USING GIS AND SWAT MODEL FOR HYDROLOGICAL MODELLING OF OUED LAOU WATERSHED (MOROCCO)

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ABSTRACT

In Morocco, study and water resources management in a watershed faces several challenges that make it more and more difficult. These challenges are mainly linked to the topography of the area, climate change and poor land use. In order to meet these challenges and to ensure the rational and efficient management of water, it is Necessary to use and develop spacial and physical hydrologic models to allow as easily and realistically as possible a simulation of the functioning of watershed systems. This study consists in using a Geographic Information System (GIS) for Hydrological Modeling based on a GIS model (SWAT Model) in order to perform an overview of the study area (Watershed of Oued Laou), and also to demonstrate the impact of climat change on soil geology, its proporties and on the watershed's water resources. Our study area covers a surface of 930 km² stretching over the Haut Rif mountains. This area is characterized by zones of steep slopes and different climates, which makes the soil favorable for landslides and erosion phenomena. This study has allowed us to come up with a water balance of the study area and to model water circulation while based on climate data, soil types and land-use in the study area.

Keywords: climate change, GIS, hydrological modeling, soil, SWAT model, watershed.

1. INTRODUCTION

Nowadays, the study of the watershed's water resources requires the use of methods and technologies that make it possible to combine several elements, namely, the watershed topography, climate change, the nature of the soil and the impact of human beings on the hydrological balance through its use of the soils ...The use of the new space technologies in this type of study has become vital due to the benefits that they offer.

Indeed the use of the Geographical Information Systems (GIS) for water resources management at a watershed allow us not only to make a model of the studied phenomenon but also to obtain a global vision integrating areas that are not accessible from the ground at different spatial (centimeter to ten meters) and temporal (hours to decades) scales.

The aim behind this work is to present the steps of the hydrological modeling in a GIS model (SWAT: Soil and Water Assessment Tool), which is applied to our study area that is the watershed of Oued Laou (Figure-1).

This modeling is applied to study and analyze the multi-temporal impact (25 years) of climate change and mainly of precipitation on water flows in each sub-basins and then by integrating it to the whole it with the whole watershed of Oued Laou.

The application of a model like SWAT requires a large number of spatial and temporal data of different types and sources, the collection and use of these data makes the use of SWAT difficult, Particularly in the case of a watershed with an area of 930 km² and a study period spanning 25 years.

The proposed methodology would make it possible to come up with a water balance of the study area, and then to model water circulation based on climate data, soil types, and land-use in the study area. The result of this modeling will provide a basis for managers and decision makers on the level of future territory development projects in the Oued Laou watershed.

2. DESCRIPTION OF STUDY AREA
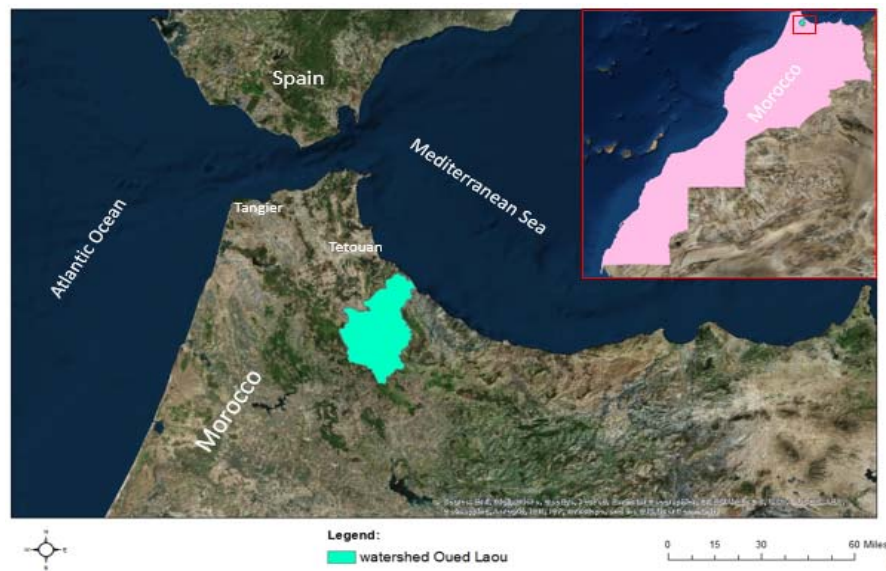
Figure-1. Map situation of the study area.

The watershed of Oued Laou (Figure-1) is a Mediterranean coastal basin, which is located in the Northwest region of Morocco in the provinces of Tetouan and Chefchaouen. It belongs to the central part of the Rif chain known as the High Rif (Stitou, 2007). With a total area nearing 930 km², the basin is characterized mainly by rugged terrain with steep slopes (25%) and significant height differences.

