

The contribution of the digital elevation models and geographic information systems in a watershed hydrologic research

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Abstract The hydrological and physical characteristic description of a watershed constitutes an essential task for hydrologic research. Usually, this one requires a hydrologic model of which the running needs a great number of data and information. The main purpose of this study was to use Shuttle Radar Topography Mission (SRTM) data, free of charge, for hydrologic studies in Algeria. This work will also be a good assessment test of hydrologic geospatial tools HEC-GeoHMS integrated in the ESRI ArcView 3.2 GIS. It is to define the watershed of Macta and its sub-basins and to extract the hydrographical network and also other topographic and hydrologic parameters from the SRTM data. The data bank with the obtained results and the schematisation of the studied watershed (Macta watershed is in the western of Algeria) will be used as a foundation of a hydrologic model.

Keywords Hydrology · GIS · DEM · Watershed · Hydrographical network · Geospatial hydrologic tool · Algeria

Introduction

We know that the physical and hydrological parameters can be taken from other sources such as topographic maps and satellite pictures, but the digital elevation model (DEM) has a lot of advantages. Nowadays, some sensors can establish

the relief of an object. It gets several products as the DEM and it is derived, which are very important for the hydrologic applications (Bradley and Maidment 1999). With only altimeter information of the DEM, you can delineate the watershed and remove the hydrographical network. At the same time, a large number of hydrographical network and watershed characteristics can be defined. The integration of the other hydrologic data such as rainfall and curve number (CN) allows estimating others hydrologic parameters like the lag time, concentration time, etc. The automation of the extraction methods permits determining the hydrological and physical parameters very quickly, particularly when the watersheds are bigger and so the manual extraction is longer. In that case, some operator mistakes can appear (Chaponnière 2005). The increased development in the geographical information domain drives in several applications to the usage of the geographic information systems (GIS), powerful tools allowing the manipulation, storage, analysis and display of spatial referenced data. The GIS play a primary role as geographical information support, management tools of geographical and thematic data, also in modelling, calculation and communication abilities (Goodchild et al. 1996). Their role in hydrology is increasing. In addition to extracted data from GIS and introduced in simulation models, GIS are more developed for hydrologic modelling that integrates simulation models (Puech et al. 2004). Therefore, a digital elevation model of Shuttle Radar Topography Mission (SRTM) and a geospatial tool (Hydrologic Engineering Center Geospatial Hydrologic Modeling Extension, HEC-GeoHMS), extension of ArcView 3.2 of ESRI, have been used to delineate the sub-basins to extract the hydrographical network, to compute the physical characteristics and some hydrological parameters and to establish the watershed schematic appropriated with a hydrologic model.

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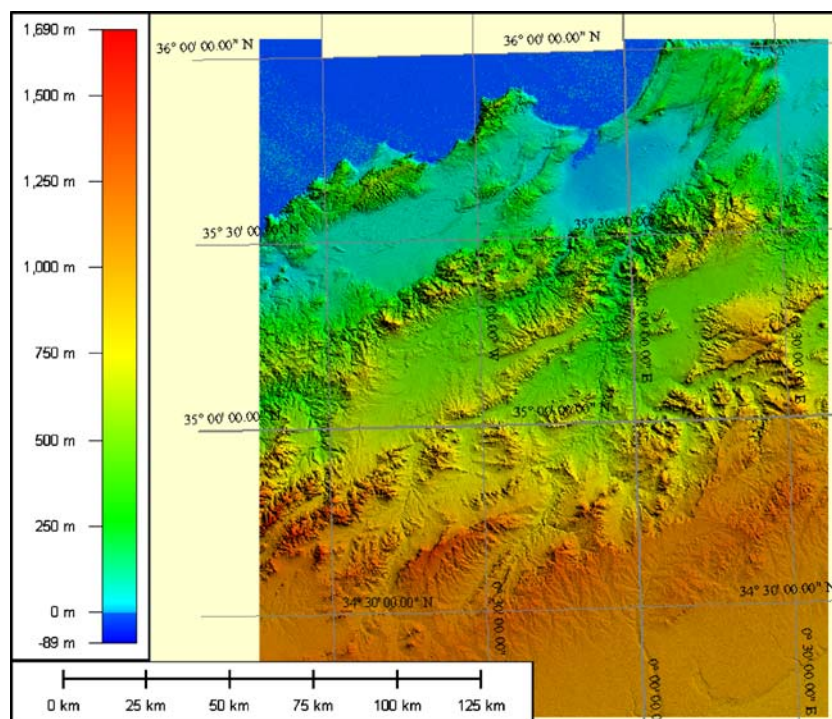
Data and tools

SRTM data

The topography is one of the factors which influence spatial and temporal variability of the hydrologic process. It can be represented by a digital elevation model that can be used by a computer (Gamache 2005). From this, we can analyse territorial structural characters as the watershed limits and its characteristics, slope map, hydrographical network extraction, etc. The data used in this application are from the SRTM version 3 with a resolution about of 3 arcsec (90 m). The source of the data is free in all the selected research areas (Fig. 1). The 3-arcsec resolution is totally appropriated to our study. The SRTM data are available in Geotiff format and are given out by the US Geological Survey (Farr and Kobrick 2000). The World Geodetic System 84 (WGS84) is used for the horizontal projection system; the vertical system is determined by the EGM 96 geoid (Earth Geopotential Model 96; Cemagref 2006).

