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Application of Soil Conservation Service Curve Number Method for Runoff Estimation in Sebou Watershed, Morocco

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ABSTRACT

In Morocco, although it is often classified as a country with a semi-arid climate, floods are very frequent. Like other basins in the kingdom, the Sebou basin with a total area of 40 000 km² has experienced more catastrophic flooding in the past and these floods have caused enormous economic and even human losses. The objective of this study is to apply different methods to calculate a Curve Number values to estimate the potential runoff for this basin. The techniques used are boils down to the different steps. Firstly, the approach was to extract automatically the sub-basins and drainage network, using Geographical Information Systems (GIS) and Digital Elevation Model (DEM) to determine all the physical characteristics of the basin. Then, preparing the land use map using remote sensing and the soil map for determining hydrologic soil Group. Thirdly, the combination of elaborated data for development of a map of Curve Number (CN) and finally, the interpolation of precipitation data recorded at rainfall stations at 30 minutes time steps to the Hydrologic Modeling System (HEC-HMS) model. The results obtained in the above steps are used for the purpose to get a spatial hydrological model and subsequently its calibration.

Keywords: geographical information systems; remote sensing; curve number; hydrologic soil group; runoff; hydrologic modeling system.

INTRODUCTION

Over the past twenty years, Morocco has experienced a number of tragic flood events that have generated flooding in several regions of the country due on the one hand to population growth, and to urban and agricultural development, industrial and tourist activities which lead to an increasing occupation of vulnerable areas and, on the other hand, to the worsening of extreme phenomena (drought and floods) following climate change. The Sebou river basin, with a total area of 40 000 km², is one of Morocco's most important basin exposed to the risk of flooding, it contributes 30% of the national potential of surface water and 20% of the groundwater resources (PDAIRE, 2011).

The work presented in this article concerns this watershed, its main objective is to prepare the necessary input data for the development of a spatial hydrological model on the basis of the HEC-HMS hydrological model, in particular the production of the Curve Number map who is considered one of the most popular methods for computing the volume of surface runoff in catchments for a given rainfall event. This approach involves the use of a simple empirical formula and readily available tables and curves. A high curve number means high runoff and low infiltration (urban areas), whereas a low curve number means low runoff and high infiltration (dry soil). The curve number is a function of land use and hydrologic soil group (HSG). It is a method that can incorporate the land use for computation of runoff from rainfall. The Soil Conservation Service Curve Number method provides a rapid way to estimate runoff change due to land use change (Shrestha, 2003; Zhan and Huang, 2004).

MATERIALS AND METHODS

Study area

The Sebou basin (Fig. 1) is located in the north west of Morocco and is separated into three distinct geomorphic regions: The Upper, Middle, and Lower Sebou. It is characterized by a much diversified geographical context.

In the Middle Atlas Mountains, the Upper Sebou rises above 2800 meters and is underlain mainly of calcareous rocks. The average annual precipitation is over 1000 mm, and at high elevations winters are snowy. The Middle Sebou is situated in the Rif and pre-Rif mountains, which have an average elevation of 2000 meters, steep slopes, and a vigorous rainfall gradient across the catchment. The main tributaries of the Sebou, which drain the Rif and pre-Rif mountains, are Ouergha and Inaouene. The catchment extends into a large valley within the Lower Sebou, where it meanders across a floodplain. The average annual rainfall in the west is 600 mm, while in the south-east it is 450 mm (Hunink, 2014).

The Sebou basin is of great importance on a geological scale, as it is located at the junction between four structural domains with different geological histories:

- The Ouergha upstream of the AL Wahda dam: essentially made up of impermeable clay-marl terrain from the Cretaceous period.
- The Gharb and Saiss basins and the Fès-Taza corridor (contained between the Rif and Middle Atlas chains) with essentially tertiary and quaternary permeable filling. The last two units also contain limestone formations of the Lias.
- The Beht is made up of impermeable Permo-Triassic and primary formations.
- The high Sebou, which is part of the Atlas domain, essentially made up of permeable Jurassic limestones.

SCS-CN method

The Soil Conservation Services Curve Number, renamed as Natural Resources Conservation