The study area, experienced heavy rainfall during the winter period of up to 400mm / month, however it is characterized by three types of climates; a typical Mediterranean climate in the mountainous area, a semi-arid climate dominant in the coastal zone, and a humid climate in the winter and dry in the summer south of the watershed.

Basin soils of Oued Laou's watershed witness erosion and landslide phenomena due to natural factors (relief, climate, geomorphology, vegetation cover major ... etc.) and human activity related factors (clearing forests, overgrazing, inadequate farming practices. ...).

3. MATERIALS AND METHODOLOGY

Before mentioning the different stages of our study, it would be useful to describe the main tool for hydrological modeling, which is ARCSWAT.

3.1 The SWAT model

ARCSWAT is a hydrological model (SWAT Model) that is linked to a GIS interface (ArcGIS) which is developed by the United States Department of Agriculture (USDA). It is a model that is continuous in time with daily steps, operating at the scale of a watershed with an area ranging from a few hundred to several thousand km².

This model is based on the physical processes that are at work in a watershed. Its rugged durability and efficiency make of it a model widely used in the field of watershed modeling (Gassman, 2007; Kharchaf, 2013), and its basic components are:

- The hydrological component: establishing the water balance on the watershed;
- The meteorological component (SWAT could also be used to determine the impact of past climate change on the water balance and for projections);
- Soil properties;
- Land Management.

3.1.1 Principle of functioning

The watershed's hydrology modeling can be divided into 2 parts:

- The "sub basin" part of the water cycle that allows making a water balance of each sub-basin, which are then integrated in the entire basin. It should be noted that SWAT's basic spatial unit representing homogeneous areas found in each sub basin is called Hydrologic Response Unit (HRU). This unit is formed by the combination of topography, soils, subsoils and land-use (Neitsch, 2005).
- The "transfer" part of the water cycle that achieves the transfer of water in networks upstream to the outlet. It takes care of calculating a concentration time and possible seepage in Riverbed, evaporation, withdrawals for agriculture or other uses along the stream's path.

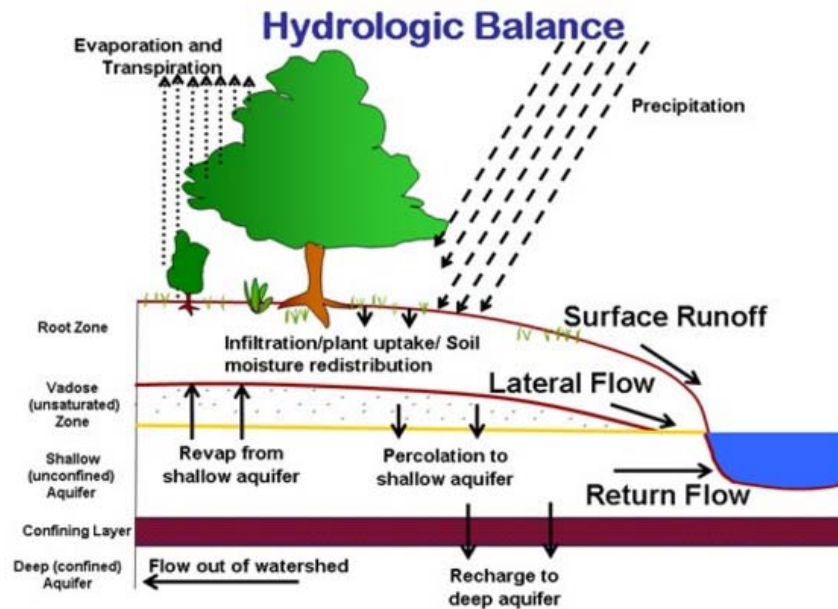SWAT's different parameters are as follows (Figure-2) (Neitsch, 2011; Nolwenn, 2003):

Figure-2. Schematic representation of water cycle in SWAT.

Rainfall is partially intercepted by vegetation and when it gets to the ground, it either infiltrates it or trickles. This operation depends on many parameters such as evapotranspiration, storage capacity of the canopy, lateral flow, and surface runoff. Whatever the studied problem, the water balance rendered into the following equation, is the basis of all modeled events:

$$SWt = SW + \Sigma \,(Rday - Qsurf - Ea - wseep - Qgw)$$

With;

SW_t	: Soil water content at time t (mm)
SW	: Soil water available in the ground for the plant at the initial time (mm)
R_{day}	: Rainfall (mm)
Q_{surf}	: Surface Runoff (mm)
E_a	: Evapotranspiration (mm)
W_{seep}	: Percolation (mm)
Q_{gw}	: basic flow (mm)
Q_{gw}	: base rate of flow (mm)