To make use of the methodology, we have chosen the northwest of Algeria, between the north parallels $35^{\circ}15'$ and $35^{\circ}57'$, and the West Meridian $1^{\circ}14'$ and $0^{\circ}40'$ (Fig. 1). It is the hydrographic region of Oranie Chott Chergui. In this zone, we have the Macta watershed which covers an area of $14,235 \text{ km}^2$ and three other watersheds named Oranese Coastal, Tafna and Chott Chergui. The limits and the hydrographical network of Macta watershed, determined from the 1/200,000 topographical plans, are available. So we can compare the obtained results.

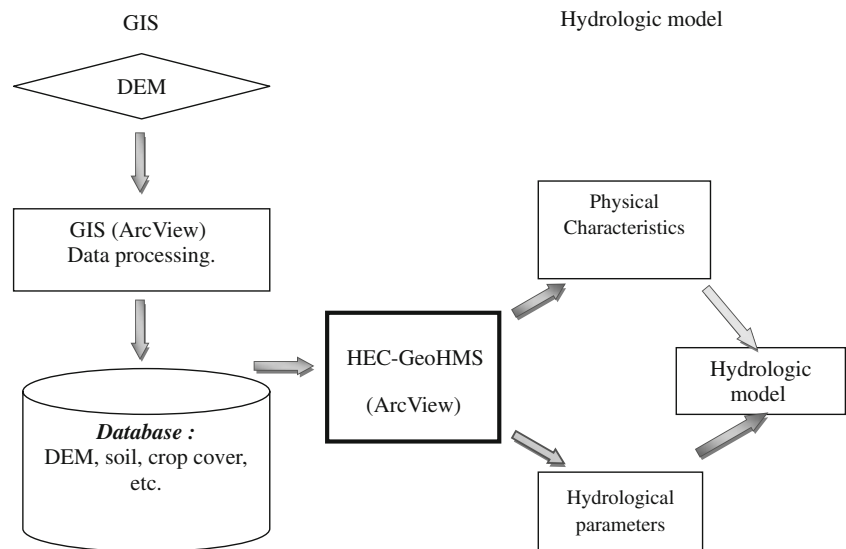
Fig. 1 SRTM data of the study area



Geospatial tools HEC-Geo HMS

HEC-Geo HMS is a geospatial hydrologic modelling extension of the ArcView 3.2 GIS. It uses Spatial Analyst extension (ESRI 1996) to develop a number of input entry data for a possible hydrologic modelling. Through analysis of the terrain digital information, it converts the drainage flows and the watershed boundaries into a hydrologic data structure. HEC-Geo HMS contributes to the valuation of the hydrologic parameters given in tabular form, extracted from the physical characteristics of watercourses and sub-basins (HEC 2003). Moreover, it allows visualising the spatial information (watershed characteristics), delineating sub-basins, extracting the hydrographical network and developing a basin schematic and a background map file (Fig. 2). The DEM of the watershed is the most important data, for this extension, which come from the GIS. Figure 2 shows the connection between the ArcView GIS, the HEC-GeoHMS module and the hydrologic model. The GIS ensures their geographic and topographic map digitisation and their treatment to obtain a spatial hydrologic database compound of DEM, soil type, crop cover, etc.

The HEC-GeoHMS software makes the processing of the DEM via the ArcView to achieve the schematisation in sub-basins of the watershed. The link between GIS functionalities and hydrologic model is made by the HEC-GeoHMS extension (HEC 2003). In this way, it translates the spatial information of the GIS into hydrologic information (Fig. 2).

Fig. 2 Relations between different tools

Applications and results

Data processing is achieved in two main steps:

1. Preprocessing allows correcting the DEM, defining sub-basins and extracting the hydrographical network.
2. Physical and hydrological parameter extraction is necessary to hydrologic modelling.

DEM preprocessing

The different steps of DEM preprocessing are presented in Fig. 3. ArcView 3.2 GIS, the Spatial Analyst extension and the geospatial tool HEC-GeoHMS are used.

DEM of the study area should be used in ESRI's grid format. The following step consists of the process DEM with the HEC-GeoHMS:

DEM correction

“Terrain reconditioning” method has been used. Here, the hydrographical network, considered as a break-line and previously digitised or obtained by other methods, is superimposed to the DEM. This method allows the user to do lower cell stream elevation and also provides an option to gradually lower the neighbouring cells along the stream. This method creates a regular transition from the overbank to the stream centerline in the DEM to make water enter the stream (HEC 2003). Thus, the flow will be forced at the moment of the network extraction and will appear in better adequacy with the terrain reality. Then, depressions and pits are filled by increasing the elevation of the pit cells to a level of the surrounding terrain in order to determine flow directions. These depressions are owed to several mistakes committed at the DEM construction,

especially at interpolation. This effect can prevent the water outflow and can distort the hydrographical network (Charleux-Demargne 2001).