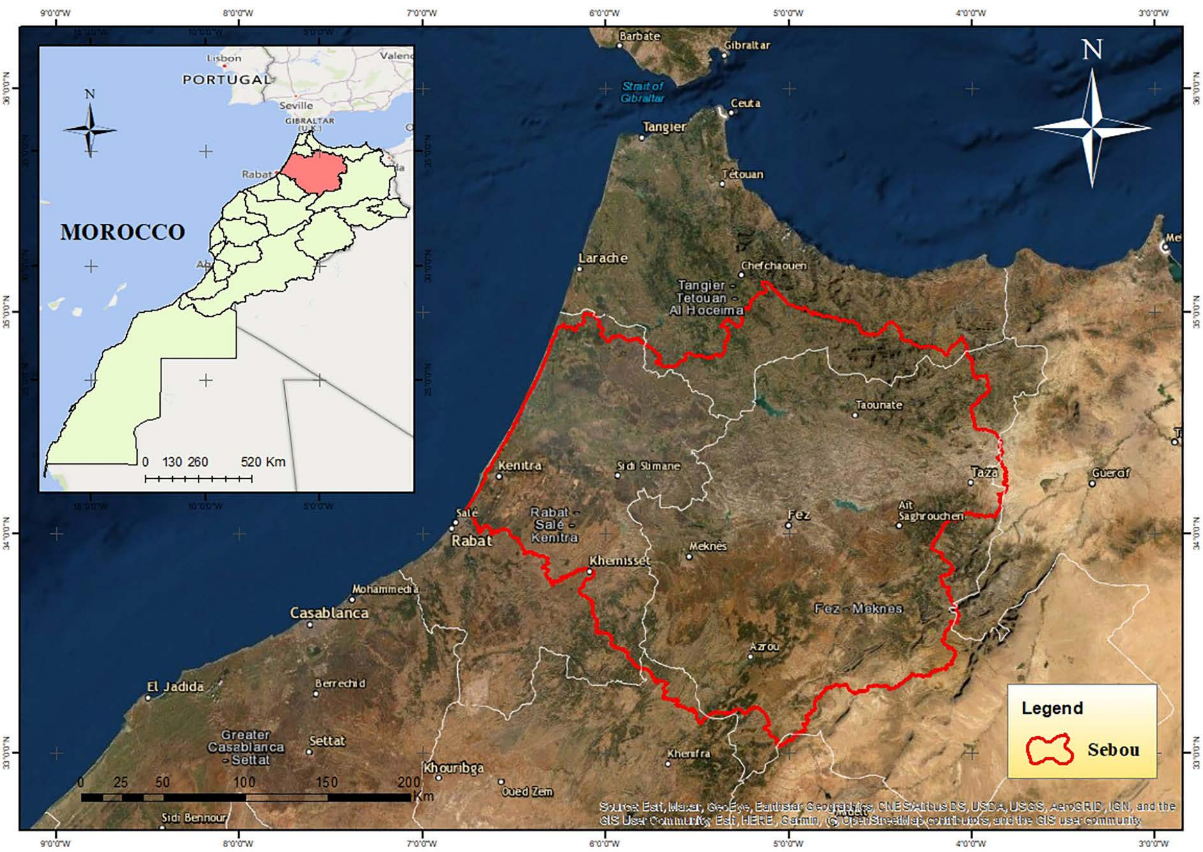

Figure 1. Geographical location of the Sebou watershed

Services Curve Number (NRCS-CN) method (USDA-SCS, 1972), is the most widely used approach for estimating surface runoff from a rain event and the characteristics of the watershed in which it occurs. This brings into play an empirical parameter representing the generation potential of soil runoff: The higher the Curve Number values, the greater the potential for runoff. The assignment of CN values is the key point in the implementation of the method. The Curve Number's value is determined by the soil's hydrologic group, land use, and beginning moisture conditions.

Methodology and data needs

The general technique for the GIS-based SCS-CN method used in this work is depicted in (Fig. 2). The curve number is generated in ArcGIS using the Geospatial Hydrologic Modeling Extension tool by combining land use, soil, basin Digital Elevation Model, and the curve number table based on the Soil Conservation Service Curve Number report TR55 from 1986.

Software used

As part of our study we used various software.

- Software ArcGIS: ArcGIS is an effective tool for collecting, organizing, managing, analyzing, communicating and disseminating geographic information. For the generation of input data, we chose ArcGIS for its capacity to interpret spatial data and compatibility with the HEC-HMS program.
- ArcHydro: is a set of data models and tools that work in ArcGIS to support geospatial and temporal data analysis.
- HEC-GeoHMS: The Hydrologic Engineering Centre's Geospatial Hydrologic Modelling Extension, HEC-GeoHMS, is a free public domain extension to ESRI's ArcGIS software and the Spatial Analyst extension. HEC-GeoHMS is a geospatial hydrology toolkit for engineers and hydrologists. The user can visualize spatial data, document watershed characteristics, do spatial analysis, delineate, schematization sub-basins and streams, create hydrologic model inputs, and assist with report production. HEC-GeoHMS allows the user to easily and simply construct hydrologic inputs that can be used directly with the HEC-HMS software (USACE, 2013).
- HWSD: (Harmonized World Soil Database) is a worldwide soil database that houses up-to-date data on the world's soil resources within a Geographic Information System (GIS). Compared to the FAO/UNESCO global map of soils, the HWSD represents significant improvements for about 60% of the earth's surface.
- QGIS: is a very powerful software that allows the processing and analysis of geographic imagery, especially for remote sensing integrating very advanced functions such as graphic modeling, classifications and Radar analysis tools.