3.2 Data preparation (Input data for the model)

The basic data required to run the model are:

▪ Topographic Data (Figure-3); it is a Digital Elevation Model (DEM) that was generated from topographic maps of the study area (Maps In 1/50000):
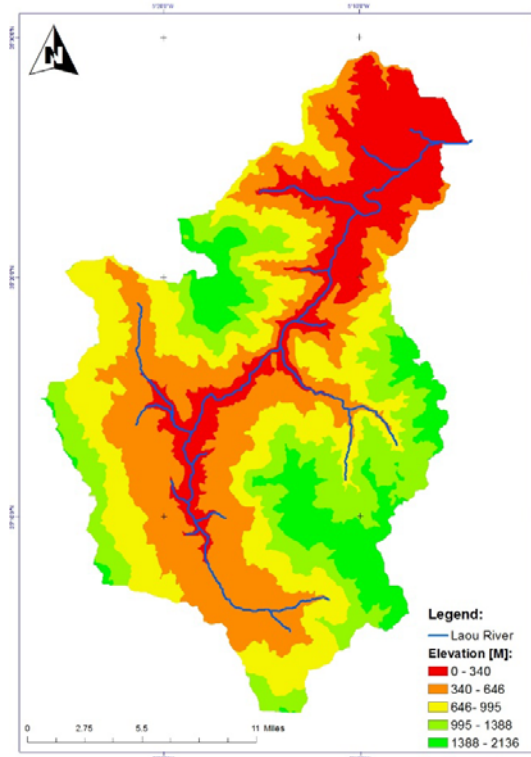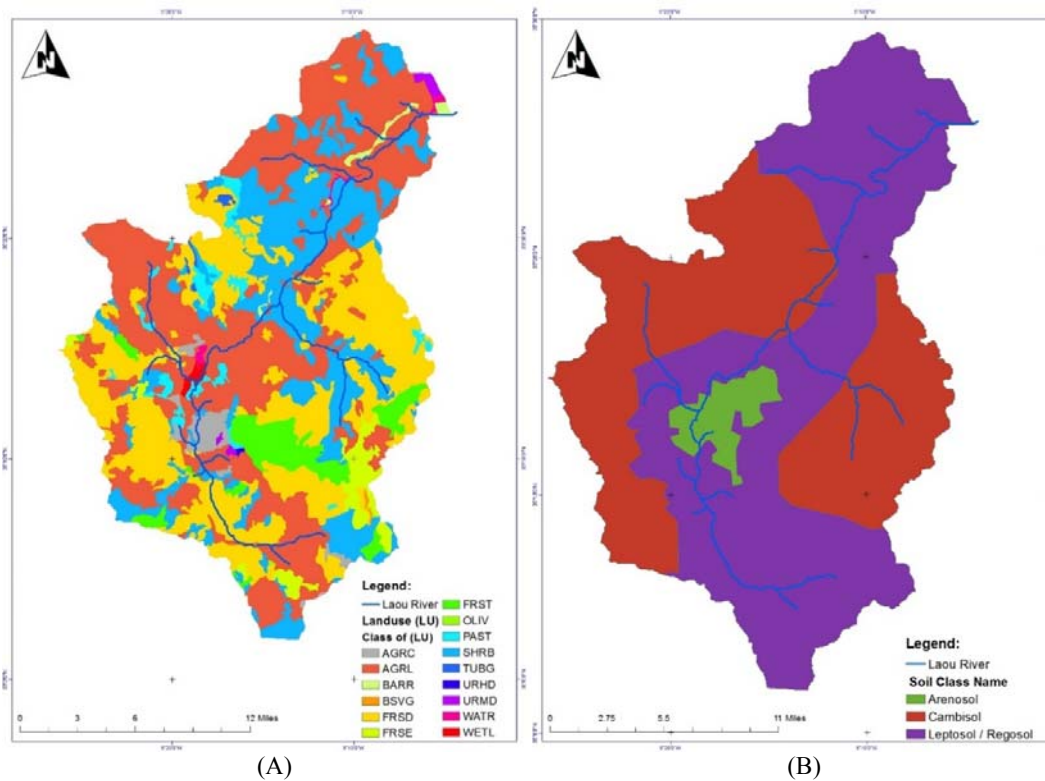

Figure-3. DEM of the study area.

▪ Land-use data (Figure-4 (A)); these are the different types of land-use (agricultural plantations, forests, buildings, vacant land ....). they were generated from multi-temporal satellite images treatment and field investigations.

