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RESEARCH ARTICLE

Lithology Data Contribution in Hydrographic Network Distribution Using Remote Sensing and GIS: Case of the Tahaddart Basin, Northwestern Rif, Morocco.

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Abstract

The Tahaddart basin (NW Rif, Morocco) shows dense hydrographic network with varied flow directions. The contribution of the remote sensing (ETM+ Landsat imageries), joined to diverse data (climatic, ranking and drainage trending streams, relief slopes, land use) of this network reported in the GIS and confronted in to data relative to lithological nature of geological formations outcropping in the drainage basin allowed to establish relationship (genetic links) between these geological parameters and the pattern of surface water circulation. The distribution of hydrographic network of the Tahaddart basin was found to be controlled by the lithologies associated to fracturation accidents.

INTRODUCTION

The estuary of Tahaddart (located to the south of the Tangier, NW of Rif, Morocco; Fig 1) extends on 3,5km, oriented NE-SW and trending N30 since the rivers of Mharhar (to the north) and El Hachef (to the south) junction until the Atlantic coast to the SW (Fig 1). This estuary joined to the Mharhar and El Hachef watershed basins are named "Tahaddart basin" and covered by four moroccan topographic maps at 1/50.000 (sheets of El Manzla, Melloussa, Larba Ayacha and Souk Khemiss Beni Arrouss). The Tahaddart basin covers an area of approximately 2740km², is characterized by a set of reliefs whose topography differs from east to the west. The western part of the basin consists on flow hills whose altitude varies from 50 to 228m (Achab, 2011). While to the NE, east and SE basin is bordered by hills (or Jebel) highest peak at 1065m (Jebel Ez Zaouia, topographic map, sheet of Khemiss Beni Souk Arrouss).

Geologically, the basin belongs entirely to the NW border of the Rif chain, west and SW of the Calcareous ridge (Suter, 1980; Fig 1). The drained geological deposits are mainly represented by argillaceous-marly quartzitics and sandstones formations of meso-cenozoic age (Fig1). The structuring of the region fits into the meso-cenozoic Rif tectonic evolution, characterized in particular by thrusting movements and mio-plio-quaternary brittle tectonics (Durand Delga et al., 1988, 1999; Suter, 1980; El Kadiri et al., 1992; Chaouni, 1996, 1999; Chalouan et al., 2008).

Up on this complex geological frame suffered by an important tectonics and composed by the juxtaposition of lithological formation (quartzite and marl) of different competence and permeability settles the hydrographic network of Tahaddart basin. The abundance of rainfall associated with the impermeability of the majority of geological formations as well as the hilly landscape has favored the emergence of dense and significant surface runoff network (Fig2).

The main purpose of this work is to present (for the first time) the contribution of geological (lithology and fracturing) and geographical (topography, slopes, land use, etc) data based on the use of GIS and remote sensing in the distribution of the hydrographic network of Tahaddart basin.