Flow direction

Flow directions are determined using the D8 algorithm. This one takes into account the eight neighbouring cells of the considered point and computes the maximal difference between the central cell and its eight neighbours. Consequently, the flow direction of every cell will be defined according to the direction of the strongest determined slope. The flow directions obtained are represented in Fig. 4a.

Flow accumulation

With the matrix used for determining flow direction, it is possible to compute its flow accumulations. Upstream cells drain to a given cell. Drainage area at a given cell is computed by multiplying the flow accumulation value by the cell area (Fig. 4b).

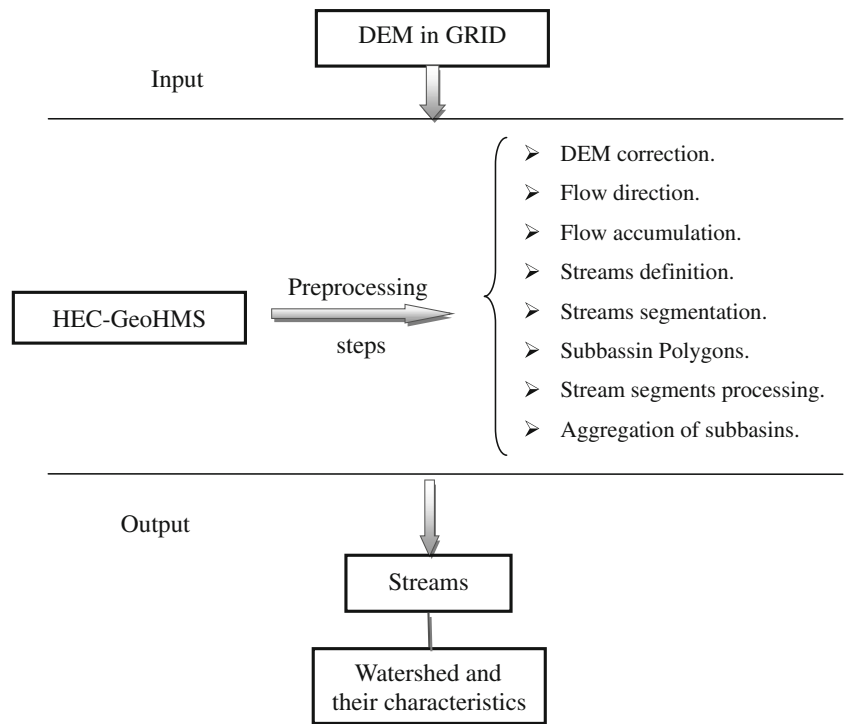
Stream definition and segmentation

To determine where the flow of the water is going, the present method uses a defined threshold. Cells with high flow accumulation, greater than a predefined threshold value, are considered part of a stream network.

After several iterations, we chose a threshold of 630 km² for the following reasons:

- The sub-basin number must be appropriate to simplify their corrections (subdivision and merge).
- Upstream sub-basin aggregation should be made easily to delineate the Macta watershed.

Fig. 3 DEM preprocessing steps



Streams are then subdivided into segments. These stream segments join two successive junctions or a junction and an outlet.

Sub-basin delineation

Here, sub-basins or watersheds are delineated for every stream segment. From direction flow and stream segments GRID, the topographic watersheds are delineated since only elevation is used. Sub-basins and stream segments obtained into GRID format can be transformed into a vector representation (Fig. 5).

Sub-basin aggregation

Sub-basins are aggregated in every stream confluence. This stage allows drawing interactively sub-basins and saving the obtained data (Fig. 6).

Extraction of hydrologic model required information

Once the terrain preprocessing is over, we can do the information extraction required from the already obtained database.