▪ Types of soils' data (Figure-4 (B))»; they are extracted by combining the soil map of the basin and

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the database "E_SOTER" of soils developed by FAO (Food and Agriculture Organization) that provides a range of information about the soil.

(A)   (B)

Figure-4. (A): Land-use map of the study area, (B): Soils map of the study area.

- Meteorological data (Figure-5): this set of data concerns the period of our study, which covers 25 years (1989-2014), these are ;

- Daily rainfall.
- Maximum and Minimum daily temperatures.
- Daily solar Radiation
- Daily average relative humidity.
- Daily average wind speeds.
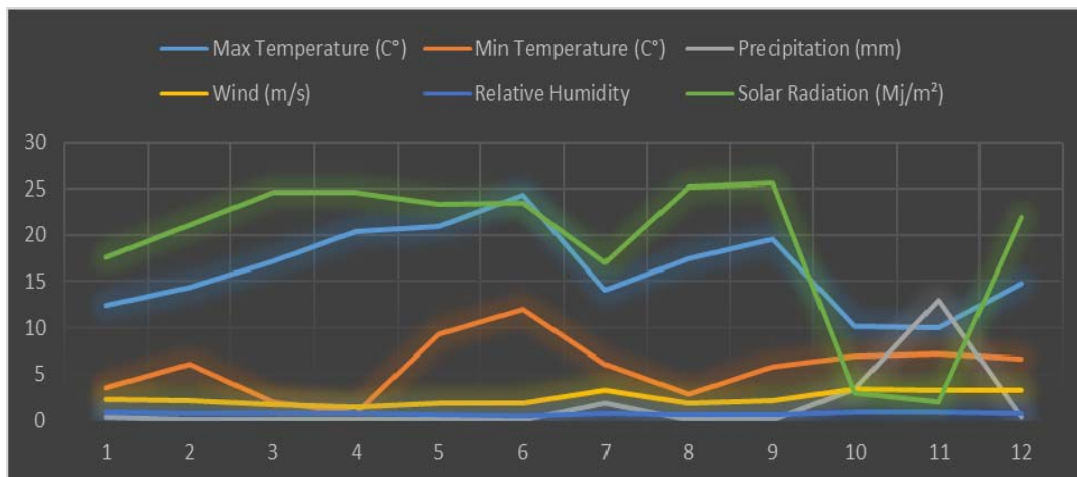
Figure-5. Extract from daily climate data used in our project, From 01/04/2009 to 12/04/2009.

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3.3 Data processing

The morphological processing of the study area is made from the DEM of the same area. Firstly, the hydrographic network is determined then the watershed and sub-watersheds which are defined by a single outlet are delimited (Figure-6). Once the watershed is determined, all the surface parameters and climate parameters must be inquired and codified to be adapted to the structuring of ArcSWAT.
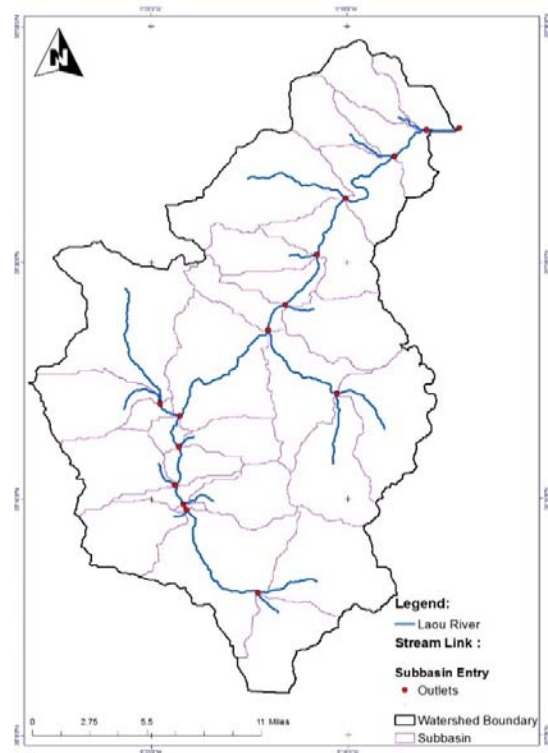
Figure-6. Identification map of hydrographic network and sub basins.

