Hydrologic model combined to a GIS for estimating hydrologic balance at watershed scale - Application to the watershed of Macta (Western Algerian)

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Abstract: - With modeling techniques, it is possible to make progress in the fields of the representation and functioning that determine the interactions between various factors into watershed. It is first necessary to understand existing hydrologic models and then implement them on real cases. Geographic Information Systems (GIS) allowed to provide these models with data which are various and require to be structured into adequate form (layers and databases). This application present an investigation of hydrologic balance over the large watershed of Macta located in the west of Algeria using the (SWAT) hydrologic model and (ArcView) GIS software. The SWAT model is calibrated for our case study and some results are presented on this paper.

Key words: - Geographic Information System, Hydrologic Model, Water resources, Watershed, Algeria.

1 Introduction

Water is a precious natural resource of which good management lead to a long-term development and represents therefore a challenge for the demographic evolution.

Hydrologic models are of a major importance for the analysis of climatic change repercussions and water resources balance [5]. So, they allow the evaluation of water resources and facilitate their management while valuing different choice consequences. A good knowledge of the problem and the analysis of various solutions require an integrated approach of the geographical information which can offer a global vision of the various components of the system.

GIS as an essential and efficient tool to collect, stock and process data required for simulations [2], are characterized by a relatively simple operations manipulating various data. Contrarily, hydrological models are characterized by complex operations including iterations on a more reduced number of data. Thus, GIS permit to group all disposed watershed data into structured database system.

The main objective of this survey is to better understand how the hydrologic model (SWAT) supported with (ArcView) GIS does works for water resources assessment inside a large watershed and to adapt the model with the conditions of Algeria's watersheds. The set up of different data into the SWAT model require a specific file format. However, it is indispensable to learn about the different tools required for the hydrologic simulation as well as data integration utilities.

An application was made on the watershed of Macta (North West of Algeria) where the obtained results show a good correspondence between simulated and observed variables for the adopted model.

2 Study area

The watershed of Macta is a part of the Hydrographical District "Oranie-Chott-Chergui" which is subdivided in two great sets: "Oranie" and "Chott-Chergui" containing four watersheds: Coastal Oranais, Macta, Tafna and Chott-chergui. The watershed of Macta is located in the North-West of Algeria (Fig. 1) and it is managed by the "Oranie Chott-Chergui watershed Agency". It covers an area of 14235 km² approximately.

The large watershed of Macta is subdivided into sixteen (16) subbasins. Each one is represented by one or more meteorological stations.

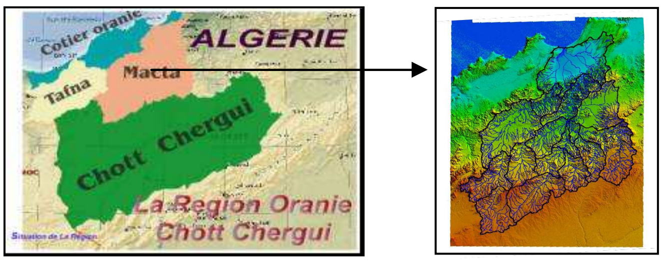

Fig. 1. Situation of the study area.

3 Description of SWAT model

SWAT is an evaluating tool of soil and water developed by the USDA - Agricultural Research Service [3]. 2002a). This model was developed for the investigation of watersheds with surfaces going from a few hundreds of Km² to several thousands of Km². SWAT is a distributed model that functions on a continuous basis with a daily time step. It requires some specific information on the atmospheric conditions, properties of soil, topography, vegetation, procedures of earth management and it incorporates equations of regression to describe the report between input and output variables [4].

This model estimates fluxes of water, nutrients, pesticides and sediments. It was validated on several watershed of the word. Its validity has been tested for numerous basin sizes. Many parameters have been predefined according to United States data.

Therefore it is necessary to adapt some values to local conditions to get realist results. The basic spatial unit to the calculation is the Hydrologic Response Unit (HRU) that is the result of the combination of a soil type, a class of land cover and a subbasin.

The modelling requires that the watershed must be divided into subbasins. Flows estimated for every HRU are added by subbasin in order to get a global flow transmitted between subbasins [1].

