception of two rivers "Haidra" upstream where rainfall is about 450 mm and "Sarrat" (59 km long) to downstream where the annual rainfall ranging from 320 mm to 380mm.

The area stretching from Djérissa and Tejerouine up Kalaa el Khasba and Kalaat Snane and is the wadi catchment Median Serrat basin, is characterized generally by a little rugged and relatively gentle slope. It has a rugged portion located east of Kalaat Snane. This part is formed by the table Jugurtha altitude 1271 m which is surrounded by Jebel Bou Jefna (1050 m) and Jebel Mzila (1047 m). Given the importance of surface water intakes, a dam on Wadi Sarrat capacity 21 million cubic meters is being built.

Figure 2 shows that the region have agriculture aptitude. Forest occupy mountains regions and trees (mainly olive) are rare. Most of the watershed area used for annual field crops (cereal). Figure 3 shows soil classes as published in the ‘Harmonised World Soil Database’. The dominant soils are ‘Cambiosols’ characterized by medium texture. ‘Fluviosols’ occupy the Oued Sarrat area. We also note the presence of ‘Vertisols’ characterized by low permeability.

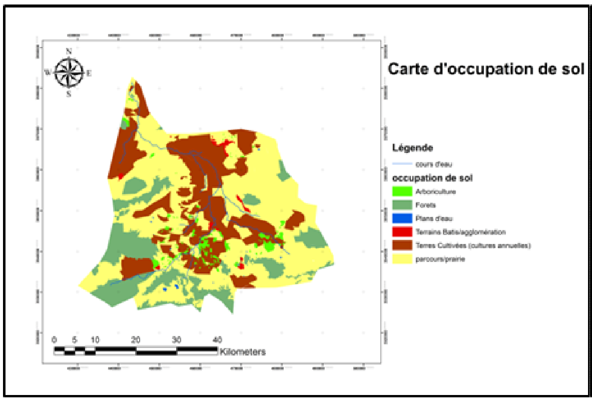


Figure 2. Landuse of watershed of Wadi Sarrat

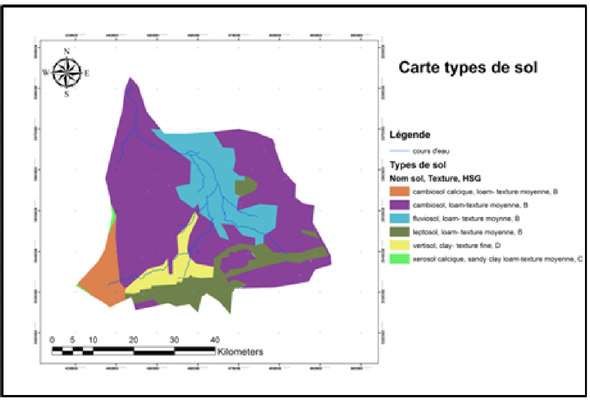


Figure 3. Soil types of watershed of Wadi Sarrat

3. Methodology

The simplified coefficient method is to subtract the water fraction lost as evapotranspiration from precipitation and simulate the rest as runoff. In fact, evapotranspiration is calculated using the CROPWAT software taking into account the climatic conditions and crop coefficients according to the percentages of the study area under crops for each watershed and calculate the effective rainfall and determine the blade run-off which is the part not used by the vegetation. However, the SCS-CN method requires more parameters for the watershed as soil hydrological classes, land cover and the average slopes. The steps of calculating the SCS-CN method are:

- Identify and map the watershed boundaries for which CN will be calculated and determine its area.
- Build thematic maps of land cover type and corresponding ground studied watershed.
- Allocate the types of hydrological soil groups (A, B, C or D).
- Overlaying the land use map and the map of hydrological soil groups.
- Identify every single polygon group on the use of terrestrial-type soil, and determine the area of each polygon.
- Assign a curve number (CN) for every single polygon, based on standard tables SCS curve numbers.
- Overlay map of the watershed on the resulting polygons.
- Calculate CN for the entire watershed polygon weighting the use of land - Soil group within the watershed.
- Calculate runoff blades from rainfall events by equation (1) and then calculate runoff rates.

$$\boxed{Q = \begin{cases} 0 & \text{for } P \leq I_a \\ \frac{(P-I_a)^2}{P-I_a+S} & \text{for } P > I_a \end{cases}}$$

Equation (1)

- **Q** : runoff (mm)
- **P** : rainfall (mm)
- **S** : maximum potential of retention after triggering runoff (mm)
- **I_a** : initial abstraction (infiltrated or intercepted by vegetation in mm) **I_a** has been considered equal to 0.2***S**.