Secondly, the overlay of the land-use and soil maps defines the HRU: they are linked only to one sub basin and therefore one single stream and have a unique land-use and soil type. For each HRU specific parameters of coverage, topography, basement and soil must be defined. For each sub-basin, parameters of weather, of topography and surface should to be specified. Finally, for the entire basin, surface parameters and climate parameters should be added (Figure 7) (Lang, 2011).
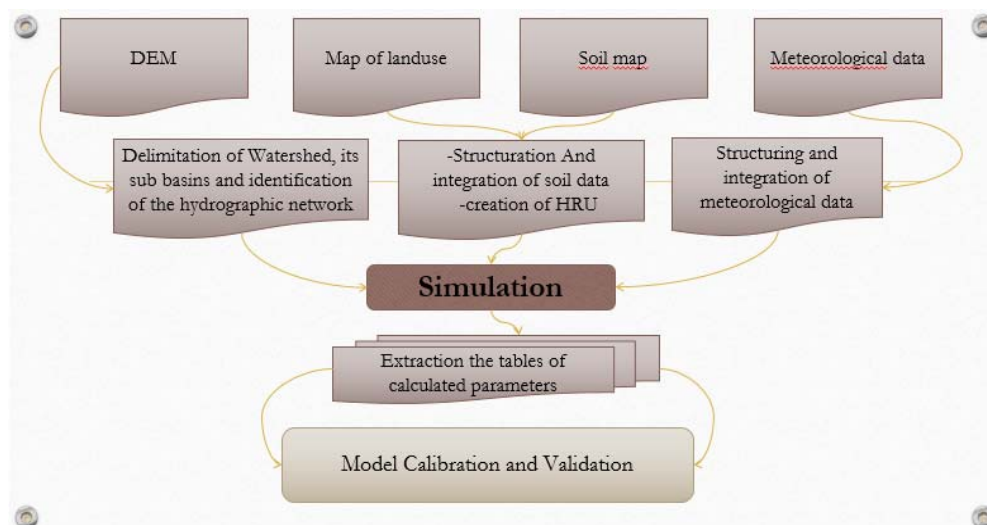
Figure-7. Structural diagram of modeling under ArcSWAT.

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4. RESULTS AND DISCUSSIONS

The result of this study is the generating of a Database (DB) (Tables 1 and 2) which represents the result of the simulation. The latter is in the shape of tables involving a set of parameters calculated during the model with a daily time step over a 25 year period.

Table-1. Extract of calculated parameters for sub basins from 1 to 6 for 01/01/2012.

SUB	Year	Area (km²)	PET (mm)	ET (mm)	SW (mm)	SURQ (mm)	GW_Q (mm)	WYLD (mm)
1	2012	22.285	1.89	0.38	40.2	0.000000999	0.144	0.151
2	2012	15.021	1.99	0.527	43.7	0.00000099	0.309	0.324
3	2012	23.979	1.9	0.399	41.5	0.000000994	0.3	0.315
4	2012	21.932	1.89	0.356	38	0.000001	0.0387	0.0414
5	2012	67.685	1.89	0.458	91.1	0.000001	0.0228	0.0249
6	2012	29.594	1.9	0.377	39.1	0.000000995	0.145	0.152

With ;
- **PET:** Potential evapotranspiration from the subbasin during the time step.
- **ET:** Actual evapotranspiration from the subbasin during the time step.
- **SW:** Soil water content. Amont of water in the soil profil at the end of the time period.

- **SURQ:** Surface runoff contribution to stream flow during time step.
- **GW_Q:** Groundwater contribution to stream flow. Water from the shallow aquifer that returns to reach during the time step.
- **WYLD:** Water yield. The net amount of water that leaves the subbasin and contributes to stream flow in the reach during the time step.

Table-2. Extract of calculated parameters for each routing reach in the sub basins from 1 to 6 for 01/01/2012.

SUB	ORGN_IN (kg)	SED_IN	ORGP_IN (kg)	SED_CONC (mg_kg)	NO3_IN (kg)
1	0.000002226	0.00000002097	0.000006679	0.00000629	0.05915
2	0.000001392	2.173	0.0001574	29.05	1.134
3	0.000004297	2.298	0.0001554	27.18	0.9887
4	0.000002193	0.00000002298	0.000006579	0.00002695	0.01311
5	0.000006754	0.0000000439	0.00002026	0	0.02314
6	0.000007877	2.85	0.0001609	31.9	0.8317

With;
- **ORGN_IN:** Organic nitrogen transported with water into reach during time step.
- **SED_IN:** Sediment transported with water into reach during time step (metric tons).
- **ORGP_IN:** Organic phosphorus transported with water into reach during time step.
- **SED_CONC:** Concentration of sediement in reach water into reach during.
- **NO3:** Nitrate transported with water into of reach during time step.

The analysis and interpretation of the various parameters calculated during the simulation would make it possible to use their values as basic information in different projects and to help in decision-making. Indeed, this information would be useful for the study of the effects of climate change on the soil, the phenomenon of erosion, the zone planning or any project related to the soil and the circulation of water in a territory Watershed. A study concerning the evolution of water content all along the studied period can be done based on the evolution of numerous parameters that can affect its presence such as precipitation and water stream flows (Figure-8).