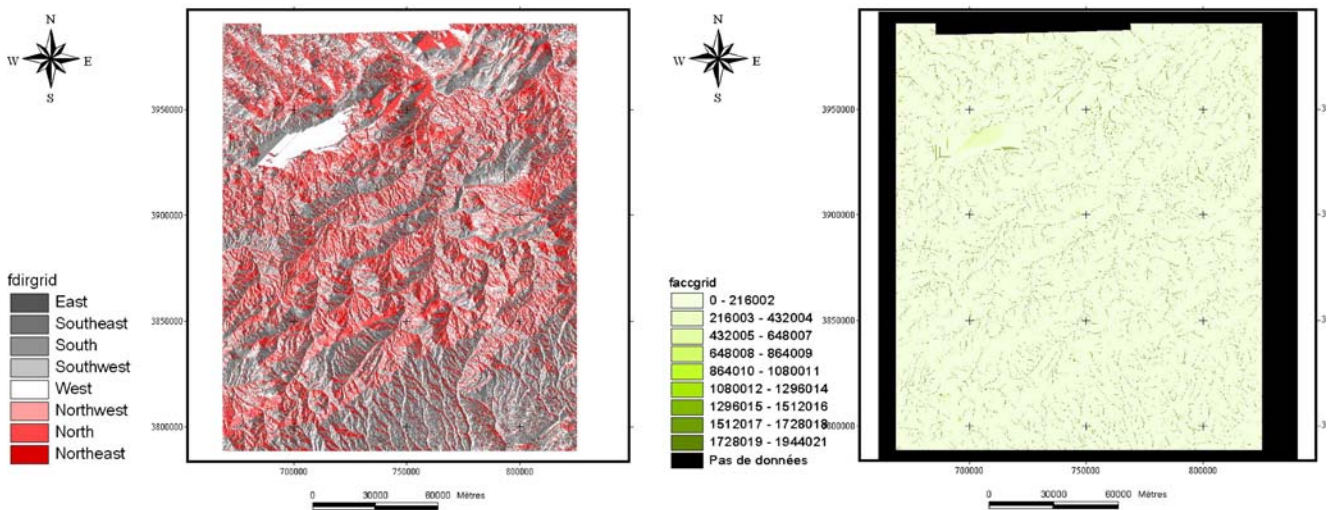
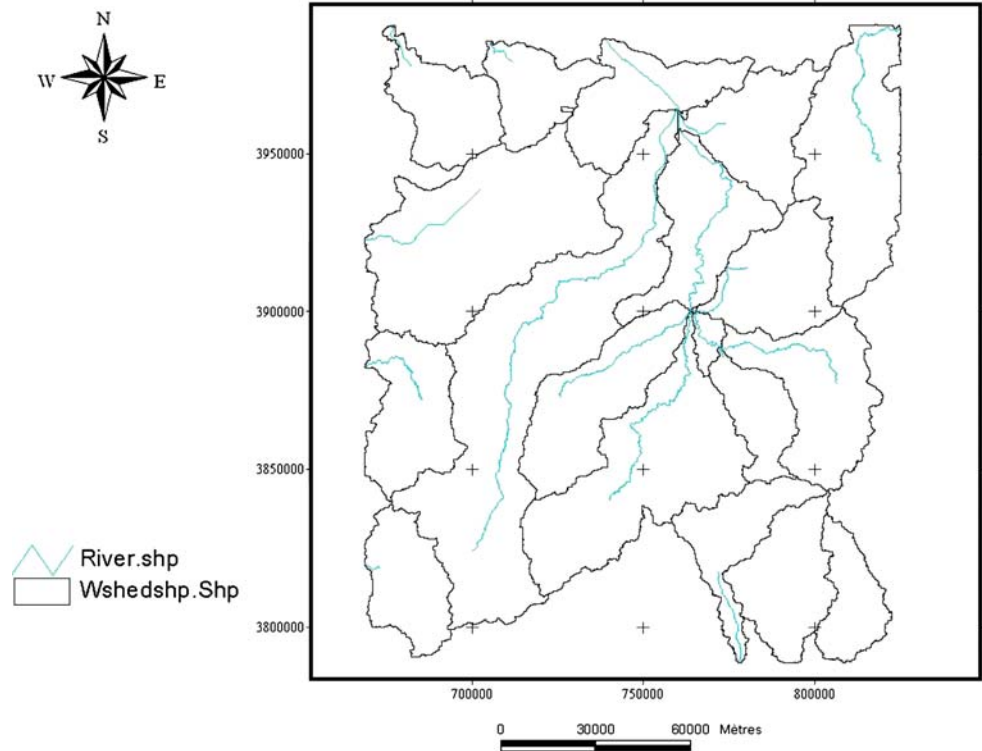


Fig. 4 Flow direction and accumulation

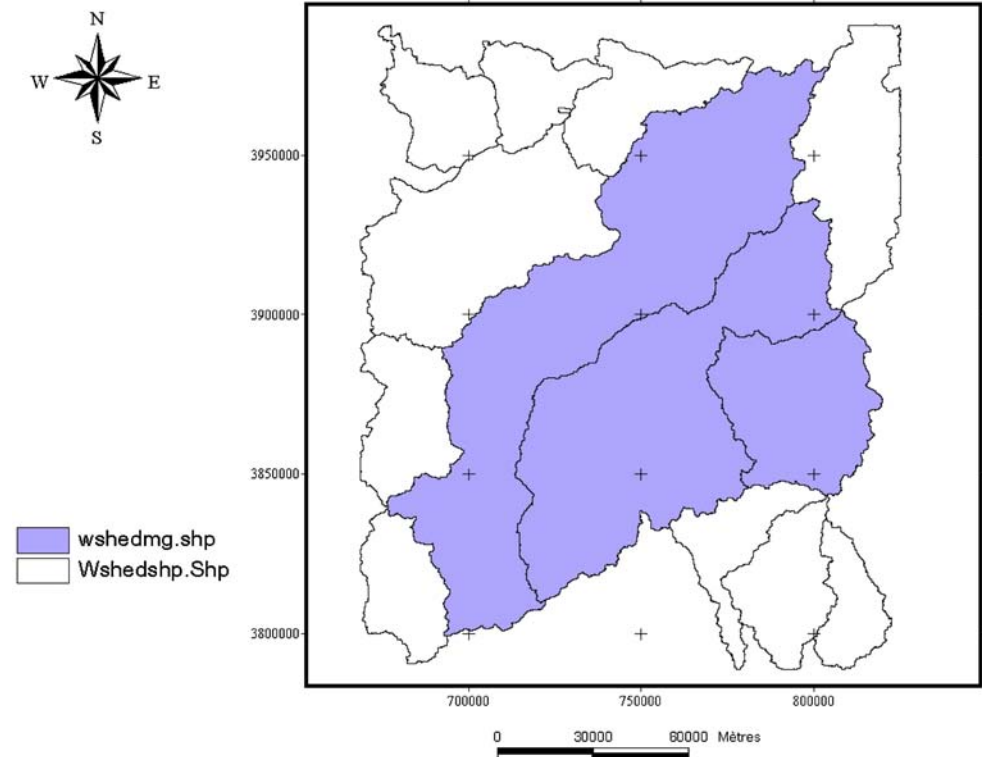
Fig. 5 Vector representation of sub-basin and stream segments