The active processes in soil are infiltration, evapotranspiration, withdrawal by plants, lateral out-flow and out-flow toward the lower horizons.

4 Application to the watershed of Macta

The principle objective of this application is to experiment the possibilities offered by the SWAT system in order to determine the hydrologic balance at the scale of the Macta watershed situated in the north west of Algeria. SWAT model examines six (06) different sections which are: climate, hydrology, erosion, plantation growth, management and water quality. We note here that our investigation will be focused to the sections "climate" and "hydrology" only.

4.1 Data sets

For an eventual execution of the SWAT model, it must be useful to dispose of a consistent data bank for the investigation area. In this case, a data set including the following information was used:

- Watershed characteristics (boundary, streams, topography, soils, vegetation etc.)
- Micro-basins characteristics (surfaces, slope, channel width, basin fraction etc.)
- Hydrology (Manning coefficient ...)
- Climate (monthly max & min temperatures, coefficient of variation of the temperature etc.)
- Information related to the weather stations (latitude, longitude, elevation etc.)

The table below display the data set of a weather station (Ras El Ma) situated within the Macta watershed.

To have an effective response to our spatial needs, different tools based on geographical information system (GIS) and database are available.

As already mentioned, the functioning of SWAT model requires the availability of data on watershed geometry, climate, soils, slopes, etc.

The GIS allowed to realize overlays between various geographic information and to produce new data (slopes, aspects, flows directions, etc.).

It is easy to connect semantic data to geometric data by making relations between database (ACCESS) and GIS tables. The principal entities engaged for the realization of our Database include the following data: agglomerations, routes, land cover, altimetry, rainfall, temperatures, wind, air humidity, weather stations, soils, water points (wells, drillings, sources), underground water, canals, dam, hydrographical network and water points (lake, sebkha, daïa).

The displayed layers needed are (see Fig. 2): watershed borders, hydrometrical stations, rainfall stations, hydrographical network, other water points (lakes, sebkhas), agglomerations and buildings, roads network, altimetry and geomorphology (relief), water points and sources (drillings, wells, sources...).

All disposed layers were transformed into one same geo-referenced format in order to facilitate their integration to the GIS. For each digitalized geo-referenced layer was associated or created an ACCESS database which contains descriptive information.

Data used by SWAT model are extracted from this established Access database that can be linked to the ArcView GIS using ODBC protocol.

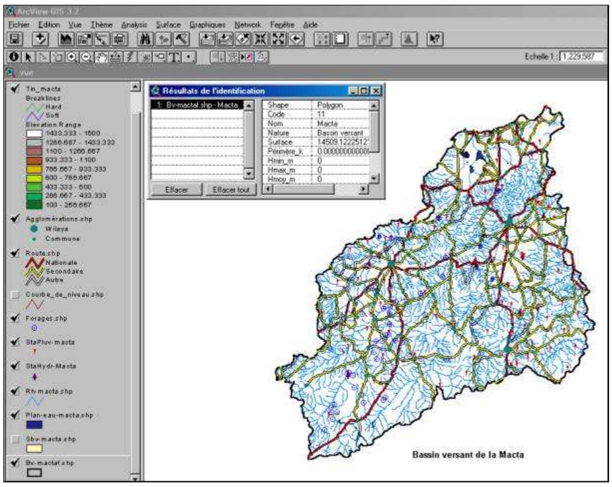

Fig. 2. Basis layers.

4.2 Watershed configuration

The watershed of Macta is configured without taking into account the presence of dams. The process of modelling which using SWAT model concerned sixteen (16) subbasins that constitute the whole watershed (see Fig. 3).

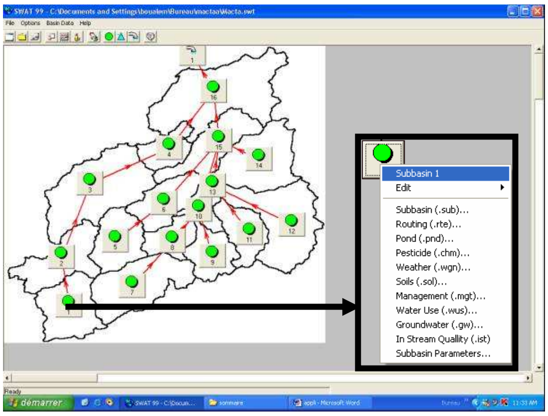

Fig. 3. Macta watershed configuration in SWAT.