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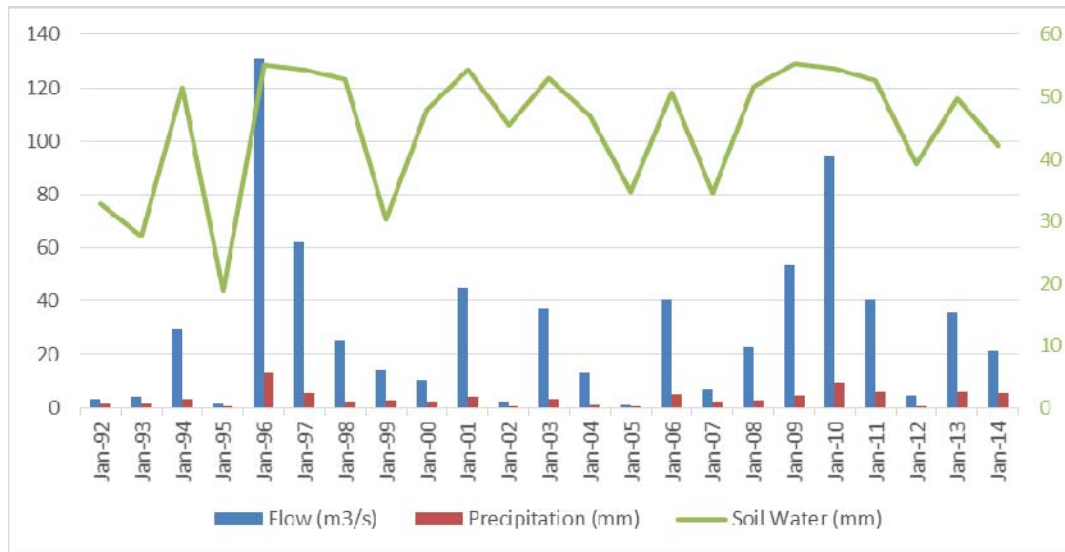
Figure-8. Evolution of the soil water content for 22 years in sub-basin number 6.

The results obtained may also be the subject of basic data for sedimentological studies. Indeed, the representation of the transport of sediments by the water stream was modeled throughout the period studied be it for the winter (Figure-9) or summer (Figure-10) seasons.
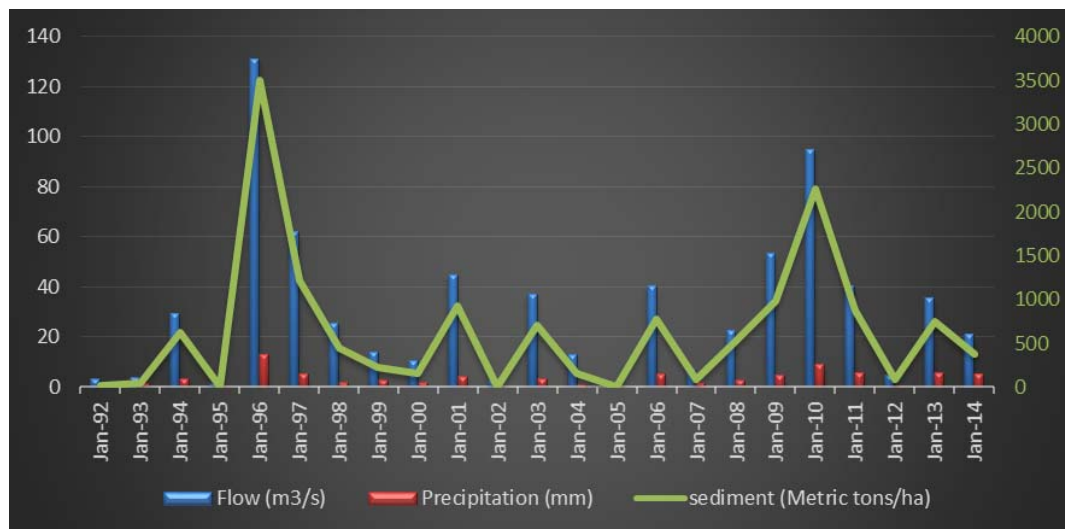
Figure-9. Extract of the quantity of sediment transported during the months of January in sub-basin number 6.