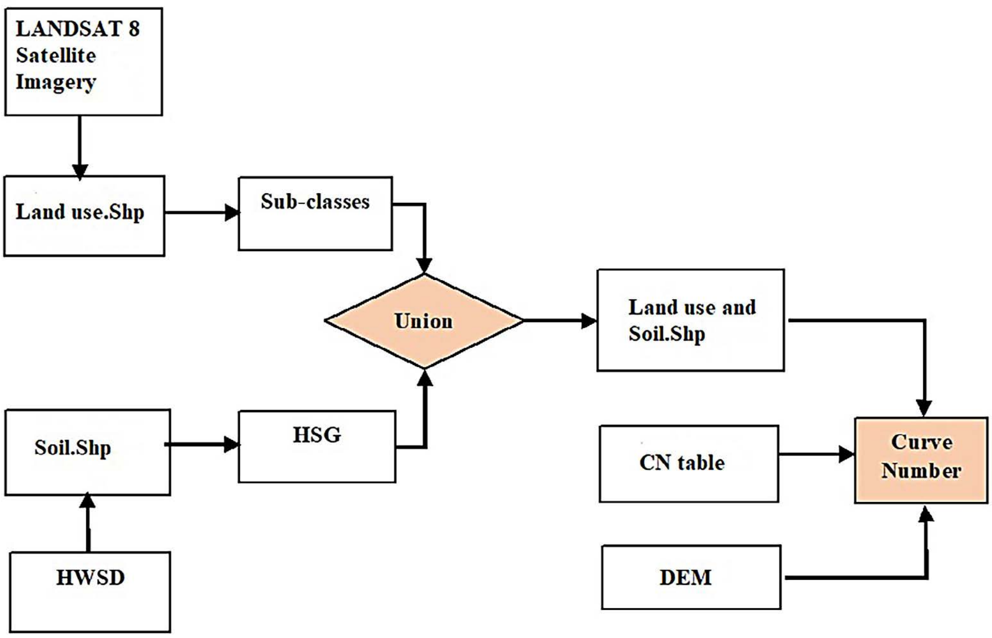

Figure 2. Methodology chart

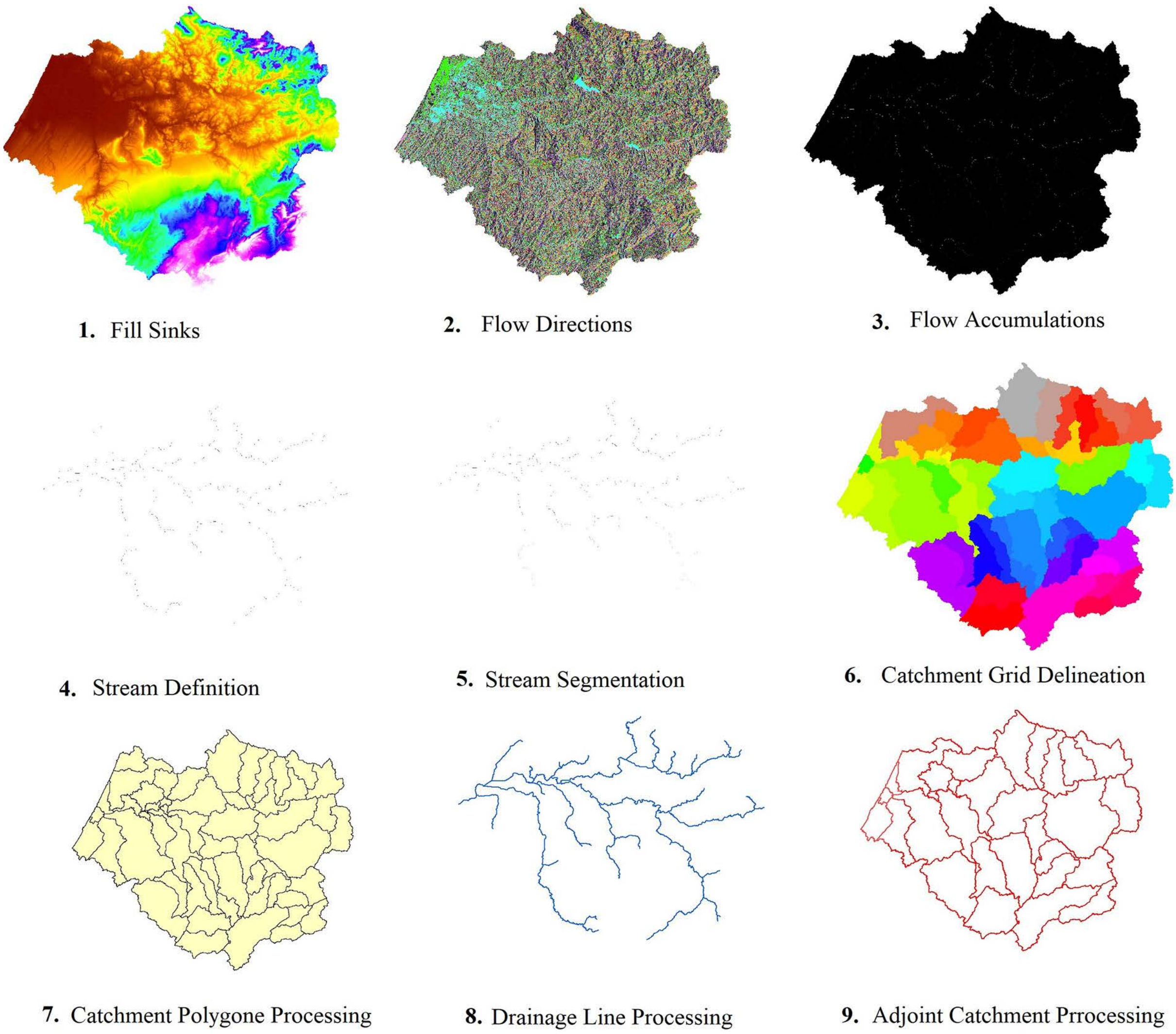

Figure 3. Delineation of the Sebou watershed using the ArcHydro tool

Digital elevation model

The digital elevation model is an essential element for the delineation of the watershed and the generation of the drainage network (Fig. 3) for our study we used the ArcHydro tool and the DEM ASTER GDEM (Advanced Spaceborne Thermal Emission and Reflection Radiometer - Global Digital Elevation Model) with an altimetric resolution of 30 m, and an altimetric accuracy between 5 and 20 m. The Sebou watershed is divided into ten sub-basins, as indicated in (Fig. 4).

Land use map

The land use map was obtained by processing 30 m resolution LANDSAT 8 Satellite Imagery by QGIS software. Satellite images were downloaded from https://earthexplorer.usgs.gov/, SEVEN bands were downloaded and then put together into a single image. A supervised classification is used to create the land use map (Fig. 5).

This operation ultimately resulted in a land use map, with the four requested classes: Medium Residential, Water, Agricultural and Forest.

Soil data processing

The Sebou basin contains a variety of soil datasets at various scales, as well as a variety of properties. The Harmonized World Soil Database is a global database that is available for the whole world, is a 30 arc-second raster database with over 16000 various soil mapping units that combines existing regional and national updates of soil information (SOTER, ESD, Soil Map of China, WISE) with the information included in the FAO-UNESCO Soil Map of the World at a scale of 1:5 000 000 (FAO, 1971, 1981). Despite

