Journal of Water Sciences & Environment Technologies

Cit this: *JOWSET, **2019** (04), N°01, 480-490*

Application of GIS to study the physiographic factors and the water resources in the watersheds of Essaouira, Morocco

Zakaria Ouzerbane[1*], Mostafia Boughalem[2], Abdellah El Hmaidi[1], Tahar Aïfa[3], Ali Essahlaoui[1], Abdelhadi El Ouali[1], Abdessamad Najine[4], Fadwa Redouani[4], Amina Wafik[5]

[1] Water Science and Environmental Engineering team, Department of Geology, Faculty of Science, Moulay Ismail University, BP 11201, Zitoune, Meknes, Morocco.

[2] Ctr Univ Ain Temouchent, Laboratory of Applied Hydrology and environment/DGRSDT, BP 284- 46000 Ain Temouchent, Algeria.

[3] Univ Rennes, CNRS, Géosciences Rennes - UMR 6118, Bat. 15, Campus de Beaulieu, F-35000 Rennes, France.

[4] Department of Earth Sciences, Faculty of Science and Technology, Sultan Moulay Slimane University, BP 523 Mghila, 23000 Beni Mellal, Morocco.

[5] Department of Geology, Faculty of Sciences Semlalia Cadi Ayyad University, BP. 2390, 40000 Marrakech, Morocco.

**Corresponding Author: Tel.: +00212 665 473 528; e-mail: ouzerbanegeophy@gmail.com*

Water resources in the area of Essaouira, like other regions of Morocco, have experienced a significant drop in quality and quantity. This situation has led to the reduction of agricultural productivity and the degradation of several ecosystems. Topographic, morphological, hydrographic and climatic characterization and surface geology have influences on the hydrological behavior of the watershed and precisely the flow regime (surface water) and infiltration (underground water). The application of Geographical Information Systems (GIS) made it possible to evaluate the physical factors of the watersheds constituting the western part of Essaouira Basin (Coastal Zone) where the watershed of Ait Tahria presents an elongated form with slight slopes and strong relief, while the slopes are relatively high with strong relief for Qsob and Tidzi watersheds. The results obtained will allow us to say that the physiographic parameters of the watersheds and the geological nature of the saturated zone and the unsaturated zone have an influence on the physical reservoir parameters of the region. This influence is remarkable at the NE portion of the Ait Tahria basin, known for its low slope, large drainage area and Cretaceous (marl and marl-limestone) geological formations where the value of the conductivity Underground water is very high. This salt and mineralized water exceeds the standards of potability.

Received: 16 January 2019
Accepted: 01 November 2019
Available online: 31 December 2019

Keywords:
Essaouira Basin
GIS
Mineralized water
Water resource
Physiographic parameter
Hypsometric curve

1. Introduction

The regular supply of water is one of the great challenges of humanity in the world, in the coming decades. This water crisis is aggravated by the dynamic interaction of several processes acting at the local, national and global levels [1].

In Morocco, the scarcity of water resources is not an exceptional concept. It stems from the peculiarities of the geographic and climatic context of the region. The various processes mentioned above exacerbate the problems of availability of this resource in quantity and quality. This will accentuate the tension between supply and demand and point to extreme situations in the near future. Due to its geographical location, Morocco is subject to various climatic influences varying from North to South under the effect of latitude and from West to East under the effect of the continentality. Rainfall is characterized by extreme irregularity that manifests itself in one year and from one year to the next. This irregularity is much more marked south of the Atlas range.

Faced with these problems, it is necessary to put in place mechanisms and actions aimed at the recognition, preservation and safeguarding of water resources.

The Essaouira Basin represent the study area, which is part of the Moroccan Atlantic coastline. It is a space that is given a heavy responsibility in the socio-economic development of the country. This development implies a significant increase in water needs in the coming years for both drinking water supply and for irrigation and industry.

The study of the physical characteristics of the three watersheds constituting the western part of the Essaouira basin is essential for the evaluation of water resources because they have an influence on the behavior and the hydrological response of the watersheds, and precisely the regime flows during flood or low water periods. The topographic, morphological, hydrographic and climatic characterization of the watersheds in the study area was carried out using Geographic Information Systems (GIS).

2. Materials and methods

2.1. Presentation of the study area

Essaouira synclinal study area is generally low, especially near Essaouira; it is part of the coastal area of the basin with an area of 1418 km^2. It is limited to the North by Jbeb Hadid, to the South by Tidzi river, to the East by the reliefs of Chiadma from the South and Haha from the North and by the Tidzi slide and to the West by the Atlantic Ocean. It is not very hilly and is characterized by low hills with altitudes between 0 and 800 meters, modeled by a low-density hydrographic network that flows into the Atlantic Ocean [2]. From North to South, two units can be distinguished namely the South Chiadma Unit and the North Haha Unit (Fig. 1).