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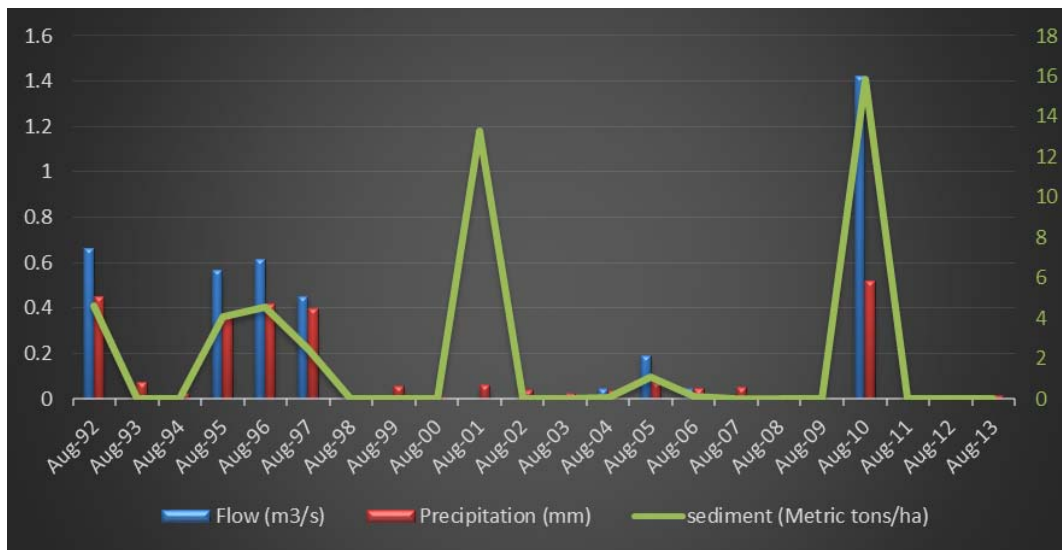
Figure-10. Extract of the quantity of sediment transported during the months of
August in sub-basin number 6.

To evaluate the model performance, the coefficient of Nash (Nash, 1970) is used as a criterion to quantify the accuracy of the simulation. This coefficient represents the ratio of the residual variance to the variance of the observed flow:

$$NS = 1 - \frac{\sum_{i=1}^{n}(Q_i^{obs} - q_i^{sim})^2}{\sum_{i=1}^{n}(Q_i^{obs} - \mu_{obs})^2}$$

With:

NS = Nash-Sutcliffe coefficient
n = total number of time steps on which the criterion is calculated
Q_i^{obs} = observed flow at time i
Q_i^{sim} = simulated flow at time i
μ_{obs} = average observed flows

The results will be greater so long as the NS criterion approaches 1. By comparison with other criteria, this one has the advantage of being easy to interpret (Moriasi, 2007). Indeed, if it nears 1, the model gives better results than a naive model giving each time a constant flow equal to the average of the observed flows; if it is less than 0.5, the reverse (Table-3) (Bouslihim, 2016).
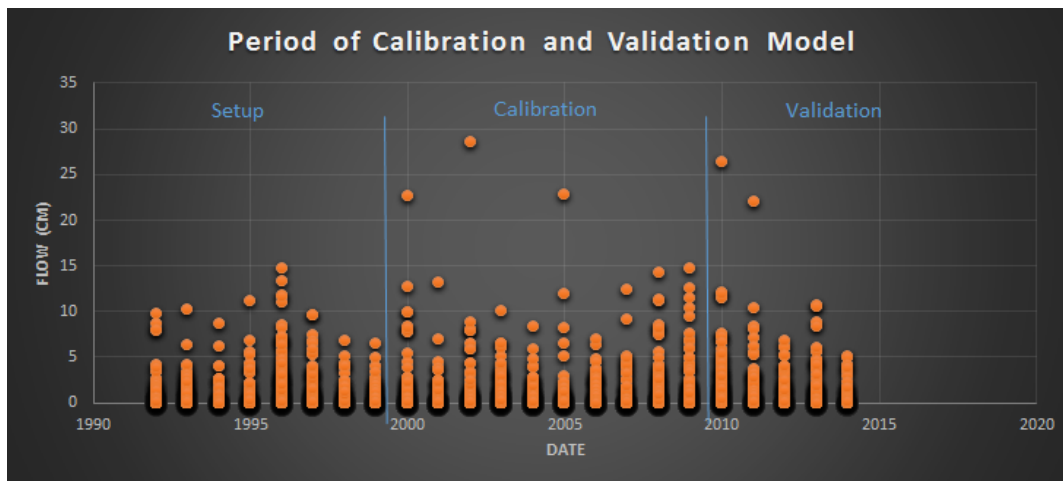
Table-3.. Model performance criteria.