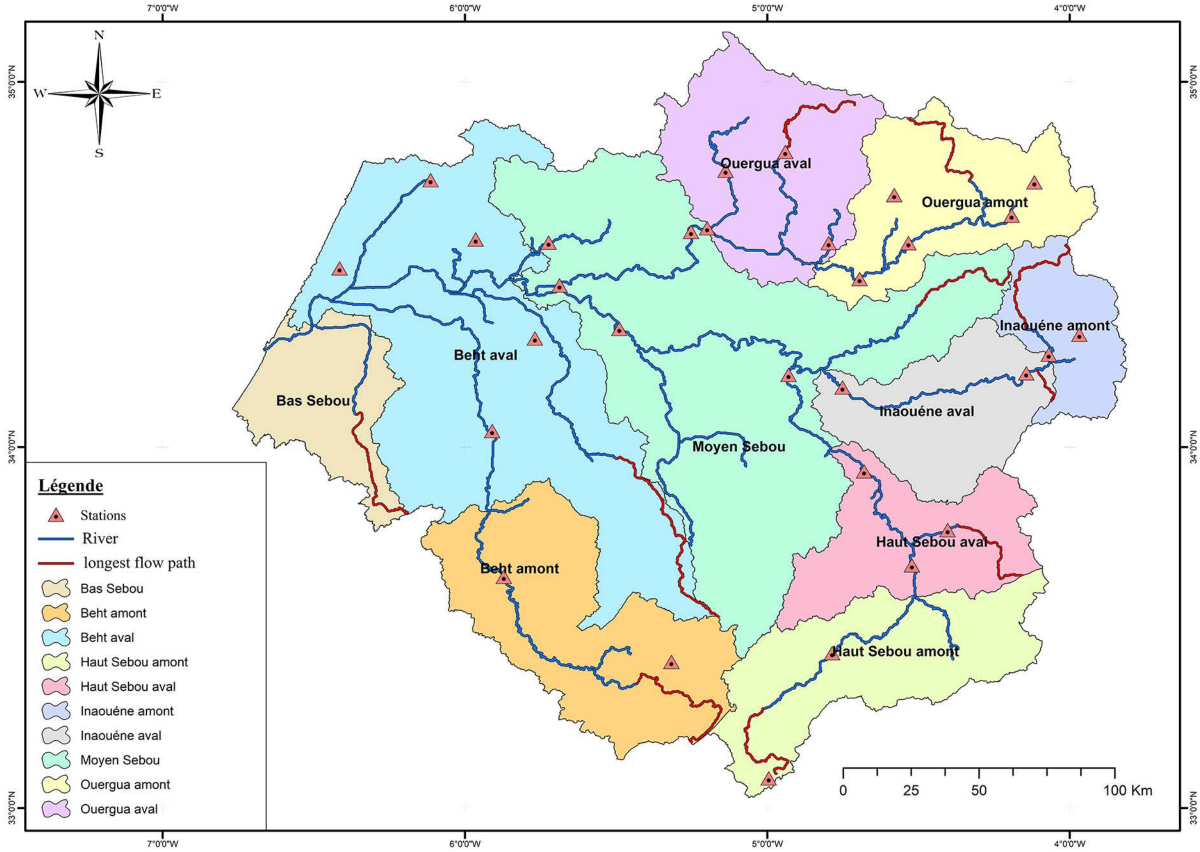

Figure 4. Map of the Sebou Sub-basins produced by ArcGIS

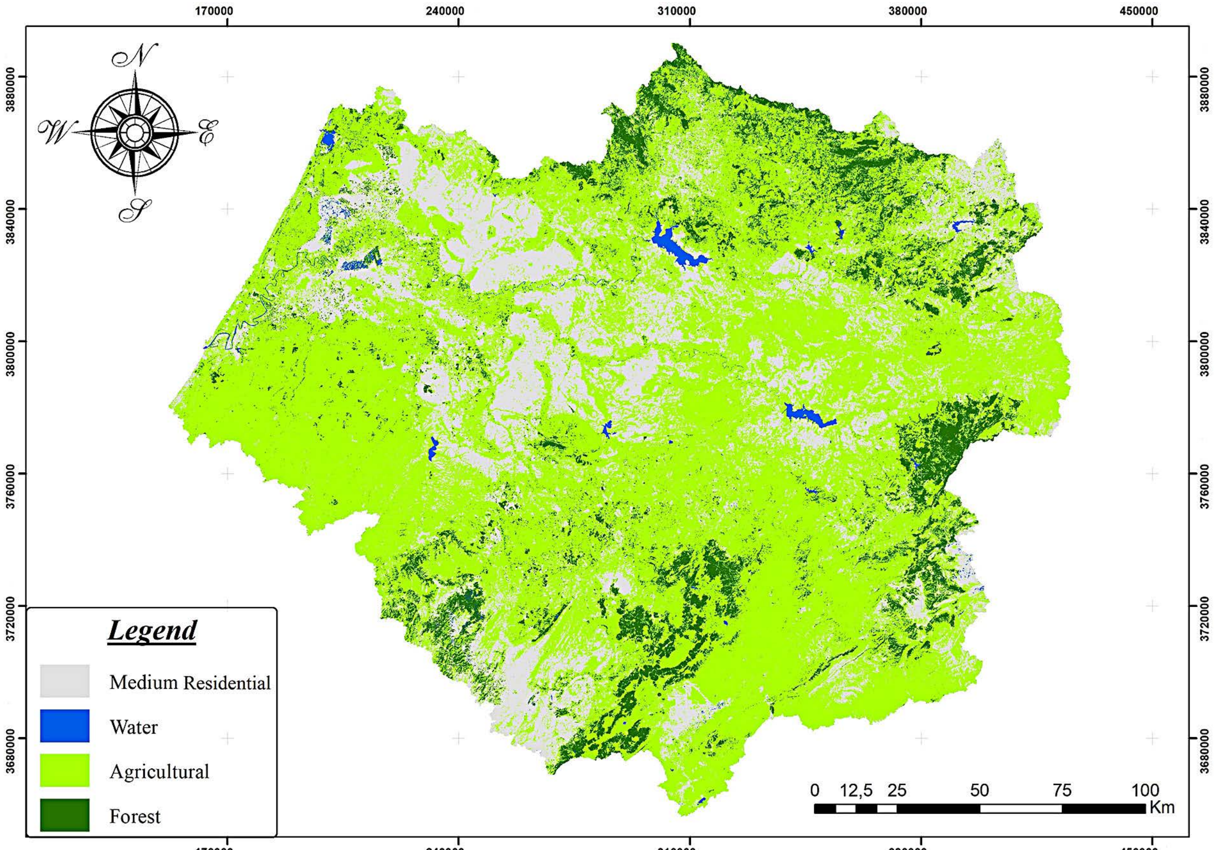

Figure 5. Land use map of the Sebou watershed developed by QGIS

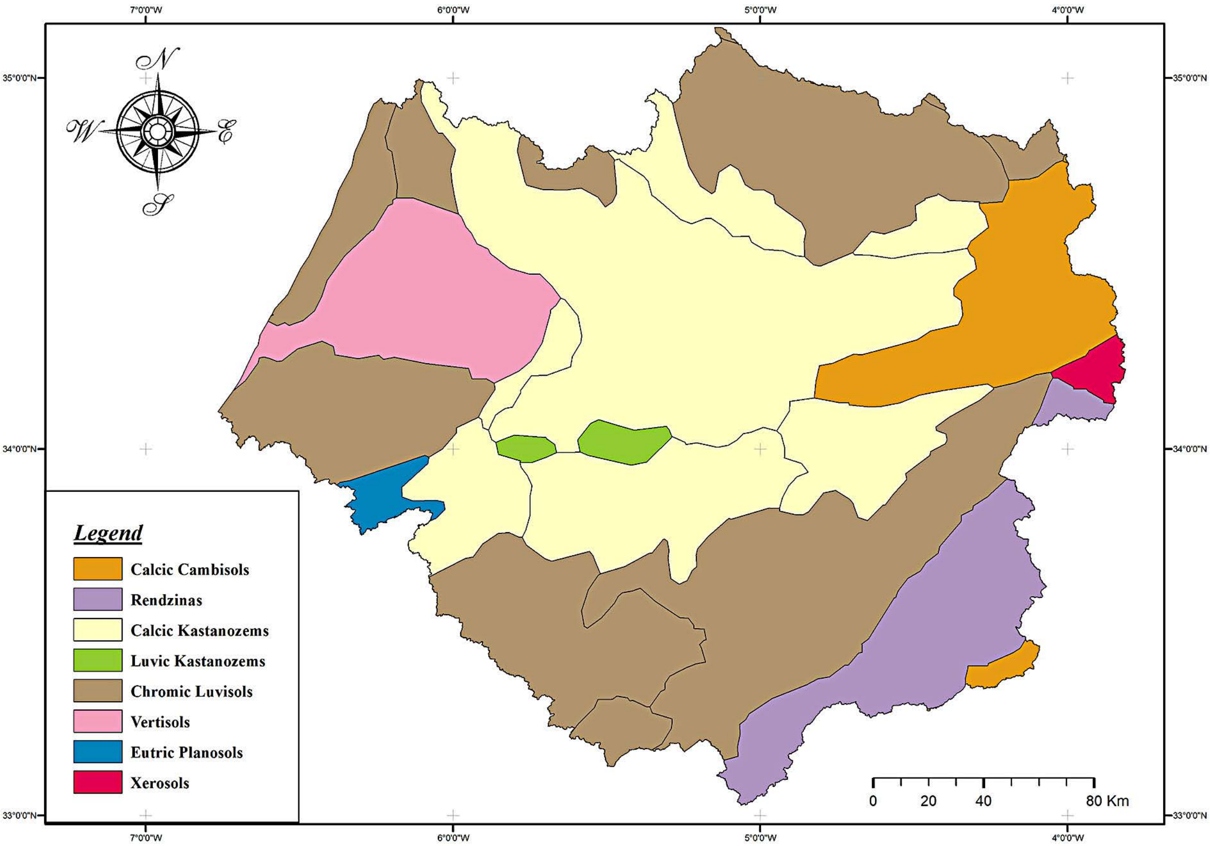

Figure 6. The soil map of the Sebou watershed extracted from the database (HWSD)

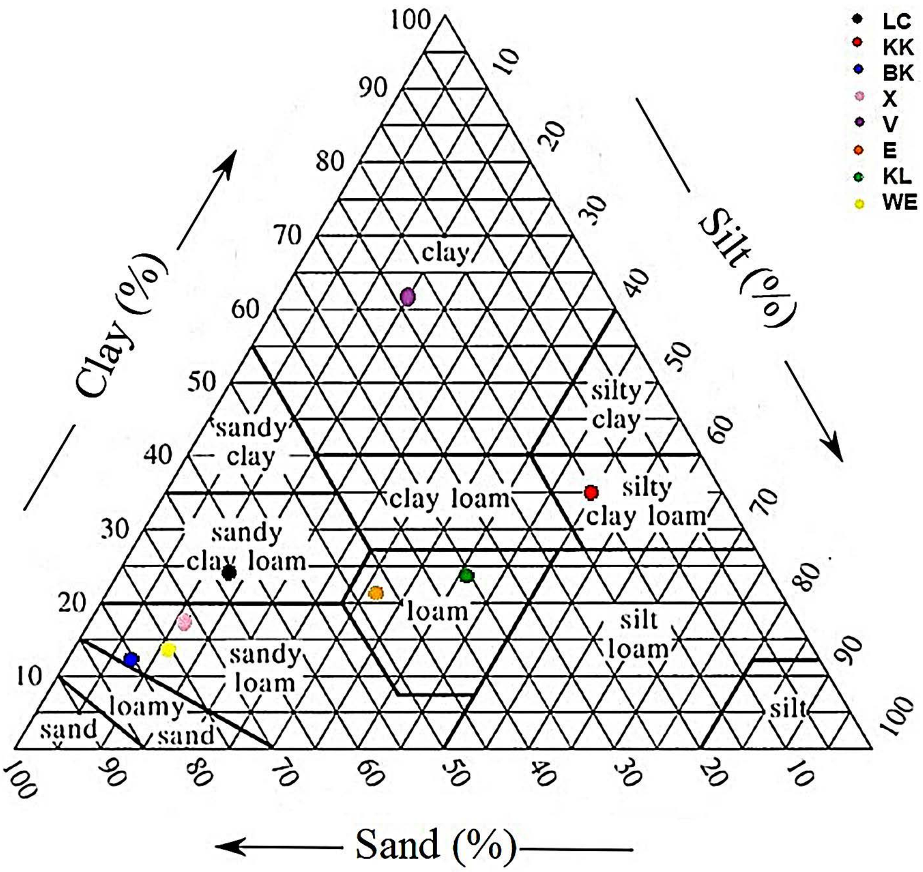

Figure 7. Soil Texture triangle of the Sebou basin generated by USDA soil texture calculator

Table 1. Percentages of sand, silt, clay of the Sebou basin by soil textural class (HWD, 2012) version 1.2

Soil	Symbol	Textural class	Sand %	Silt %	Clay %
Chromic Luvisols	Lc	Sandy clay loam	64.3	12.2	23.5
Calcic Kastanozems	Kk	Silty clay loam	16.5	48.9	34.4
Calcic Cambisols	Bk	Sandy loam	81.6	6.8	11.7
Xerosols	X	Sandy loam	72.8	10.5	16.8
Vertisols	V	Silt	24.6	14.4	61
Rendzinas	E	Silt	48.5	30.8	20.7
Luvic Kastanozems	Kl	Silt	36.7	40.3	23.1
Eutric Planosols	We	Sandy loam	76.6	10.3	13.1

its coarseness, this database contains the majority of the parameters required by the HEC-HMS model. The (Fig. 6) depicts the primary soils of the Sebou basin.

Hydrologic soil groups

The classification of soils retained by the SCS method is a classification which consists of grouping soils under four hydrological groups (A, B, C, D) based on estimates of their infiltration potential. Soils are assigned to one of four groups based on their infiltration rate. The SCS soil scientists characterize the four groups as follows (TR 55, 1986); (TR 55, 1986)

Group A: Soils with a high infiltration rate (low runoff potential) when fully wet. These are mainly well-drained or excessively drained deep sands or stony sands. These soils have a high water permeability coefficient