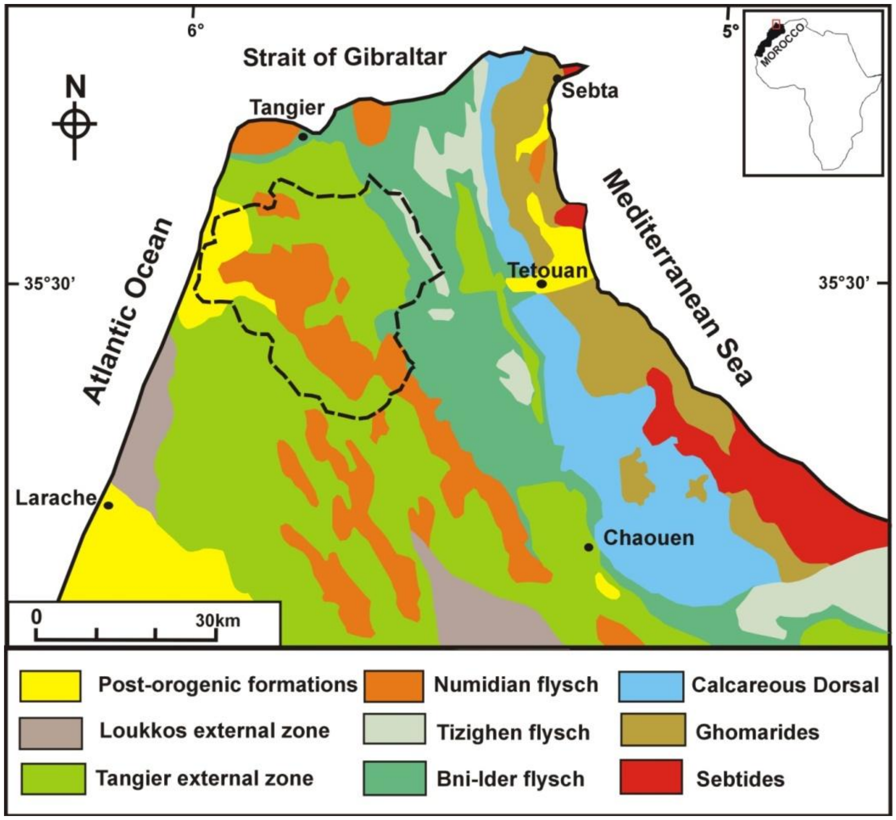


Figure 1. Lithological map of northwestern Moroccan Rif chain. Dark dashes: study area.

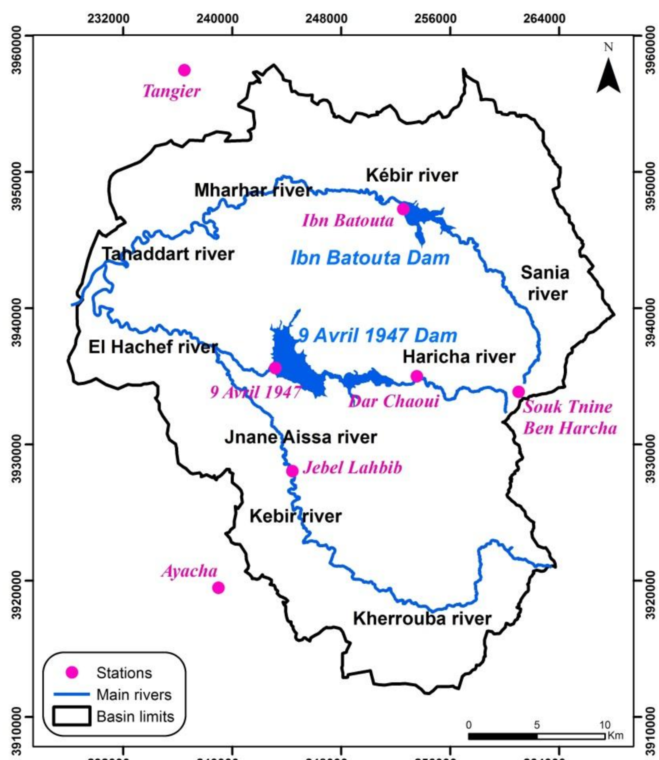


Figure2. Main streams and meteorological stations of Tahaddart basin.

METODOLOGY:

Multi dates and Multi sensor satellite imagery (1999, 2003, 2009 and 2013) acquired from Landsat Thematic Mapper (TM) and Operational Land Imager (OLI) have been used in this study. Data obtained from geological and topographic maps (1:50.000) were introduced into the GIS in order to generate other thematic layers.
The satellite images were geometrically corrected to the Universal Transverse Mercator (UTM) projection system (zone 29). They were radiometrically corrected to remove the effect of aerosols from the atmosphere, but also for further analysis mainly to optimize the visual quality of the colored compositions.
Spectral and spatial enhancement techniques were applied including band-combination, principal component analysis and band-rationing for visual interpretation and identification of lithology, fracturing and land use. The processing of these data was performed by ArcGIS 10 and Erdas Imagine.