4.3 Results

Calibration of the model is divided into several steps:

- water balance and stream flow,
- sediment,
- nutrients.

Our study, is limited at the water balance and stream flow witch is first done for average annual conditions. Once the model is calibrated for these conditions, we can shift to monthly or daily records to fine-tune the calibration.

In this case, we disposed of climatic data issued from ten (10) weather stations covering 16 subbasins over a period of 17 years.

Monthly and yearly temperatures and precipitations resulting from the simulation were compared to those measured by weather stations that are summarized in the following figures (4 & 5).

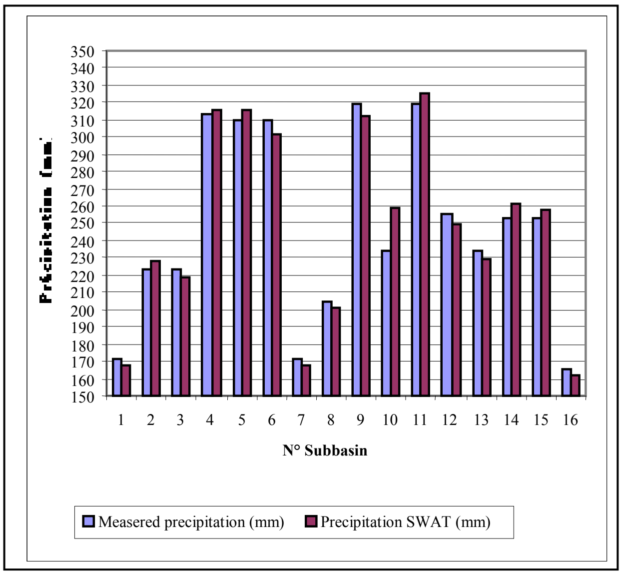

Fig. 4. Variation of calculated and observed average annual precipitations of subbasins.

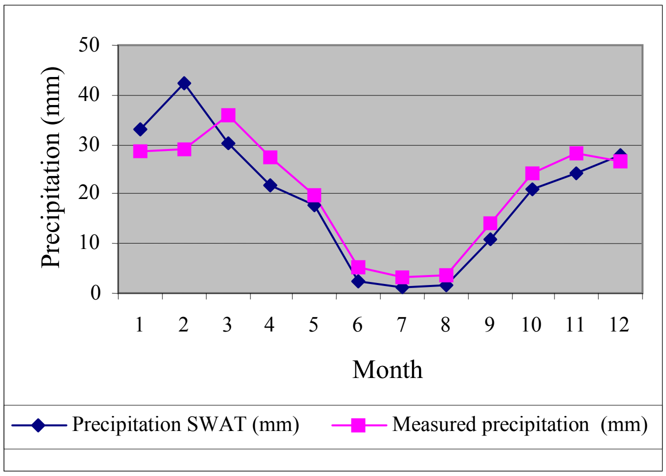

Fig. 5. Variation of calculated and observed monthly average precipitation of Macta.

4.3.1 Surface runoff calibration

SWAT model uses "Curve Number" approach developed by the USDA service for the estimation of ground outflows. In our case, the CN is adjusted until surface runoff is accepted (see table 1). If these last values still not reasonable after adjusting CN, we must adjust soil available water capacity and/or soil evaporation compensation factor.

Subbasin	Curve Number CN	Subbasin	Curve Number CN
1	90	9	91
2	85	10	90
3	91	11	85
4	90	12	90
5	92	13	90
6	85	14	86
7	82	15	88
8	90	16	85

Table 1. Curve Number (CN) values used for simulation.

4.3.2 Subsurface flow calibration

Once surface runoff is calibrated, measured and simulated values are compared. By the way, some parameters are given as follow (see tables 2 & 3):

- PREC : precipitation (mm) ;
- SURQ : surface runoff (mm);
- LATQ : lateral flow (mm) ;
- ET : actual evapotranspiration (mm);
- PET : potential evapotranspiration (mm) ;
- WYLD: net water yield (mm).