Group B: Soils with a moderate infiltration rate when fully moist. These are mainly deep or moderately deep soils, whose texture is fine to moderately coarse. These soils have a water permeability coefficient moderate.

Group C: Soils with low infiltration rate when fully wet. These are mainly soils with a layer that prevents downward movement of water or soils with moderately fine to fine texture. These soils have a low water permeability coefficient.

Group D: Soils with a very low infiltration rate (high runoff potential) when fully wet. These are mainly clays with a high shrinkage-swelling power, soils with a high water table or soils with a compact clay horizon.

To transition from soil classification to hydrological classification, it is essential to calculate the hydraulic conductivity of each type of soil according to its composition of sand, silt and clay. The values of these four components are shown in the Table 1. The textural class of each type of soil was determined using the triangular diagram of soil texture shown in (Fig. 7).

The results obtained are used to estimate the hydraulic conductivity of the soil using the Soil Water Characteristics (SPAW model) software developed by USDA, using the method of Dr. Keith Saxton. The hydrological groups by hydraulic conductivity values are given in the table below (Table 2).

The soil map of Sebou obtained according to the hydrological classification, presented in (Fig. 8) shows that the most dominant class is class B and C indicating moderate and low infiltration rates, followed by class A characterized by high infiltration. The result of the hydraulic conductivity of the estimated soil is presented in (Table 3).