Main elements of watershed

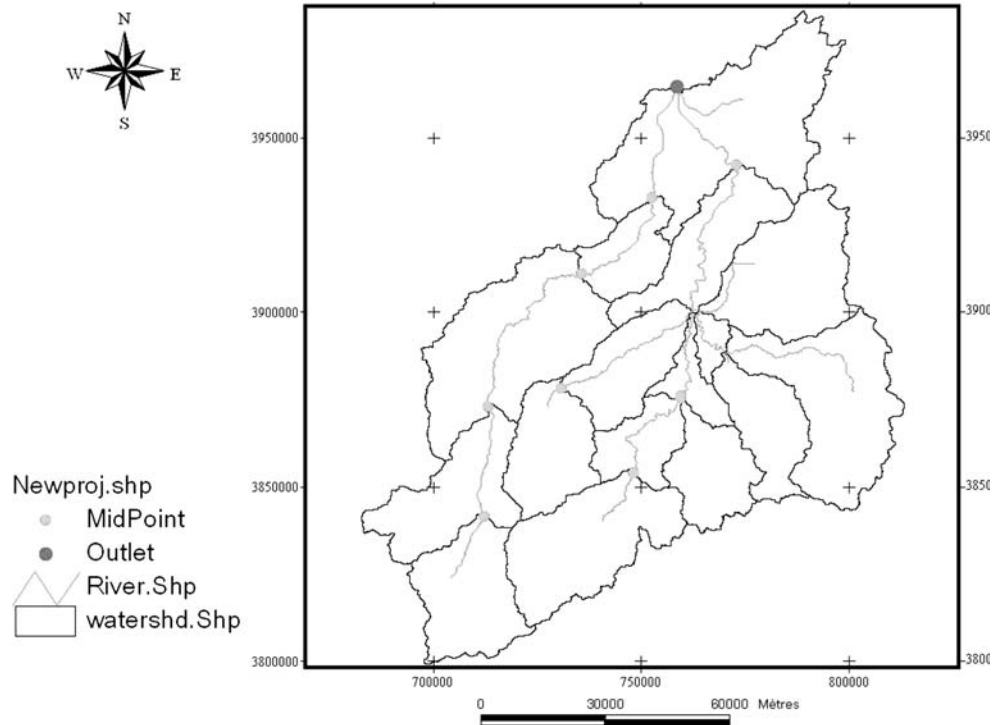
Sub-basins, reaches and junctions constitute the main elements of the watershed. To establish these elements, it is necessary first to choose the outlet of Macta watershed

Fig. 6 Sub-basin aggregation



(Fig. 7). We should note here the role of the topographic map that gave us an idea of where the Macta watershed is from and the place its outlet is situated. The used method called, “original stream definition”, allowed creating our study area. A new project is formed taking into consideration

Fig. 7 Sub-bassins merge



only the study zone (Macta watershed). The new results required for the following steps of the project are related to the study zone only (Fig. 7).

HEC-GeoHMS gives the possibility to update sub-basins and streams. It allows merging or subdividing them. Using the “basin subdivision on existing stream” method and taking into account the data already published by the National Agency of

Hydraulic Resources (ANRH), it is possible to define the cross point of published watershed and the existing streams and therefore to create new sub-basins.

Once sub-basins are corrected, we can compare between the results obtained in this work and data already published by ANRH. It concerns the polygons and the hydrographical network of sub-basins (Fig. 8).