If simulated base flow is too high or too low, an adjustment of some factors (groundwater revap coefficient, threshold depth of water in the shallow aquifer is required.

TIME (Mon)	PREC (mm)	SURQ (mm)	LATQ (mm)	ET (mm)	PET (mm)	WYLD (mm)
1	33.15	3.93	0 .03	14.76	71.66	3.91
2	42.21	6.55	0.04	21.40	103.40	6.53
3	30.38	4.71	0.04	26.20	161.64	4.71
4	21.81	2.53	0.03	29.42	191.49	2.53
5	17.90	1.12	0.02	68.20	232.33	1.12
6	2.53	.01	0.01	28.21	273.60	0.02
7	1.29	.00	0.01	4.33	249.52	0.01
8	1.48	.00	0.00	1.69	241.61	0.00
9	10.94	.22	0.00	5.50	194.40	0.22
10	20.92	.32	0.01	7.69	133.53	0.32
11	24.20	.67	0.01	7.15	72.89	0.67
12	27.82	1.81	0.02	9.56	71.93	1.80
Year	234.63	24.04	0.22	225.72	1998.40	21.84

Table 2. Hydrologic balance main elements of Macta (monthly average values).

	AREA (Km^2)	PREC (mm)	SURQ (mm)	ET (mm)	PET (mm)
1	926.689	167.174	6.338	173.031	1974.580
2	922.418	227.970	9.190	231.094	1976.317
3	1723.840	218.445	29.802	198.289	2127.788
4	468.327	316.001	62.616	263.358	1978.098
5	753.024	315.342	63.704	263.901	1945.639
6	694.661	302.039	27.372	284.841	1977.594
7	1237.009	168.024	0.546	180.304	1972.236
8	455.515	200.696	10.129	203.324	1973.089
9	597.864	311.645	70.227	251.716	1983.052
10	257.651	258.975	0.543	269.201	1996.848
11	613.522	324.883	29.210	306.873	1986.220
12	1447.685	248.903	23.919	236.694	1987.888
13	139.502	228.807	18.488	221.806	2000.422
14	1178.646	260.667	17.382	253.970	1974.724
15	841.280	258.004	22.969	243.932	1978.608
16	1977.220	161.398	0.382	174.574	1977.979
Basin (total)	14234.853	3968.973	392.817	3756.908	1988.193

Table 3. Hydrologic balance main elements of subbasins (annual average values).

4.3.3 Discussion of results

Comparison between measurement and simulated results shows small variations. At the precipitations level, for example, the values vary from 1.01 mm for December to 13 mm for February with a yearly difference of 12 mm.

CN adjustment required several iterations. Results presented correspond to surface runoff judged acceptable. In the same way, to calibrate subsurface flows some parameters are adjusted (groundwater "revap" coefficient, threshold depth of water).

Other results regarding the potential evapotranspiration, the real evapotranspiration, lateral and superficial outflows, etc. were also calculated and recorded on specific files. They can be consulted at any moment.

5 Conclusion

Certainly, SWAT model permits the modelling and the estimation of several weather parameters at a watershed scale, but in our case some ground data needed for an optimal simulation are not very pertinent and can make our predictions doubtful.

Furthermore, the difficulties for acquiring data necessary for an optimal simulation using SWAT model remain an obstacle which limited our investigation just for the hydrologic cycle. Consequently, obtained results are experimental and not definitive or final. The availability of data in digital form allowed the proposed method to make the best possible usage of existing hydrological information.

The experiment of the SWAT model on the watershed of Macta was performed thanks to the data sets obtained from the weather stations covering this watershed. Its implementation requires a data base and a validation of the model. The SWAT model gave results highly correlated with values observed by the weather stations.

Finally, it seems that this model offers wide perspectives for the simulation of hydrologic balances and can help specialists to make the correct decision.

GIS and hydrologic models improve the good management of water resources. However, geographical data spatialisation and manipulation are indispensable for the hydrological studies, particularly the topographic parameters.

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