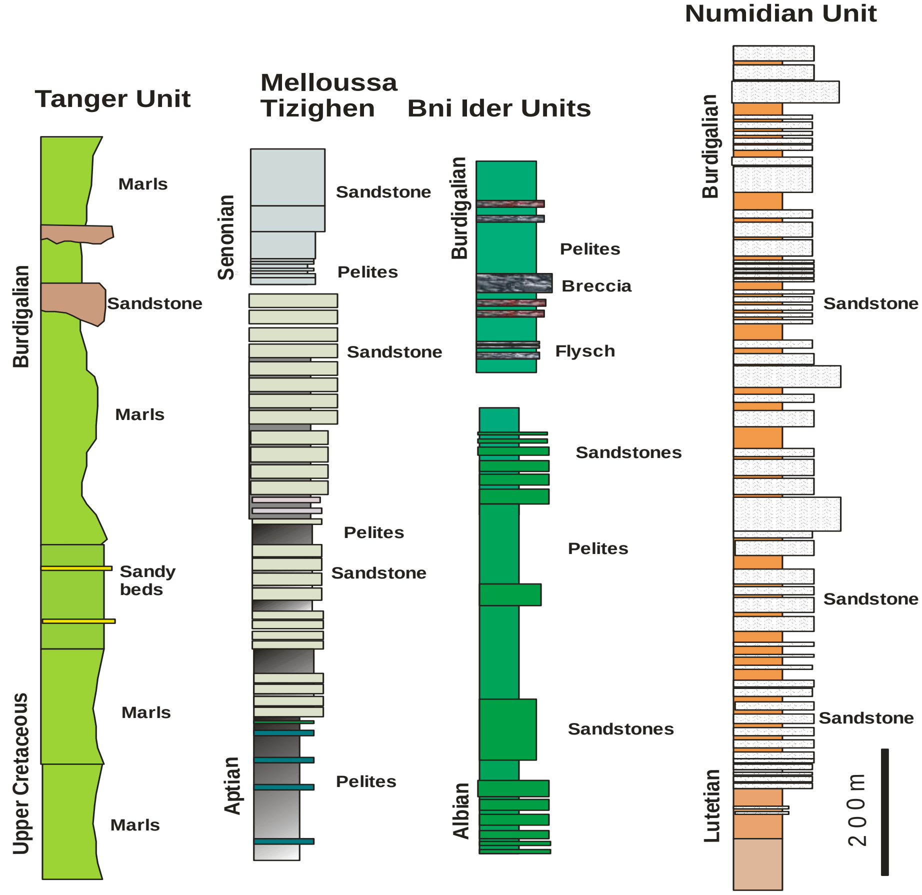


Figure3. Lithological columns of the main thrust sheets of the northwestern Rif (summarized from Chalouan et al., 2008).

LITHOLOGICAL DATA

Structural frame

Three main structural domains form the northwestern Rif arc (Fig 1), from inside to outside and bottom to top: (i) the Internal Zones, (ii) the Maghrebian Flyschs and (iii) the External Zones (Durand Delga et al., 1988, 1999; Suter, 1980; El Kadiri et al.,1992; Chalouan et al.,2008).The Tahaddart basin is bounded on the east by the Calcareous Range (Dorsale), this separates the external zones and the Maghrebian Flyschs (Fig 1). In the study area, this last one includes four main thrust sheet: (i) Numidian flysch (Aquitanian-Oligocene) situated mainly south and westward to Mharhar river; (ii) Melloussa flysch (Middle to Upper Cretaceous); (iii) Bni Ider and Jbel Tisighen flysch (Cretaceous-Oligocene); (iv) Talaa-Lakraa unit (Upper Cretaceous-Paleocene) (Durand Delga et al., 1988, 1999). The Intra-Rif of External Zones includes the Tangier Unit (Upper Cretaceous), Ketama Unit (Triasic-

Turonian), Loukkos and Habt Units (Upper Cretaceous -Miocene; Didon and Hoyez, 1978). Each structural domain consists of complex tectonic units stacked or as thrust sheet with similar lithologies within a given complex.

Tahaddart basin lithology

The lithological series of different thrust sheets outcropping in the Tahaddart basin (Numidian, Bni Ider, Meloussa and Tanger unit) was widely studied, summarized here mainly according to El Gharbaoui (1981), Chalouan et al., (2008) and new field investigations (Fig 1,3).

The base of Melloussa serie is composed by siliciclastic flysch relatively fine grained (Aptian-Albian). This flysch formation of 700m thick is followed upward by thin black cherts (20m) and calcareous microbreccias (Cenomanian-Turonian), and then at the top of the series appear Senonian pelites and microbreccias (100m).

The Bni Ider flysch lithology (up to 800m thick, Fig 3**)** includes a lower "pre-flysch" series composed by spongolites and black shales of upper Albian-Cenomanian-Turonian age. These levels are followed upward by Upper Cretaceous colored pelites and calciturbidites. The Campanian layers include reef fragments and rudists of unknown origin, whereas the Maastrichtian flysch contains Permian-Triassic fragments. Calciturbidite flows emplaced during the Paleocene. Thick sandstone layers with local nummulite accumulations correspond to the Early Eocene, and nummulitic turbidites represent the Middle-Late Eocene. The Eocene-Oligocene transition is marked by the emplacement of chaotic breccias and olistoliths within greenish-reddish pelites. The series is topped by a thick sandy-micaceous turbidite accumulation dated from Late Oligocene to Middle Burdigalian.