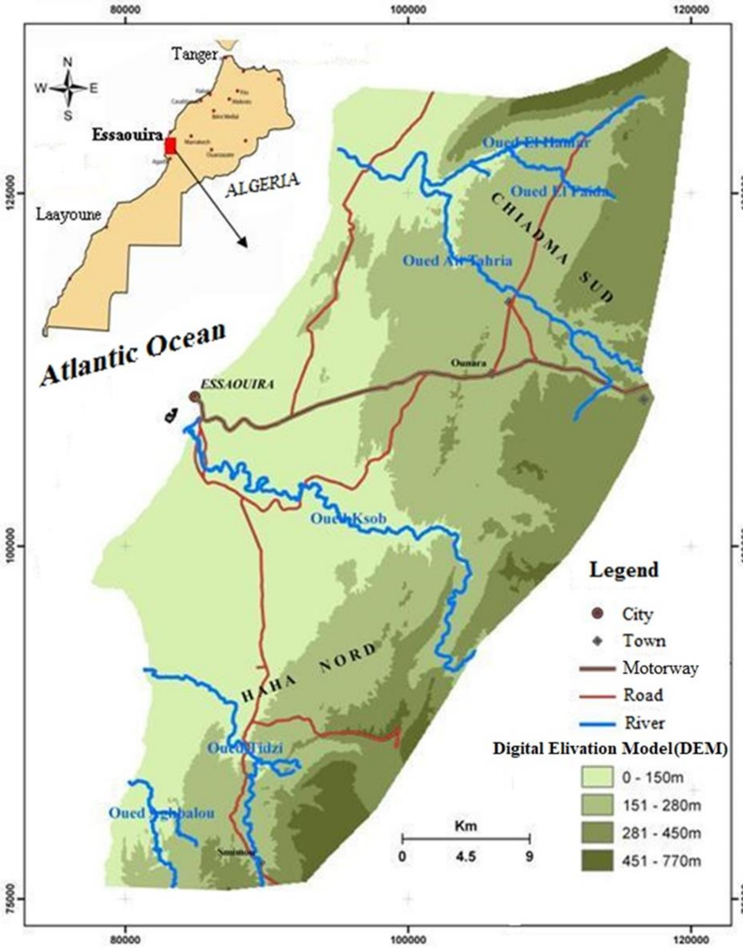

Fig. 1: Geographic location and DEM of the study area.

2.2. Hydrography of the study area

The Essaouira basin is crossed by a set of watercourses of unequal importance due to the scarcity of surface water and their origins. Three main rivers cross the study area (Fig. 2).

The Ait Tahria river which crosses the watershed of Ait Tahria and takes birth in the surrounding hills and in the anticline of Jbel Hadid. It is less important, does not have a hydro-climatic station, and only works in the rainy season.

The Tidzi river crosses the Tidzi watershed, and originates at Tidzi's diapir, it has no hydro-climatic station.

The Qsob river crosses the Qsob watershed, it is the confluence of the Igrounzar river and Zeltene river cross successively the sub-basins of Igrounzar and Zelten [3].

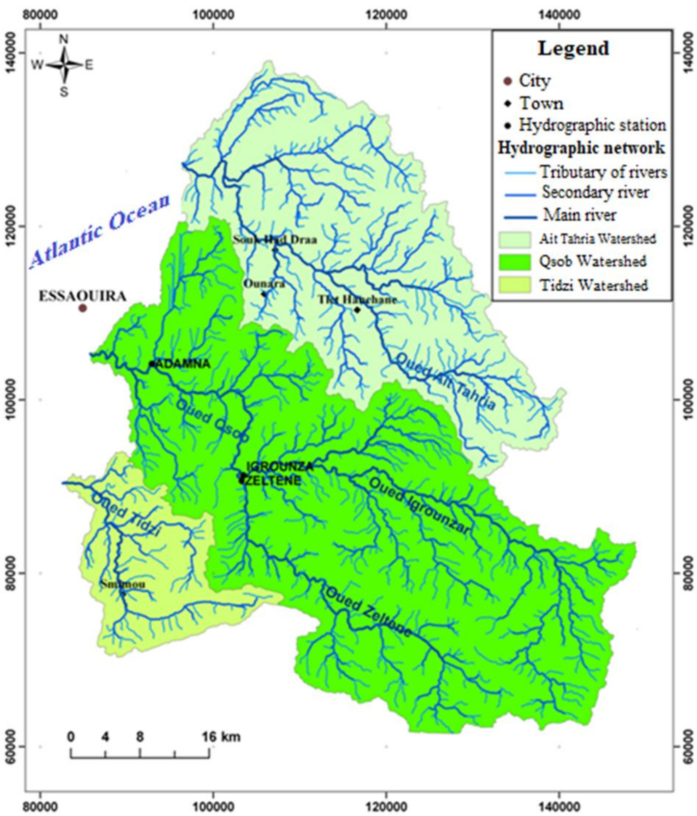

Fig. 2: Watersheds and hydrographic networks of the study area (Ouzerbane 2015).

2.3. *Geological situation of the study area*

The geological formations flush in the synclinal zone of Essaouira are generally of quaternary and plio-quaternary age (Fig.3). From the south to the north of the study area, the stratigraphic series extends from the Triassic to the Quaternary [3].

2.3.1. Triassic formations

They are outcropping in the South-Eastern part of the study area in the Tidzi region in a NE-SW direction forming the Tidzi diapir over a large area while in the extreme south of the study area, these formations outcrop on a smaller area along Aghbalou river. Saliferous red clays, doleritic basalts and reddish sandstone pelites mainly know these formations.