Model performance	Nash-Sutcliffe coefficient
Very good	$0.75 < NS \le 1.00$
Good	$0.65 < NS \le 0.75$
Satisfactory	$0.50 < NS \le 0.65$
Unsatisfactory	$NS \le 0.50$

To validate the model, the Nash coefficient is applied to the simulation results while based on a single variable that is frequently measured which is the flow of streams (Fadil, 2011).

The procedure of calibration and validation of the model requires selecting a calibration period and another for validation (Figure-11);
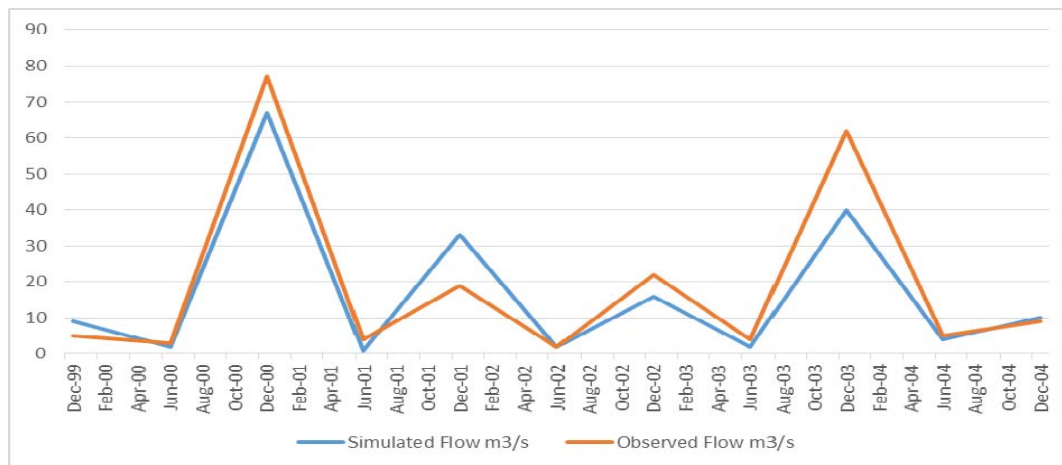
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Figure-11. Period of calibration and validation of our model.

Nash coefficient calculated for our modeling is located in the first class according to the model performance criteria (Table-3). The Nash coefficient approaches 0.7 during the calibration period and 0.8 during the validation period (Figure-12 and Figure-13).

Figure-12. Comparison between observed flow and simulated flow for the Calibration (1999-2004).
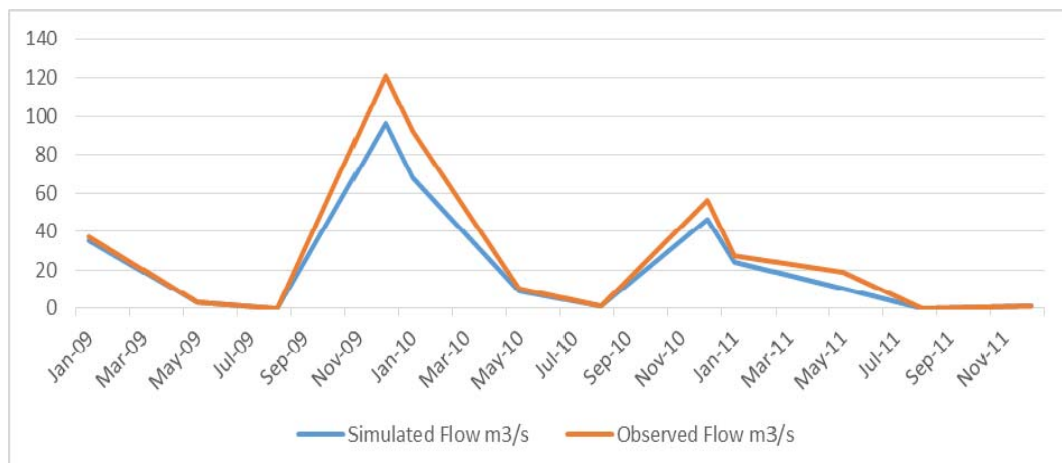
Figure-13. Comparison between observed and simulated flow for the Validation (2009-2011)

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5. CONCLUSIONS

The use of multi-source and multi-date data in a GIS for hydrological modeling under the SWAT model has made it possible to study the evolution history of any soil-related activity in the Oued Laou watershed for a period of 25 years. Despite the extent of the study area (an area of 930km²) and the different sources of data collected, however, the results obtained in our study are quite satisfactory.

Indeed, the obtained results allowed dividing the watershed of Oued Laou into sub basins and then creating a spatial database for each sub-basin, which contains information on the evolution of the soil and water circulation.

These results can be the basis for the implementation of various projects from different fields, namely; spatial planning, the study landslide and erosion phenomena, the study of soils and water resources.

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