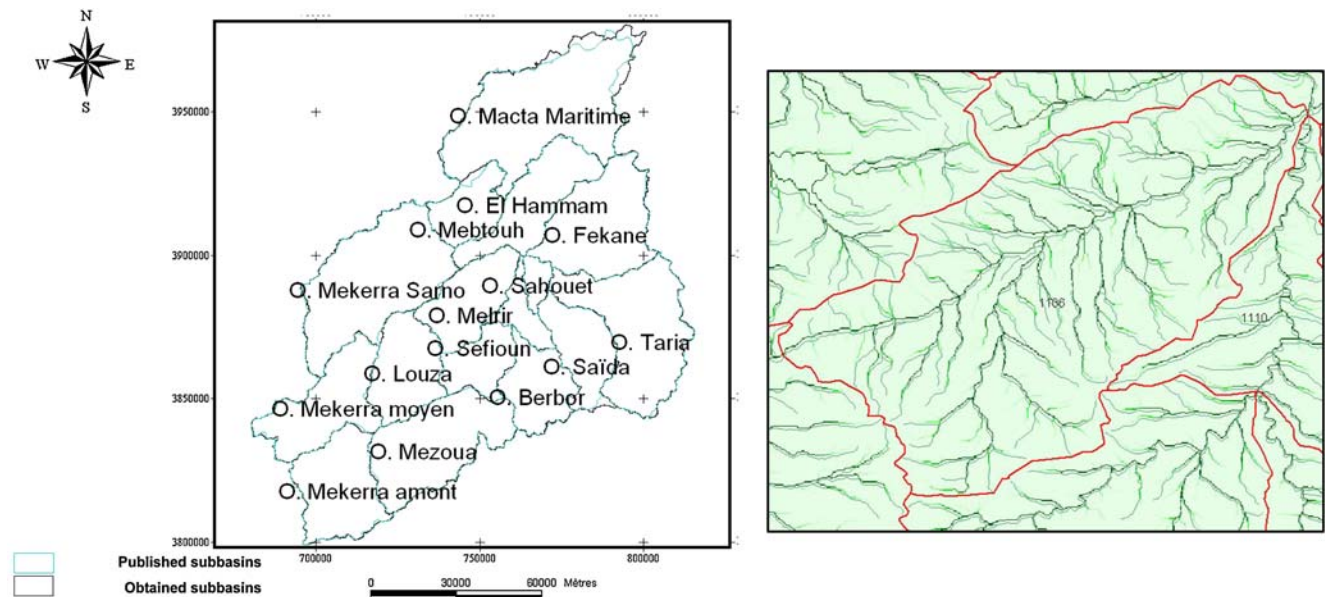


Fig. 8 Comparison between project results and published data

Table 1 Stream and sub-basin physical characteristics

	Physical characteristics
Stream	Length
	Upstream elevation
	Downstream elevation
	Slope
	Stream profile
Watershed	Area
	Centroid location
	Centroid elevation
	Longest flow path
	Longest flow length
	Upstream elevation
	Downstream elevation
	Slope between endpoints
	Slope between 10–85%
	Centroidal path
	Centroidal length

Physical characteristics of Macta watershed

Stream and sub-basin physical characteristics which are determined by HEC-GeoHMS and saved in attributed tabular allow estimating the main parameters required to hydrologic models, mentioned in the following Table 1.

The main obtained values are presented in Tables 2 and 3.

Table 2 Main physical characteristics of sub-basins

Code	Name	Area (km ²)	Perimeter (m)	Centroid elevation (m)	Stream slope	Centroidal length (km)	Watershed slope
1116	O.Macta Maritime	2,097.29	398.53	101	0.006	13.95	5.04
1115	O.El Hammam	856.46	232.10	339	0.008	33.63	12.92
1112	O.Taria	1,466.41	295.97	1,086	0.007	63.39	7.87
1114	O.Fekane	1,202.99	227.78	664	0.009	39.10	5.1
1113	O.Sahouet	140.41	79.88	519	0.011	15.74	6.2
1111	O.Saida	643.89	192.52	901	0.01	35.49	9.04
1106	O.Melrir	703.56	168.95	587	0.011	29.14	6.29
1110	O.Hounet	262.40	140.34	625	0.015	27.46	7.8
1101	O.Makerra amont	932.95	199.89	1,174	0.009	30.40	4.43
1102	O.Makerra moyen	938.47	232.64	1,009	0.013	35.39	8.63
1103	O.Makerra Sarno	1,747.06	288.60	595	0.009	44.25	4.51
1104	O.Mebtouh	495.55	140.88	332	0.015	21.14	11.04
1107	O.Mezoua	1,257.58	244.52	1,126	0.009	31.22	5.97
1105	O.Louza	758.05	166.97	845	0.011	21.80	6.49
1109	O.Berbor	613.08	178.66	894	0.013	32.52	7.24
1108	O.Sefiou	461.91	143.76	912	0.013	34.86	5.76

Hydrological parameters of Macta watershed

From streams and sub-basin physical characteristics, HEC-GeoHMS allows estimating some hydrologic parameters. It will be used with hydrologic modelling. Among these parameters are:

- Sub-basin CN: This parameter is used to estimate the surface flow based on the soil type and the land use (Mendas et al. 2008).
- Concentration time: estimated by the TR55 method (technical release) of the Natural Resources Conservation Service (NRCS).
- Sub-basin lag time: estimated in two stages; the first one consists in computing a slopes grid of the watershed (Fig. 9), and the second one consists in estimating the lag time by the curve number method of the NRCS.