2.3.2. Jurassic formations

Mainly gypsiferous limestones and marl-limestones dating from the Upper Jurassic Jbel Hadid north of the syncline of Essaouira form them.

2.3.3. Cretaceous formations

They are outcropping on the entire Essaouira basin with thicknesses varying from one place to another. In the study area, the Cretaceous is exposed to the east by gray marls and lumachellic limestones of Senonian age, turquoise limestone dolomitic limestones, limestones, marls and gypsiferous marls of the Cenomanian along Oued Tidzi. To the west, the outcrops of Albien correspond to green marl surmounted by dolomitic limestones of Maestrichtian age. Lower Cretaceous formations are also exposed to the NW of the study area.

2.3.4. Quaternary and Plio-Quaternary formations

They constitute the main outcrops in the study area. From the center of the area to the Atlantic coast to the west, the sand dunes and calcarenites become important in terms of area and thickness. The Quaternary Plio is almost flush over the entire study area by sandstones, fine sands, yellow limestones and conglomerates.

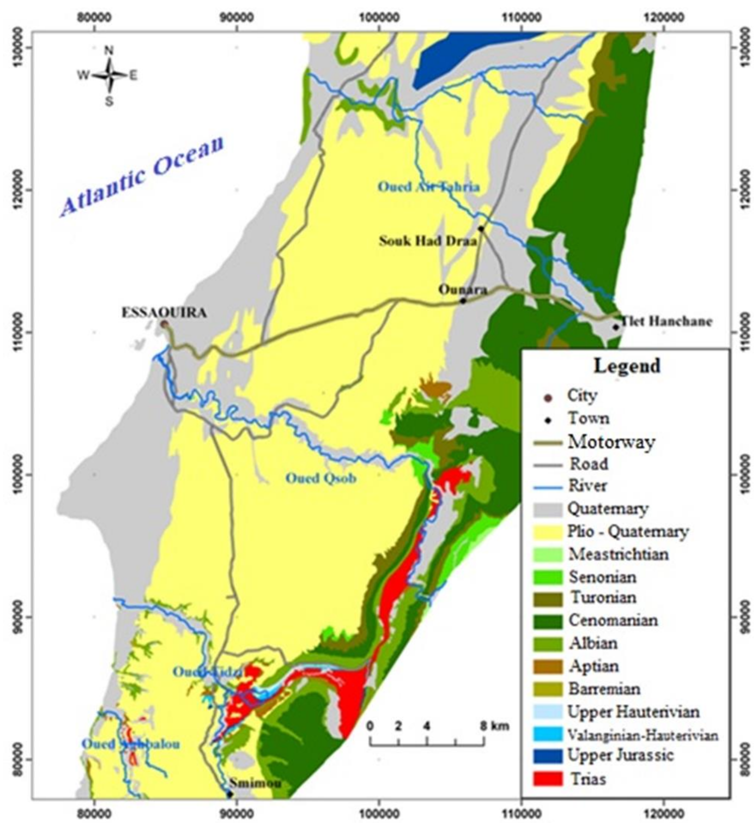

Fig. 3: Geological map of the coastal zone of Essaouira [3].

2.4. Hypsometry of watersheds in the study area

The relief of a watershed is very important in their hydrological behavior, it influences the runoff, the infiltration and the evaporation, because many hydroclimatic parameters vary with the altitude and the morphology of the basin. The study area is composed mainly of 3 watersheds namely:

- Watershed of Ait Tahria river.
- Watershed of Qsob river.
- Watershed of Tidzi river.

2.5. Compactness index Kc

The compactness index Kc (Gravelius compactness index) or shape index, provides information on the shape of the watershed which has a great influence on the overall flow of

the watercourse and especially on the shape of the hydrograph at the outlet of the basin, resulting from a given rain. This so-called Gravelius coefficient is defined as the ratio of the perimeter P of the basin to that of a circle of the same surface S. It is expressed by the following formula [4, 5]:

$$K_c = \frac{P}{2\sqrt{\pi S}} = 0{,}28\ \frac{P}{\sqrt{S}}$$

Where:
Kc: Gravelius compactness index
P: Perimeter in km of the watershed.
S: Area of the catchment area in km2.
It is close to one (1) for a watershed of almost circular shape and greater than 1 when the basin is of elongated shape. A circular watershed is better drained than an elongated basin.

2.6. Equivalent rectangle

The equivalent rectangle or rectangle of Gravelius corresponds to a purely geometric transformation of the watershed. It then takes a rectangular shape while keeping the same characteristics. In this case, the contours become parallel to the sides of the equivalent rectangle. Climatology, soil distribution, vegetation cover and drainage density remain unchanged between contours.
The equivalent rectangle is a rectangle of length L and width l, having the same perimeter P and the same surface S as those of the basin. The longer an equivalent rectangle is elongated, the less it will be drained [4, 5]. The dimensions of the equivalent rectangle are determined by the following formulas:

$$L = \frac{K_c\sqrt{S}}{1{,}12}\left(1 + \sqrt{1 - \left(\frac{1{,}12}{K_c}\right)^2}\right)$$

$$l = \frac{K_c\sqrt{S}}{1{,}12}\left(1 - \sqrt{1 - \left(\frac{1{,}12}{K_c}\right)^2}\right)$$

Where:
L: Length of the equivalent rectangle in km.
l: Width of the equivalent rectangle in km.
Kc: Gravelius compactness index.
S: Watershed area.