* S : maximum potential of retention is given by Equation (2) :

$$\boxed{S = \frac{25\,400}{CN} - 254}$$

Equation (2)

* Equations (3) and (4) are used to correct the CN value according to the soil moisture condition

$$\boxed{CN_I = \frac{4.2 \times CN_{II}}{10 - 0.058 \times CN_{II}}}$$

Equation(3)

$$\boxed{CN_{III} = \frac{23 \times CN_{II}}{10 + 0.13 \times CN_{II}}}$$ Equation (4)

- Conditions AMC I : represent dry ground, with rainfall of the dormant season (5 days) of less than 12.70 mm and 35.56 mm under growing season.
- Conditions AMC II : represent average moisture conditions soil with average rainfall in the dormant season 12.70 mm to 27.94 mm and growing season rainfall of 35.50 to 53.34 mm.
- Conditions AMC III : represent soil saturated with rains in the dormant season of more than 27.94 mm and the growing season rainfall greater than 53.34 mm.

* The correction of CN by the average slope SLP according to Williams given by Equation (5)

$$\boxed{\left[CN_{II}\right]_{SLP} = \frac{\left(CN_{III} - CN_{II}\right)}{3} \times \left[1 - 2 \times \exp\left(-13.86 \times SLp\right)\right] + CN_{II}}$$ Equation(5)

CN is then calculated and corrected (depending on moisture condition antecedent) and integrated into equation 2 that will allow computing Q (mm) using equation (1).

4. Results and discussion

4.1. Spatial distribution of CN, S and I_a

To use this runoff calculation method, the soil type and land cover maps were developed by GIS tools. The intersection between the developed maps will give us combinations occupation-identical type of soil or hydrological response units. A join in the attribute table of the map obtained with the CN values of each combination will give us the spatial distribution of Cni (Figure 4). The weighted average CNc will give us a value for each sub-watershed.

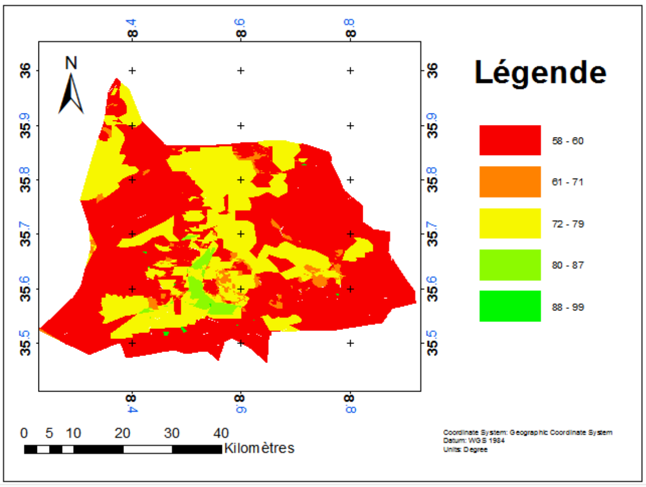


Figure 4. Spatial distribution of CNi in watershed of Wadi Sarrat

Areas assigns an important CN (colored green) correspond to areas of high runoff. These are actually impervious areas (clay) or water bodies. However, the areas with weak CN values (colored red) correspond to areas with high infiltration and thus a low runoff potential. The figure 5 shows the spatial distribution of the maximum potential retention after runoff initiation. The 'S' parameter is small in impervious areas (high runoff) and important in areas characterized by high infiltration. The blue colored areas are characterized by low runoff and a major infiltration. The green areas show the contrary case since these areas are with low potential infiltration (Clay) (Figure 5).