RESULTS AND DISCUSSION

Calculation and generation of curve number

The curve number is calculated in ArcGIS using the Geospatial Hydrologic Modeling Extension through the union between of land use attributes, hydrological soil groups, The Digital Elevation Model of basin and curve number table (Table 4). The 1986 SCS TR55 study was used to create the CN table, which gives the curve number values for various soil combinations. The various procedures involved in generating the grid of curve numbers are described in (Fig. 9).

Table 2. Hydraulic conductivity by hydrological groups (TR-55 Second Ed, June 1986)

Hydrologic group	Hydraulic conductivity (in /hr)
A	Greater than 0.30
B	0.15 and 0.30
C	0.05 and 0.15
D	Between 0.0 and 0.05

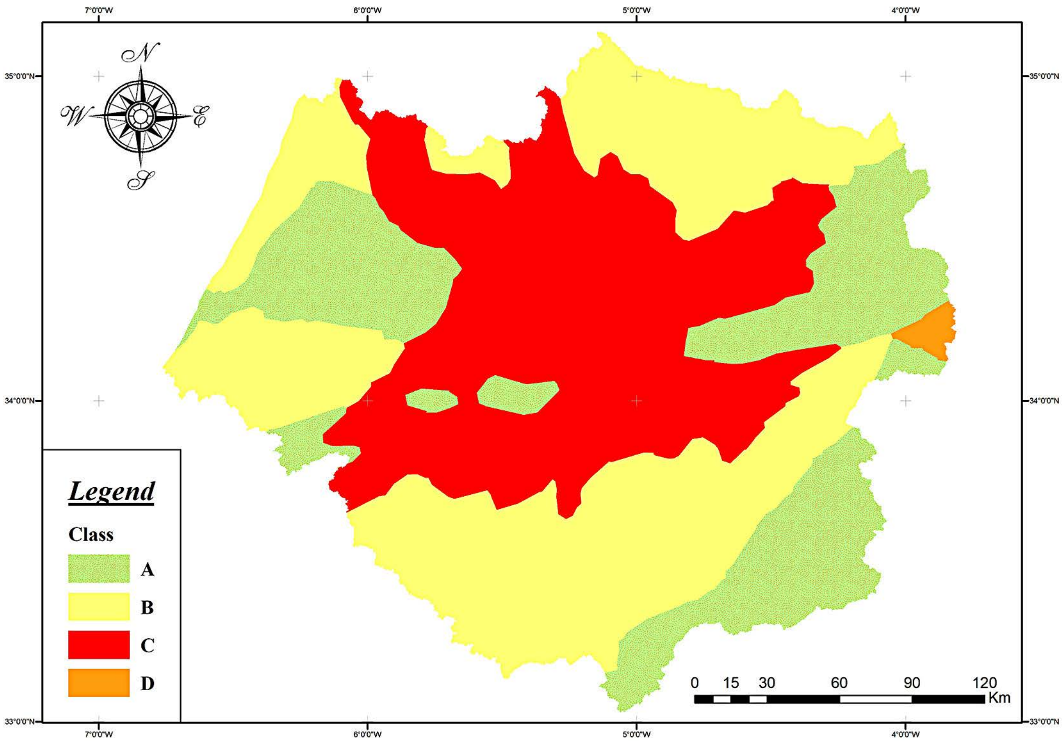

Figure 8. Soil of the Sebou watershed according to hydrological soil classification

Table 3. The hydrological group of each type of soil according to the Rawls equation

Soil	Sand %	Silt %	Clay %	Hydraulic conductivity (in /hr) Equation of Rawls	Hydrological group According to the Rawls equation
Lc	64.3	12.2	23.5	0.30	B
Kk	16.5	48.9	34.4	0.14	C
Bk	81.6	6.8	11.7	1.89	A
X	72.8	10.5	16.8	1.17	A
V	24.6	14.4	61	0.01	D
E	48.5	30.8	20.7	0.61	A
Kl	36.7	40.3	23.1	0.47	A
We	76.6	10.3	13.1	0.97	A

Table 4. Curve Number Lookup table

LUvalue	Description	A	B	C	D
1	Water	100	100	100	100
2	Medium residential	57	72	81	86
2	Forest	30	58	71	78
3	Agricultural	67	77	83	87

The values of the curve number range between 100 and 30, is determined by three factors: The hydrological classification of the soil, the land use and the initial soil moisture conditions, who can be dry (I), average (II) or wet (III).

The values presented in (Fig.10) indicate the average initial humidity conditions (CNII) and the curve number of CNI and CNIII are determined using the equations (1) and (2) (Chow and al. 1988).

$$\mathrm{CN(I)} = \frac{4.2 \times \mathrm{CN(II)}}{10 + 0.058 \times \mathrm{CN(II)}} \quad (1)$$

$$\mathrm{CN(III)} = \frac{23 \times \mathrm{CN(II)}}{10 + 0.13 \times \mathrm{CN(II)}} \quad (2)$$