Main obtained hydrological parameters are illustrated in Table 4.

Macta watershed schematic

As soon as sub-basins and extracted basic topographic characteristics are delineated, the watershed schematic can be built for a possible hydrologic model use. Here, sub-basins are represented by points, whereas streams are represented by linear segments linking these points. The connectivity between points and links are established by a hydrological network elements built from upstream to

Table 3 Main physical characteristics of streams

Code	Name	Stream length (km)	Upstream elevation (m)	Downstream elevation (m)	Stream slope
1116	O.Macta Maritime	0.064	86.00	86.00	0.0000
1116	O.Macta Maritime	1.821	87.00	86.00	0.0005
1116	O.Macta Maritime	19.759	87.00	87.00	0.0000
1116	O.Macta Maritime	34.107	109.00	87.00	0.0006
1115	O.El Hammam	0.704	391.76	381.00	0.0153
1115	O.El Hammam	1.970	394.47	381.00	0.0068
1114	O.Fekane	29.584	524.00	394.47	0.0044
1113	O.Sahouet	24.604	514.00	394.47	0.0049
1111	O.Saida	4.004	536.00	514.00	0.0055
1112	O.Taria	55.827	809.00	514.00	0.0053
1106	O.Melrir	51.336	664.00	391.76	0.0053
1110	O.Hounet	34.303	592.00	391.76	0.0058
1116	O.Macta Maritime	37.551	152.00	86.00	0.0018
1101	O.Makerra amont	22.220	1,118.00	996.00	0.0055
1101	O.Makerra amont	0.127	1,008.65	996.00	0.0995
1102	O.Makerra moyen	37.672	996.00	719.00	0.0074
1103	O.Makerra Sarno	67.995	719.00	393.32	0.0048
1104	O.Mebtouh	39.774	393.33	152.00	0.0061
1107	O.Mezoua	21.754	982.00	836.00	0.0067
1105	O.Louza	8.441	702.00	664.00	0.0045
1109	O.Berbor	0.577	600.00	592.00	0.0139
1108	O.Sefioun	44.372	836.00	600.00	0.0053
1115	O.El Hammam	65.693	381.00	109.00	0.0041