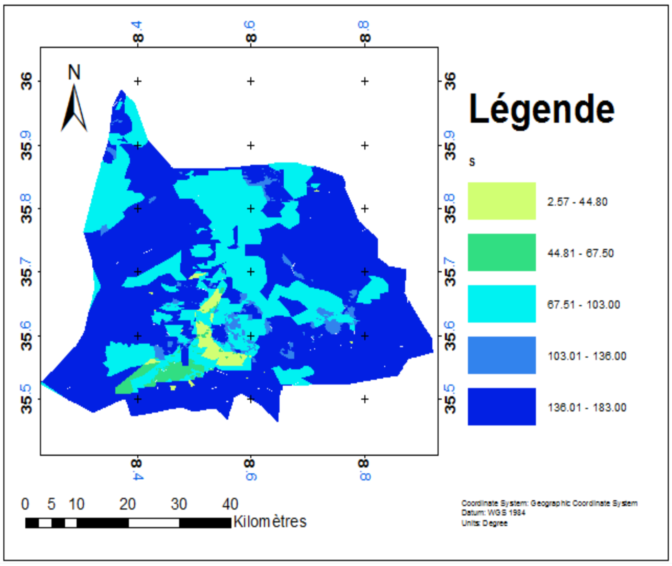


Figure5. Spatial distribution of S in watershed of Wadi Sarrat (in mm)

This spatial distribution of ‘S’ gives a clear idea about the area assigns a high runoff potential and understand its causes and identify the areas of intervention. The periphery of the basin is characterized by low runoff since these forest areas dominance that play a key role in intercepting runoff, which can be an effective solution to fight against water erosion.

The initial abstraction ‘Ia’ depends on ‘S’ and has the same spatial distribution. This parameter includes all loss (water retention in depressions, interception by vegetation, evaporation and infiltration). The calculation of various parameters is summarized in Table 1.

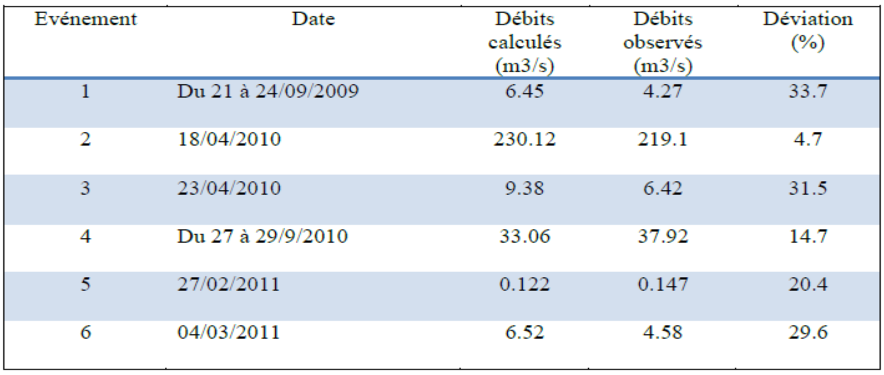
Table1. Calculation of parameters ‘CN’, ‘S’ and ‘Ia’ according antecedent moisture conditions

Id	Sous bassin versant	Superficie (km²)	AMC I			AMC II			AMC III		
			CN	S(m)	Ia(mm)	CN	S(mm)	Ia(mm)	CN	S(mm)	Ia(mm)
1	Sidi Hmid Salah	220.914	47	285	57	67	124	24.8	83	54	10.8
2	Haidra	693.710	45	310	62	66	130	26	82	56	11.2
3	El Khomes	327.187	42	355	71	63	149	29.8	79	64	12.8
4	Assikka	243.472	41	360	72	62	151	30.2	79	65	13
5	Ain Zarga	245.285	41	360	72	62	151	30.2	79	65	13

4.2. Spatial distribution of CN,S and I_a

Table 2 shows the comparison between the rates calculated by the SCS-CN method and flow rates observed for six separate rainfall events. The deviation between the calculated and observed streamflow varies from 5% for event 2 up to 30% for events 1, 3 and 6. The estimated rates by SCS-CN method generally gives satisfactory results with superior performance to 80% for some rainfall events.