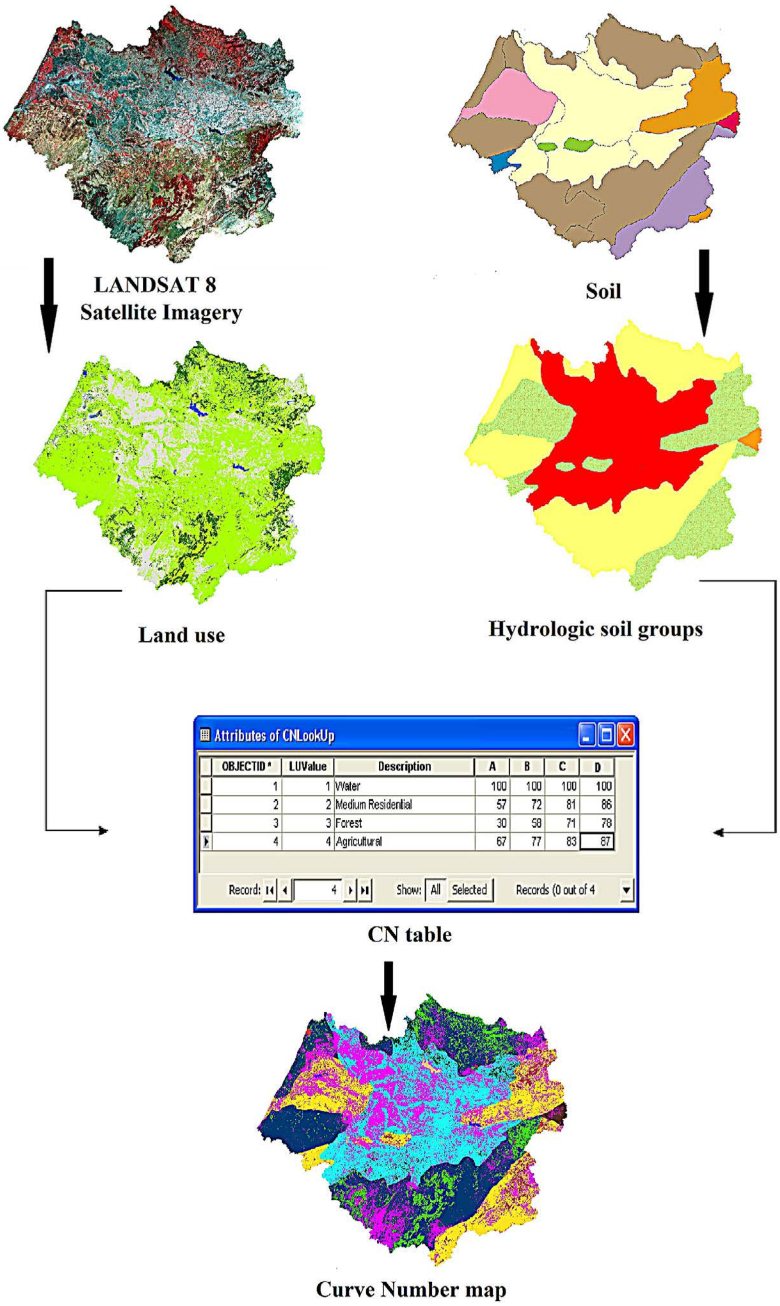

Figure 9. The different Steps used to create the curves number

Table 5. The CN values calculated by the HEC-GeoHMS tool, data is for three antecedent runoff conditions: average, dry, and wet

Sub-basin	CN II (average)	CN I (dry)	CN III (wet)
Ouergua aval	70.98	50.67	84.90
Ouergua amont	71.56	51.39	85.27
Beht aval	68.45	47.68	83.31
Moyen Sebou	76.47	57.72	88.20
Bas Sebou	54.40	33.38	73.29
Inaouéne amont	53.53	32.60	72.60
Inaouéne aval	65.78	44.67	81.55
Haut Sebou aval	61.14	39.79	78.35
Haut Sebou amont	48.60	28.42	68.50
Beht amont	74.63	55.27	87.12

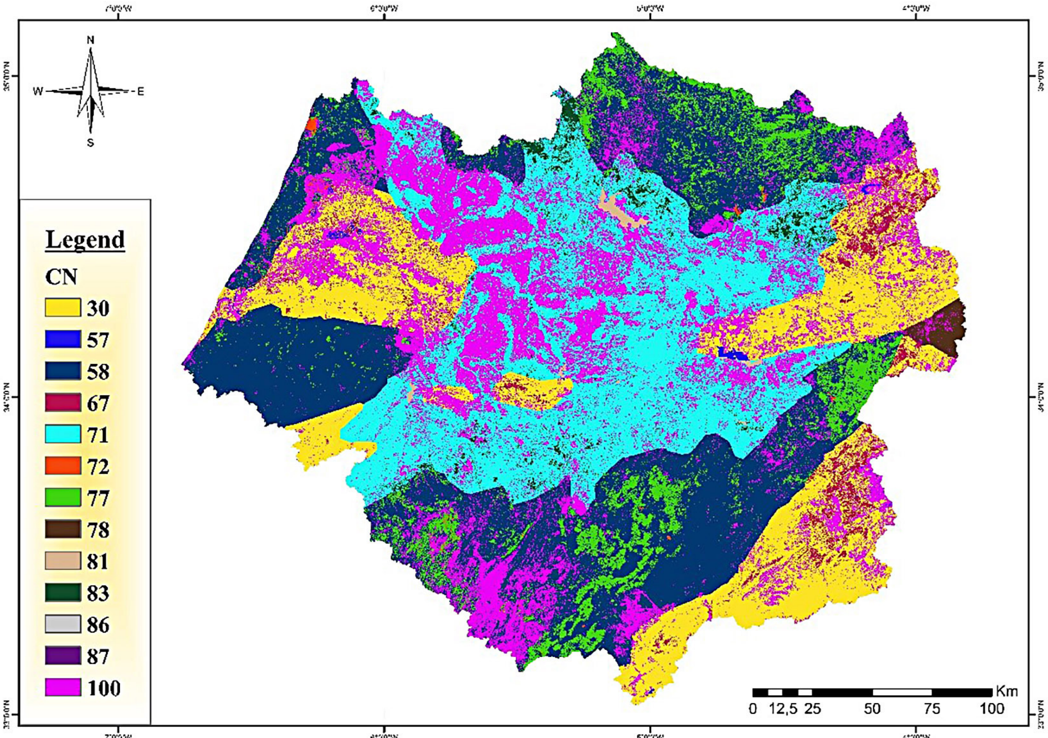

Figure 10. Resulting map of the curve number values of the Sebou watershed

The cartographic analysis of the map and the results obtained by calculating the CN values at the level of each sub-basin by the HEC-GeoHMS tool (Table 5) demonstrates that the majority of soils in the Sebou watershed have a moderate to low infiltration rate which demonstrates that the potential for runoff is high, as a result, the risk of flooding in these areas is extremely excessive.

HEC-HMS Model

The HEC-HMS software allows hydrological modeling with a large number of models, whether for modeling precipitation losses, runoff, base flow or river flow (USACE, 2000; USACE, 2008). Among all the models it offers, only one allows the spatialized modeling of runoff which is the ModClark method.

With this runoff modeling model, two models can be used for modeling precipitation losses which are:

- Gridded SCS Curve Number;
- Gridded Soil Moisture Accounting.

The first was developed for the modeling of extreme events, while the second for continuous modeling over long periods and which can take into account an alternation of dry weather and periods of precipitation.

Since our project is part of the hydrological modeling for flood protection of the Sebou watershed, we must therefore adopt the first model which estimates the excess precipitation generated by the runoff at a time t as a function of the cumulative precipitation at that time, the ground cover and the initial soil moisture.

The SCS runoff equation is (USACE 2000):

$$p_e = \frac{(p - I_a)^2}{p - I_a + S} \quad (3)$$

where: P_e – excess precipitation (mm);
p – rainfall (mm);
I_a – initial abstraction (mm);
S – potential maximum retention after runoff begins (mm).