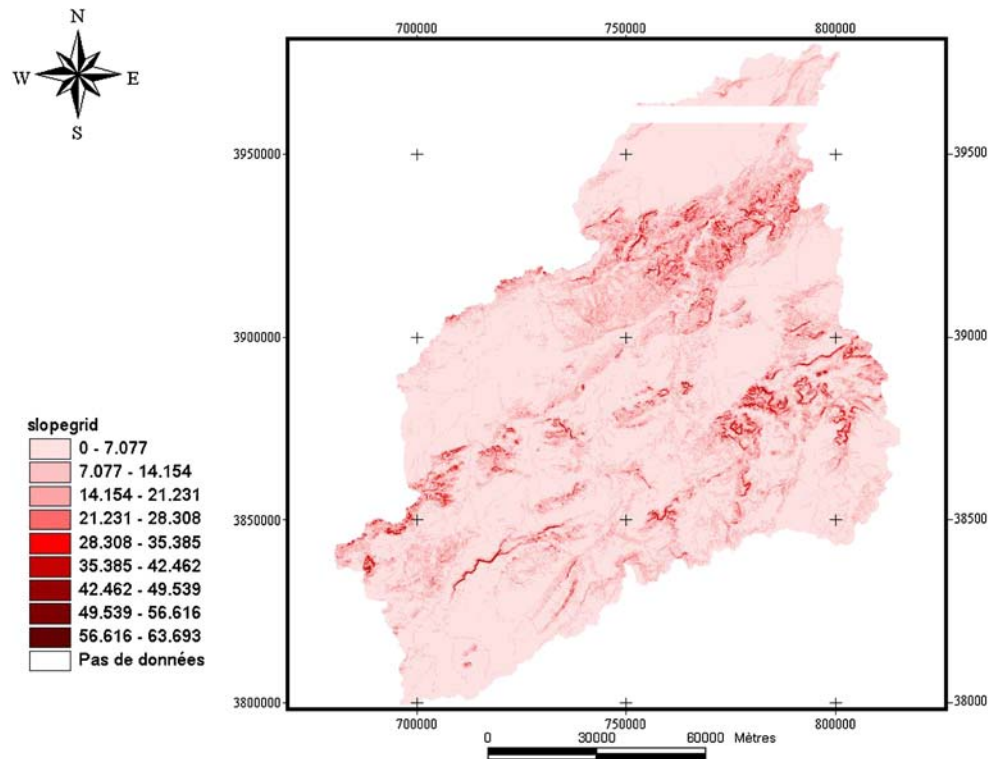
Fig. 9 Macta watershed slopes

Table 4 Main sub-basin hydrologic parameters

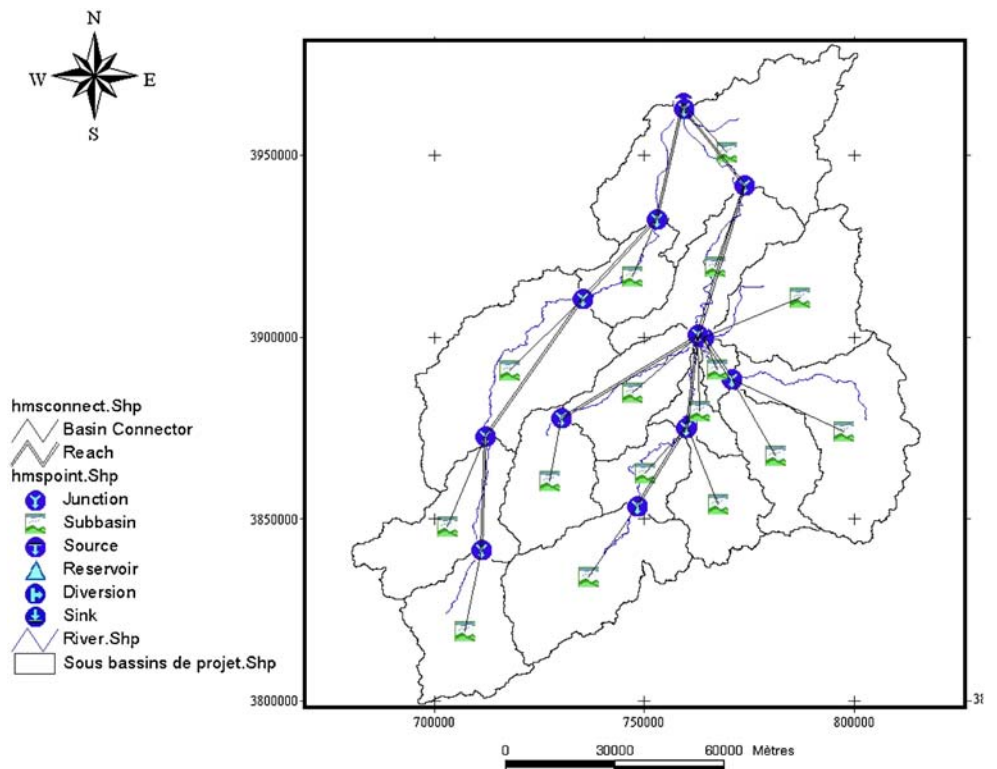
Code	Name	CN	Rainfall 2years (mm/24h)	Lag basin (h)	Concentration time (h)
1116	O.Macta Maritime	85	0.453	9.958	16.597
1115	O.El Hammam	88	0.694	6.218	10.363
1112	O.Taria	90	0.700	8.705	14.508
1114	O.Fekane	86	0.694	9.515	15.858
1113	O.Sahouet	90	1.051	3.893	6.488
1111	O.Saida	85	0.874	7.251	12.085
1106	O.Melrir	85	0.847	7.351	12.252
1110	O.Hounet	90	0.640	4.647	7.745
1101	O.Makerra amont	90	0.469	7.278	12.130
1102	O.Makerra moyen	85	0.612	7.237	12.062
1103	O.Makerra Sarno	91	0.612	9.764	16.273
1104	O.Mebtouh	90	0.858	3.819	6.365
1107	O.Mezoua	82	0.469	9.956	16.593
1105	O.Louza	92	0.847	4.795	7.992
1109	O.Berbor	91	0.874	4.919	8.198
1108	O.Sefioun	90	0.558	5.792	9.653

downstream. Hydrologic element connectivity and related geographic information are captured in an ASCII text file that can be read by hydrologic model as basic data (Puech et al. 2004). Figure 10 shows the HMS Macta watershed schematic. It is the representation of hydrologic model of the watershed and its elements (reaches, junctions, etc.) and their connectivity.

Conclusion

Macta watershed and its sub-basins have been automatically delineated, the hydrographical network has been extracted, and some physical characteristics and hydrologic parameters have been estimated. All these data are saved in a databank useful for a hydrologic modelling. The time gain was of a

Fig. 10 Hydrologic elements of sub-basins and streams



great importance since a manual extraction is long and can be submitted to mistakes. The results of the physical elements, particularly the sub-basins and the hydrographical network, determined in this survey can be considered satisfactory. Previously delimited sub-basins were not exactly the same as those already published, but thanks to the functions by HEC-GeoHMS tools, the update is efficient, very flexible and in very fast manners. Results sharpness depends on the resolution and the quality of the used DEM and of the threshold predefined during data processing. However, the SRTM data with a resolution of 90 m can be considered as reliable for big watershed hydrologic studies. As for estimated hydrologic parameters, they can be valorised after the hydrologic model execution. It is therefore important to note that the obtained results are not definitive but remain experimental. The watershed is schematised in a manner to be used by a hydrologic model that, once the necessary data are available, can do hydrologic simulations. HEC-GeoHMS offered us the better possibility to exploit the geographical information stored in the GIS.

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