Table 2: Calculated steam flow by the SCS-CN method and field observations



Evénement	Date	Débits calculés (m3/s)	Débits observés (m3/s)	Déviation (%)
1	Du 21 à 24/09/2009	6.45	4.27	33.7
2	18/04/2010	230.12	219.1	4.7
3	23/04/2010	9.38	6.42	31.5
4	Du 27 à 29/9/2010	33.06	37.92	14.7
5	27/02/2011	0.122	0.147	20.4
6	04/03/2011	6.52	4.58	29.6

Deviations in computed results may be due to uncertainty on rainfall and flow records in the gauging station or due to the effects of the initial abstraction that can change from one event to the other following the changes in antecedent humidity condition.

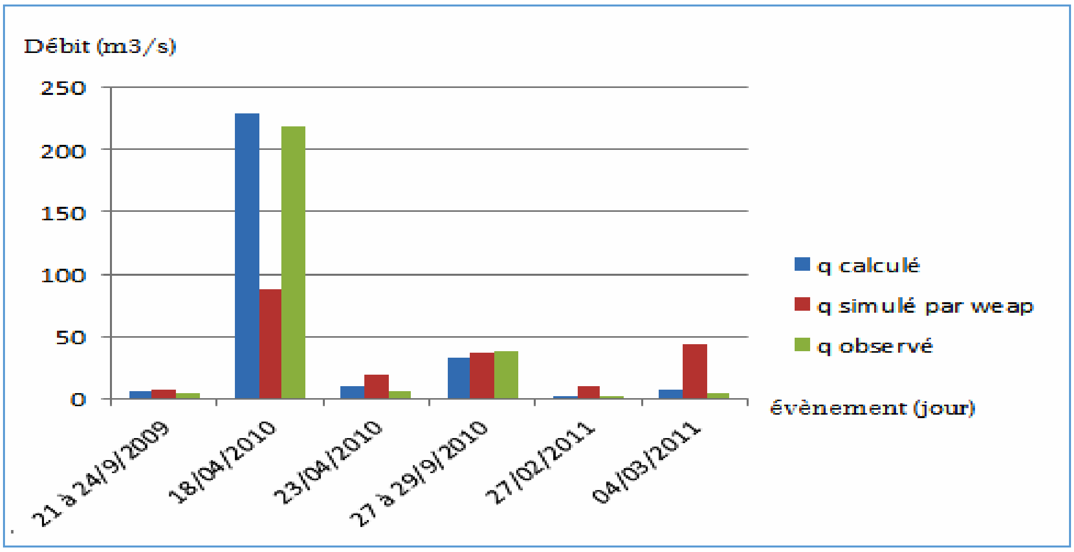


Figure 6. Comparison of calculated and observed steam flows for the 6 rainfall events in watershed of Wadi Sarrat.

Figure 6 shows clearely that the flow rates calculated by the SCS-CN method (blue) are much closer to the observed flow rates (green) the the simplified coefficient methode used by WEAP. The SCS-CN method takes into account the physical characteristics of the watershed and especially the hydrological soil, le land cover and the soil moisture condition.

5. Conclusion

The proposed methodology, based on GIS tools, helped facilitate the implementation of SCS-CN method. Results for six rainfall events have shown that the SCS-CN method can give more accurate results than the simplified coefficient method. It involves in the calculations the soil type, land cover and soil moisture before the rainfall event. It can give results for non-gauged basins and compare results with other basins with similar characteristics.

It is also very important to remember that the SCS-CN method was developed in humid regions whose characteristics may be different from the semi-arid region of our case study. To overcome this problem, it is more convenient to check the expression of the initial abstraction (Ia) and its operating requirements for semi-arid areas.

The programming method in WEAP framework can be a rewarding prospect of development for hydrologists and water resource managers. This will require new features of WEAP oriented geographic information systems (GIS).

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