We also have the following empirical relation:

$$I_a = 0.2S \quad (4)$$

From where:

$$P_e = \frac{(\mathrm{p} - 0.2\mathrm{S})^2}{p + 0.8S} \quad (5)$$

where: the parameter S are related to Soil, land use and initial soil moisture through the Curve Number by the equation below:

$$S = \frac{25400 - 245\ \mathrm{CN}}{CN} \quad (6)$$

The HEC-HMS model requires instantaneous flow and rainfall data, in this study we have performed the mounting and the calibration of the hydrological model by the event available from 06/03/2010 to 13/03/2010. The advantage of using HEC-GeoHMS is to be able to import the necessary geometry and hydraulic parameters of the basins directly into the HEC-HMS model. HEC-HMS results can be viewed in tables or graphs from the basin model screen. The graphs of the simulated and observed flows for the five sub-basins considered for which the rainfall-flow data were available are represented in (Fig. 11). Table 6 shows the model performance evaluation data.

We note for the first four sub-basins that the flows (observed and simulated) are very close at the level of the peak. In addition, the Nash coefficient is positive for all sub-basins except the "Moyen Sebou sub-basin", which means that the model is acceptable.

The difference between the flows (observed and simulated) for the sub-basin "Moyen Sebou" is considerable, this is caused by the fact that this sub-basin is located downstream of the dams, unlike other basins considered upper.

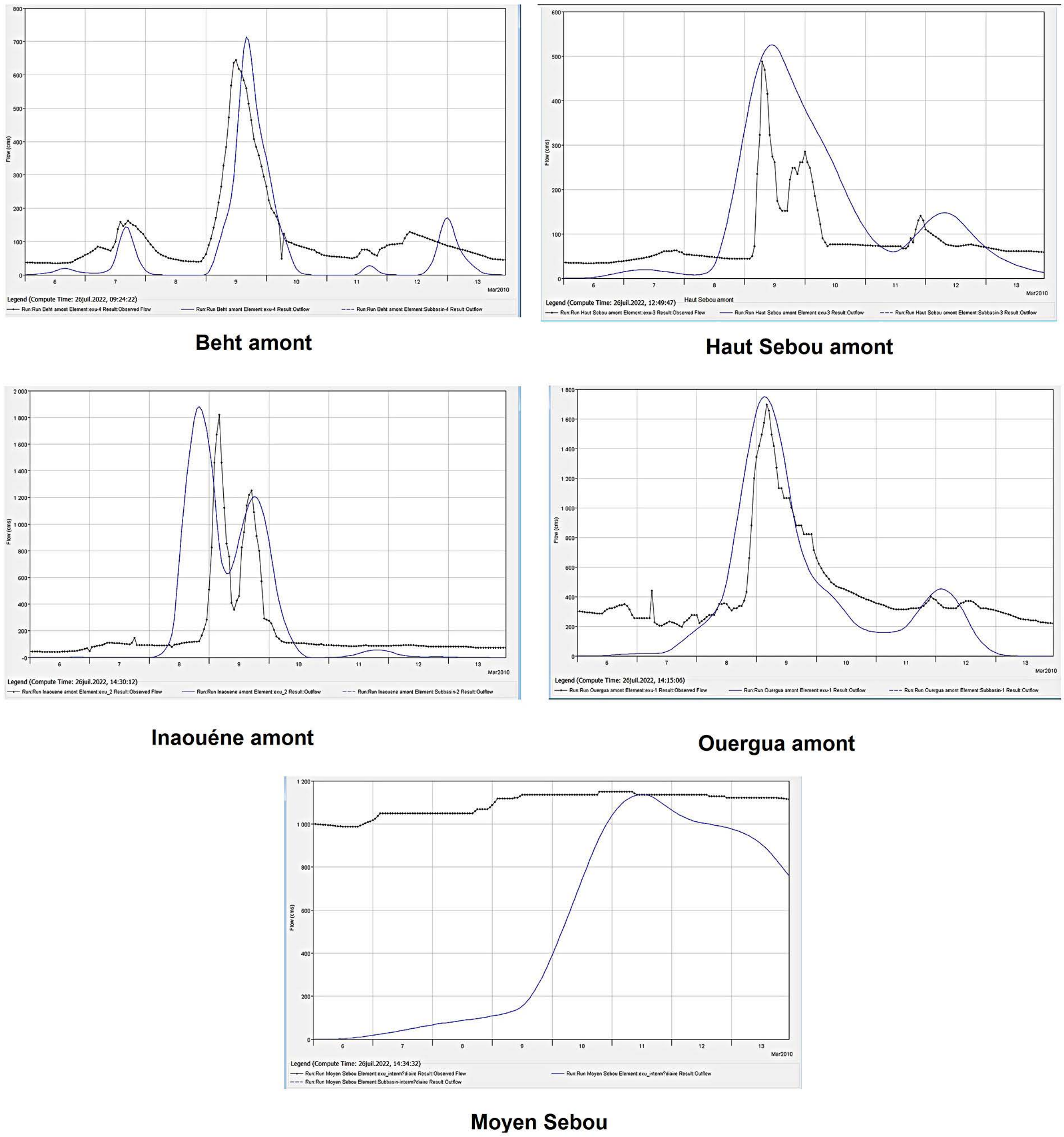

Figure 11. Graphs resulting from the simulation of the sub-basins (06/03/2010 to 13/03/2010)

Table 6. Results of the simulation of the Sebou sub-basins

Sub-basins	Peak flow (m^3/s)		Nash
	Observed	Simulated	
Ouergua amont	1697	1703.9	0.416
Inaouène amont	1820	803.4	0 495
Haut Sebou amont	488	239.5	0.519
Beht amont	645	713.7	0.546
Moyen Sebou	1150	1135.8	–

CONCLUSIONS

This study has been carried out to estimate runoff in Sebou watershed using curve number method, remote sensing and geographic information systems (ArcHydro and HEC-GeoHMS). The results show that the most dominant class of hydrologic soil groups is class B and C with moderate and low permeability and dominant land use is Agriculture. The runoff area analysis indicate that the majority of the values reported on the curve number map are high to average, which shows that the basin layers is impervious with a high potential for runoff. Through the procedure detailed above, we obtain the most optimal configuration to represent the hydrological performance of the Sebou watershed by the HEC-HMS software. Admittedly, the precision of the model in each sub-basin is different, but within the framework of the objective of the system which is the flood forecast, we can affirm that the result obtained by HEC-HMS is satisfactory. The precision of the model developed can be further improved by using more precise meteorological data with a shorter time step.

Acknowledgments

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