2.7. Average slope (Pmean)

For the calculation of the average slope of a watershed, only the length L of the equivalent rectangle is needed thanks to the following formula:

$$P_{mean} = \frac{\Delta h}{L}$$

Where:
P_{mean}: Average slope in m / km
Δh: altitude difference $\Delta h = Alt_{max} - Alt_{min}$
L: Length of the equivalent rectangle.

2.8. Roche slope index (I_p)

It's defined as the sum of the square roots of the average slopes of each elemental fraction between two successive level curves weighted by the area considered, the Roche slope index I_p is calculated by the following formula [4, 6]:

$$I_p = L^{-1/2} \sum_i \sqrt{\frac{S_i}{S_T}(d_{i+1} - d_i)}$$

Where:
I_p: Roche slope index.
L: Length of the equivalent rectangle.
$(d_{i+1} - d_i)$: Difference between two contour d_{i+1} and d_i
S_i / S_T: Fraction of the total area between the d_i and d_{i+1} coasts

2.9. Global slope index (I_G)

The global slope index I_G is defined as the ratio of the difference in elevation (useful difference) between the altitudes of $H_{5\%}$ and $H_{95\%}$, between which 90% of the area of the watershed falls, and the length L of the rectangle equivalent. The global slope index I_G expressed by the following formula [4, 7]:

$$I_G = \frac{D_u}{L} = \frac{H_{5\%} - H_{95\%}}{L}$$

Where
D_u: Useful elevation.
L: Length of the equivalent rectangle.
$H_{5\%}$ and $H_{95\%}$ are determined from the hypsometric altitude curve.

2.10. Specific difference (D_S)

The specific height difference does not depend on the area as the overall slope index but it depends on the hypsometry ($D_u = H_{5\%} - H_{95\%}$) and the shape of the watershed (l/L). The specific height difference is expressed by the following formula [4, 8]:

$$D_S = I_G\sqrt{S} = \frac{D_u}{L}\sqrt{Ll} = D_u\sqrt{\frac{l}{L}}$$

Where:
D_u : useful (global) unevenness.
L: Length of the equivalent rectangle.
l: Width of the equivalent rectangle.
The specific height difference (DS) gives the classification of relief (Tab. 1) according to the classification of ORSTOM (Office of Scientific and Technical Research Overseas), independent of watershed surfaces [8].

Tab 1: Classification of the reliefs by the specific height difference D_S

Interval of the D_S (m)	Type of relief
D_S <10	very low
10m < D_S < 25	low
25m < D_S < 50	rather low
50m < D_S <100	moderate
100m < D_S < 250	rather high
250m < D_S < 500	high
D_S > 500	very high

.

2.11. Length of the main watercourse (LMW)

Length of the main watercourse LMW is the length between the outlet and the watershed ridge of a watershed. It is expressed in km and measured along the segment of the highest order watercourse up to the watershed. At the junctions, if we meet segments of the same order in this case we follow the segment that drains the largest area.

2.12. Density of drainage (D_d)

It corresponds to the ratio of the total length L of a river of any order on the total surface S of a watershed. The drainage density D_d is expressed by the following formula:

$$D_d = \frac{\sum L}{S}$$

3. Results and discussion

3.1. Hypsometry of the watershed of Ait Tahria

The altitudes of the watershed of Ait Tahria river (Fig. 4) vary between 9 m at the outlet towards the Atlantic Ocean and 794 m at the furthest point. The hypsometric curve gives the distribution of altitudes relative to the areas they occupy (Fig. 5), it is obtained by the systematic planning of the areas delimited by two level contours in a watershed (Tab. 2).

The analysis in Table 2 shows that the most frequent altitude for the Ait Tahria watershed is between 400 and 500 m with an area of 235 km².

The shape of the hypsometric curve reflects the state of maturity of the relief and its erosive capacity [9]. The curve drawn for the Ait Tahria watershed shows an 'S' shape, with a slight slope (Fig. 5).

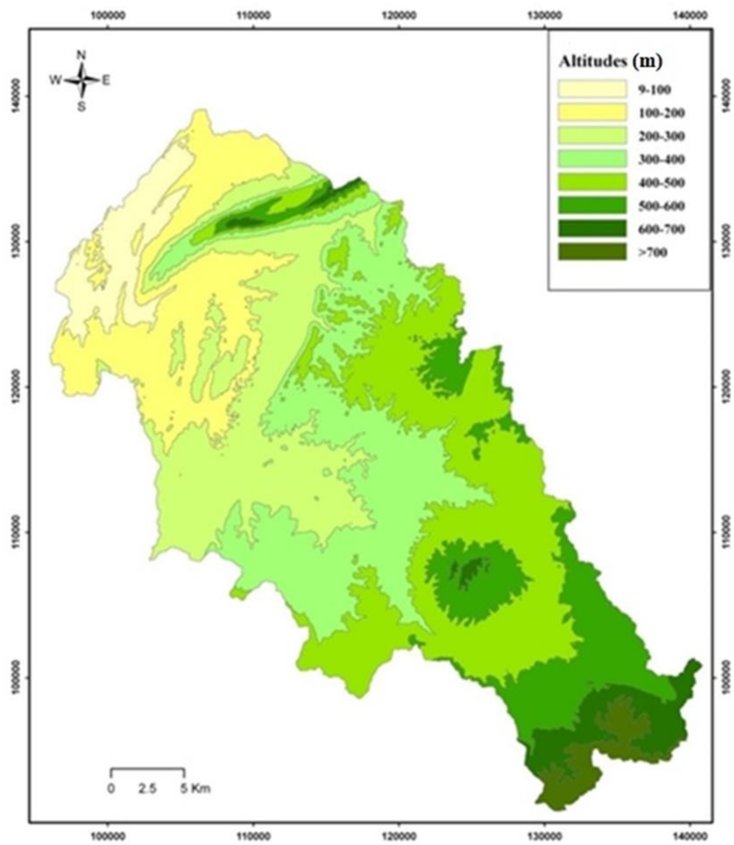

Fig. 4: Hypsometric map of the watershed of Ait Tahria.

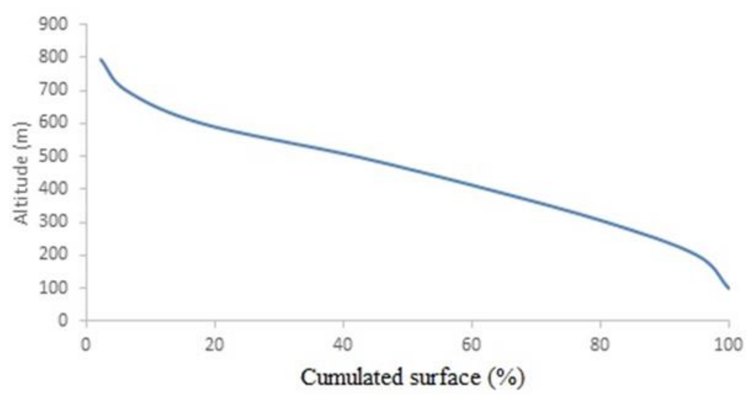

Fig. 5: Hypsometric curve of the Ait Tahria watershed.

Tab 2: Classification of the reliefs by the specific height difference DS.

Areas	Altitude (m)	Area (km^2)	Frequency (%)	Cumulated surface (%)
S1	9 - 100	48	4,91	100
S2	100 - 200	137	14,01	95,09
S3	200 - 300	181	18,51	81,08
S4	300 - 400	201	20,55	62,58
S5	400 - 500	235	24.03	42,02
S6	500 - 600	115	11,76	18,00
S7	600 - 700	39	3,99	6,24
S8	> 700	22	2,25	2,25
Total		978	100	

3.2 Hypsometry of the Qsob watershed

The altitudes of the watershed of Qsob river (Fig. 6) vary between 6 m at the outlet to the Atlantic Ocean and 1703 m in the farthest part at the level of the High Atlas. The results of systematic planning of the areas delimited by two contoured level curves are summarized in Table 3.

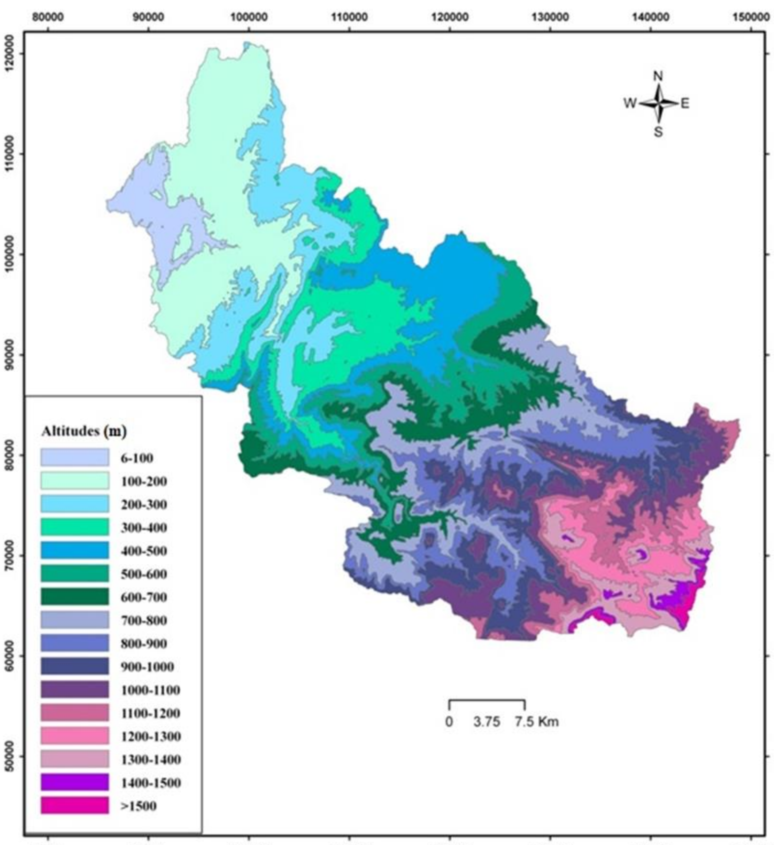

Fig. 6: Hypsometric map of the Qsob watershed

The analysis in Table 3 shows that the most frequent elevation for the Qsob watershed is between 100 and 200 m with an area of 235 km², or almost 14% of the total area of the Qsob watershed. From this table, I draw up the hypsometric curve relative to the watershed (Fig. 7), its shape reflects the state of maturity of the relief and its erosive capacity, the curve drawn for the catchment of Qsob shows that the relief is in steady state, with a steep slope at high altitudes and low at low altitudes.

Tab 3: Hypsometry of the Qsob watershed.

	Altitude (m)	Area (km²)	Frequency (%)	Cumulated surface (%)
S1	6 - 100	57	3,30	100
S2	100 - 200	235	13,62	96,70
S3	200 - 300	157	9,10	83,08
S4	300 - 400	147	8,52	73,99
S5	400 - 500	165	9,56	65,47
S6	500 - 600	117	6,78	55,91
S7	600 - 700	137	7,94	49,13
S8	700 - 800	144	8,34	41,19
S9	800 - 900	122	7,07	32,85
S10	900 - 1000	126	7,30	25,78
S11	1000 - 1100	114	6,60	18,48
S12	1100 - 1200	67	3,88	11,88
S13	1200 - 1300	67	3,88	8,00
S14	1300 - 1400	49	2,84	4,11
S15	1400 - 1500	14	0,81	1,27
S16	> 1500	8	0,46	0,46
Total		1726	100	

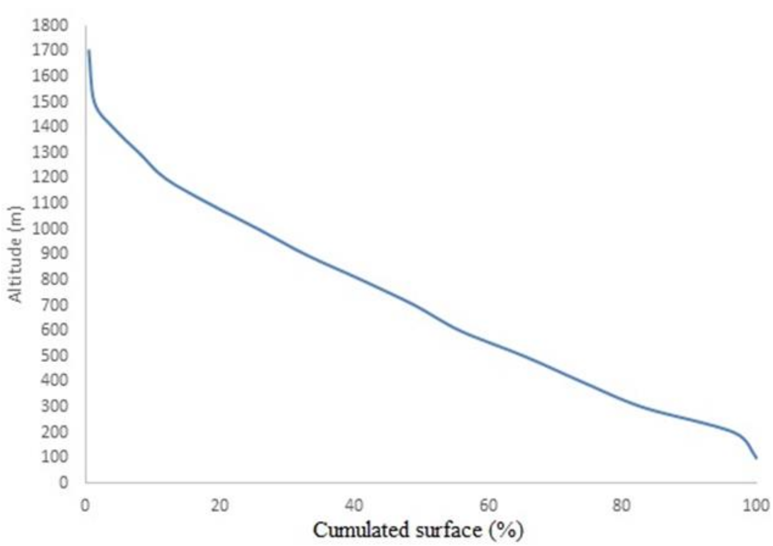

Fig. 7: Hypsometric curve of the Qsob watershed.

The analysis of the hypsometric map (Fig. 6) shows a spatial distribution of altitudes with their abundances in the catchment, we note that above the altitude class 300-400 m the curves of the altitude intervals presents a certain tightness giving an idea on the slope of relief in this place due to the geology of the region.

3.3 Hypsometry of the Tidzi watershed

The altitudes of the Tidzi watershed (Fig. 8) vary between 4 m at the outlet to the Atlantic Ocean and 905 m at the furthest point at Tidzi's diapir. The systematic planning results of the areas delimited by two contoured contour lines are summarized in Table 4.

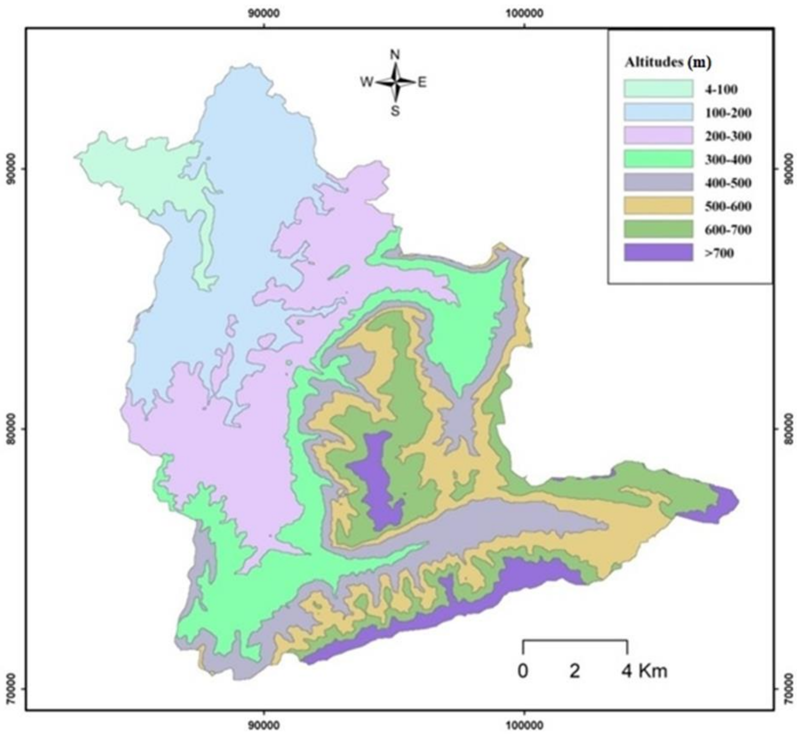

Fig. 8: Hypsometric map of the Tidzi watershed.

The analysis in Table 4 shows that the most frequent altitude for the Tidzi watershed is between 200 and 300 m with an area of 55 km², or almost 20% of the total area of the Tidzi watershed.

Tab 4: Hypsometry of the Tidzi watershed.

Areas	Altitude (m)	Area (km²)	Frequency (%)	Comulated surface (%)
S1	4 – 100	12	4,24	100.00
S2	100 – 200	54	19,08	95,76
S3	200 – 300	55	19,43	76,68
S4	300 – 400	40	14,13	57,24
S5	400 – 500	37	13,07	43,11
S6	500 – 600	40	14,13	30,04
S7	600 – 700	33	11,66	15,90
S8	>700	12	4,24	4,24
Total		283	100	

From this table, the hypsometric curve relative to the watershed (Fig. 9) is drawn, its shape reflects the state of maturity of the relief and its erosive capacity, the curve drawn for the Tidzi watershed shows that the relief is in a state of equilibrium with a steep slope reflects the rapid evolution of the slopes within the watershed.

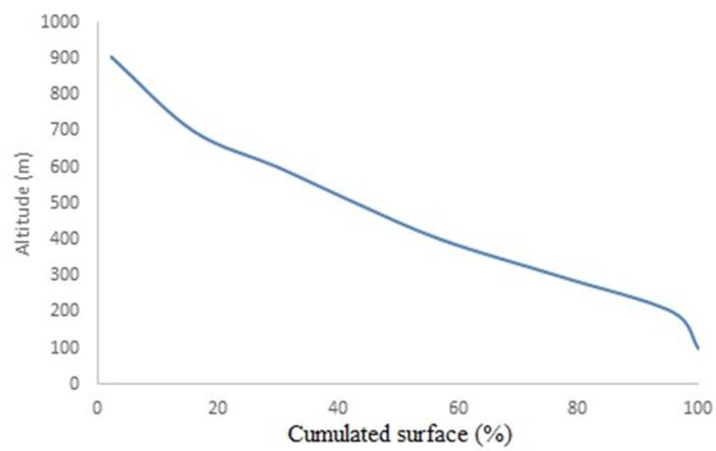

Fig. 9: Hypsometric curve of the Tidzi watershed.

3.4 Physical parameters of watersheds in the study area

The watersheds of the study area are spatially very close, and are very distinct in their physiographic and lithological characteristics and in their hydrological regimes. They have an elongated shape and extend in a principal direction from the South-East to the North-West. The main physiographic characterizations of these basins using the Geographical Information System (GIS) are summarized in Table 5.

Tab 5: physiographic parameters of watersheds of Essaouira.

Parameters	Qsob Watershed	Ait Tahria Watershed	Tidzi Watershed
P (km)	274	202	104
S (km²)	1726	978	283
K_c	1,86	1,82	1,74
L (km)	124,16	91,04	46,29
l (km)	13,90	10,74	6,11
S_{re} (km²)	1726	978	283
P_{re} (km)	276,12	203,56	104,80
Alt_{max} (m)	1703	794	905
Alt_{min} (m)	6	9	4
Alt_{mean} (m)	100,28	99,42	104,28
Alt_{med} (m)	680	480	440
Δh (m)	1697	785	901
P_{mean}	13,67	8,62	19,46
I_p	3,43	2,77	4,16
D_u	1160	520	660
I_g	9,34	5,71	14,26
D_s	388,15	178,63	239,86
LMW (km)	112	73	42
D_d (km/km²)	0,06	0,07	0,15

Finally, The analysis of the results obtained for the calculation of the physical parameters of the watersheds in the study area (Table 5) uses GIS, shows that the three basins have an elongated shape, since their compactness indices Kc is greater than 1. The area the Qsob river watershed is twice that of the Ait Tahria river watershed and six times that of the Tidzi river watershed. The altitude difference, generally greater than 785 m and close to 1697 m, reflects a relatively rugged morphology, with a very steep slope for Qsob and Tidzi respectively of the order of 13,63 % and 19,46% and very low for Ait Tahria of the order of 8,62%. The elongated shape and relatively steep slopes of the Qsob and Tidzi watersheds and their tributaries and the low permeability outcrops (Marls and marl-limestones) are all parameters that give the flows a torrential and muddy character and provide an environment conducive to floods [10].

The calculation of the specific height difference Ds makes it possible to classify the relief of the watershed according to the OSTROM classification. Thus, the two watersheds of Qsob and Tidzi belong to the category of strong relief, on the other hand the watershed of Ait Tahria belongs to the category of the rather strong relief. The Qsob river has a length of water very important of the order of 112 km compared to that of the other two rivers Ait Tahria and Tidzi. The drainage density Dd is almost similar for the Qsob and Ait Tahria catchment and is low compared to the Tidzi catchment. These different physiographic parameters and their variations from one watershed to another, combined with other geological features, will be reflected in the climatic, hydrological and hydrogeological behavior of each basin.

Conclusions

The coastal zone of Essaouira is a semi-arid zone to which belong the three studied watersheds (Ait Tahria, Qsob and Tidzi), it is essentially covered by formations of quaternary and plio-quaternary age. The three watersheds can reach exceptional flooding points and the flows of these floods are significant compared to drained areas of the Qsob (1,726 km2), Ait Tahria (978 km2) and Tidzi (283 km2) basins. The catchment areas are elongated, with low slopes for Ait Tahria watershed and relatively high for Qsob and Tidzi watersheds. The classification of these basins by their specific gradients Ds according to the OSTROM classification gave the category of strong relief to watersheds Qsob and Tidzi, against the watershed of Ait Tahria belongs to the category of rather strong relief.

The salinity of the superficial reservoir waters in the North-East of the Ait Tahria watershed and the Northern part of the Tidzi watershed (Ouzerbane 2015) is related to the influence of the physiographic parameters of the watersheds (slope, density drainage, Length of the main watercourse...), Diapirism and the geological nature of the saturated and unsaturated zone of the aquifer.

The elongated shape of the basins, the relatively steep slopes of the streams, and the low permeability outcrops are all factors that influence the flow of very muddy surface waters and the diminished infiltration-to-runoff ratio. It can be concluded that, in addition to the climate of the study area, its physical environment may provide an environment conducive to sudden flooding of streams, heavy rain falling on such watersheds usually translates into surface, so the response and concentration times of the surface waters are shortened. This suggests extensive monitoring of the protection of topsoils from floods and erosion, and the installation of dykes and dams to artificially recharge the groundwater in the area and the storage of surface water.

Acknowledgements

We are pleased to acknowledge the NATO program CLG n° 983954 for granting part of this study. The logistic support during exploration and sampling is funded by the Faculty of Science and Technology, Sultan Moulay Slimane University - Béni Mellal (Morocco). This is a contribution of the UNESCO-IGCP638 program.

References

1. M Bahir, A Mennani, M Jalal, Y Fakir. *Impact de la sécheresse sur les potentialités hydriques de la nappe alimentant en eau potable la ville d'Essaouira, Mogador, Maroc, Revue Secheresse*, Mars **2002**, pp (13-19) FRANCE.
2. Z Ouzerbane, A Najine, T Aïfa, A El Hmaidi, A Essahlaoui, F Radouani. *Etude géophysique par imagerie électrique du système aquifère au Nord-Est du bassin d'Essaouira, Maroc*, Journal of Hydrocarbons Mines and Environmental Research. **2013**, 4, 1, 57-70.
3. Z Ouzerbane. Thèse. Contribution de la géophysique, des SIG et de l'analyse multicritère à la reconnaissance des ressources en eau et leur vulnérabilité à la pollution. Cas du sous-bassin côtier d'Essaouira, Maroc, Université Moulay Ismail, Faculté des sciences, Meknès, **2015**.
4. M Roche. Hydrologie de surface, Gauthier-Villars : Paris, **1963**.
5. M Jalal, B Blavoux, M Bahir, Y Bellion, N E Laftouhi, J M MPuig, A Mennani, M Daniel. *Etude du fonctionnement du système aquifère karstique Cénomano-Turonien de l'oued Igrounzar (Bassin d'Essaouira, Maroc),* Journal of African Earth Sciences, **2001**, 32 (4), 803-817.
6. M Morell, T Bernard, Y L'Hote. Acquisition et constitution d'une information hydrologique de base, Ecole Polytechnique Fédérale de Lausanne, ISBN 973-98954- I – 7, **1999**, 201.
7. S. Riad. Thèse en cotutelle. Typologie et analyse hydrologique des eaux superficielles à partir de quelques bassins versants représentatifs du Maroc, Université Ibnou Zohr, Agadir, Maroc, **2003**.
8. JP Laborde. Elément d'hydrologie de surface, Cours d'Hydrologie, Université de Nice – Sophia Antipolis : France, **2000**.
9. A El Hmaidi, N Monir, M El Abassi, A Essahlaoui, A Abdellaoui, A El Ouali. *Outils SIG et caractérisation physiographique et climatique du bassin versant du barrage Sidi Chahed (NE de Meknès, Maroc),* International Journal of Innovation and Applied Studies, ISSN 2028-9324 Vol. 8 No. 1 Sep. **2014**, 29-45.
10. A El Mimouni, L Daoudi, M E Saidi, A Baiddah. *Comportement hydrologique et dynamique d'un bassin versant en milieu semi-aride : exemple du bassin versant du Qsob (haut atlas occidental, Maroc),* Rev. C. & G., 24 (1-2). **2010**, 99-112.