The lithological serie of the Numidian flysch (Fig3) begins with a "pre-flysch" series composed by varicolored clay deposits. They were deposited at depth during the Paleogene (Lutetian to Oligocene). The weakness of this formation has greatly favored the detachment of the more than 1000m thick of Numidian flysch. The Numidian sandstones consist of thick yellowish layers, poorly cemented. Graded bedding is poorly marked, the sandstones layers are channelized, often amalgamated and organized into upward thinning sequences interleaved with reddish pelites. Indeed, the turbidite sequence is overlain by brownish siliceous supra-numidian clays of lower Miocene (Aquitanian-Burdigalian).

The Tangier unit shows marly-pelitic formations (up to 1000m thick) dated of Upper Cretaceous to Eocene. Some facies contrast with the dominant pelites, such as the Cenomanian-Turonian phtanites, the Lower Senonian cone-in-cone nodules, the Campanian-Maastrichtian calcareous microbreccias.

The description of different lithological series that outcrop in the Tahaddart basin shows clearly the contrast between the lithology of Tangier Unit composed mainly by marly formations which predominate the drainage basin of the main rivers, and that of Numidian, Melloussa and Bni Ider Units essentially composed by quartzitic formations (sandstones and pelites) predominating the main higher watersheds.

Fracturing of lithological units

From structural point of view, the fracturing type varies from one unit to another, for instance, the Bni Ider unit deposits are folded with external verging however all other units are mainly affected by faulting and thrusting tectonic.

A geological mapping (geological maps of Morocco, 1/50000, sheet of Melloussa, Al Menzla-Tanger, and geological map of the Rif, 1/500000, Suter, 1980) and new field investigations, allow distinguishing thrusting faults, strike slip faults and minor vertical displacement faults. Thrusting faults show east and/or west vergence. In the Tahaddart basin six majors directions of vertical faults (mainly strike slip faults) have been identified (Tahiri et al., 2013): NE-SW or N20 to N40 (24%), NNW-SSE or N150 to N160 (23%), NW-SE or N110 toN135 (22%), N-S orN170 toN10 (14%), ENE-WSW orN60 toN70 (11%), E-W N80 to N100 (6%) (Fig 4). Dextral faults are also more abundant (65%): NE-SW (29%), NNW-SSE (26), NW-SE (24%), N-S (12%), ENE-WSW (7%), E-W (2%) (Fig4). The main senestral faults trending are: NW-SE (19%), NNW-SSE (18%), ENE-WSW (18%), N-S (17%), NE-SW (16%), E-W (12%) (Fig4).

A Remote sensing analysis

Fracturing is expressed on Landsat 8 images, ETM + by more or less straight lineaments delimiting or shift areas of different lithologies or within the same lithological zone and/or morphotectonic structures. Offsets allow the determination of horizontal movements of different faults (Fig 5). Most of lineaments are regional and affect any part of the chain (Chaouni, 1993, 1999; Ait Brahim and Sossey, 2003; Sossey, 2005). The main lineaments directions are (Fig 5): NW-SE (24%), NNE-SSW (22%), NE-SW (18%), E-W (11%), NNW-SSE (10%), N-S (9%) and ENE-WSW (6%).

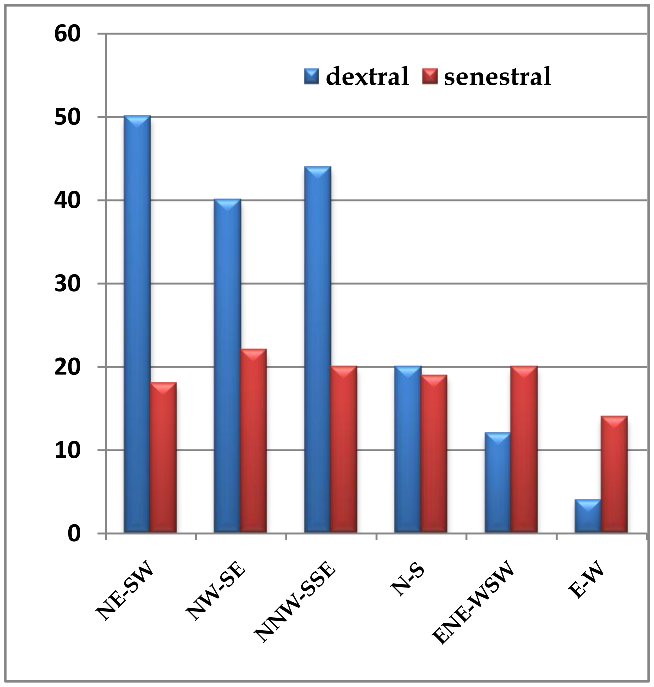


Figure4. Strike slip faults directions.

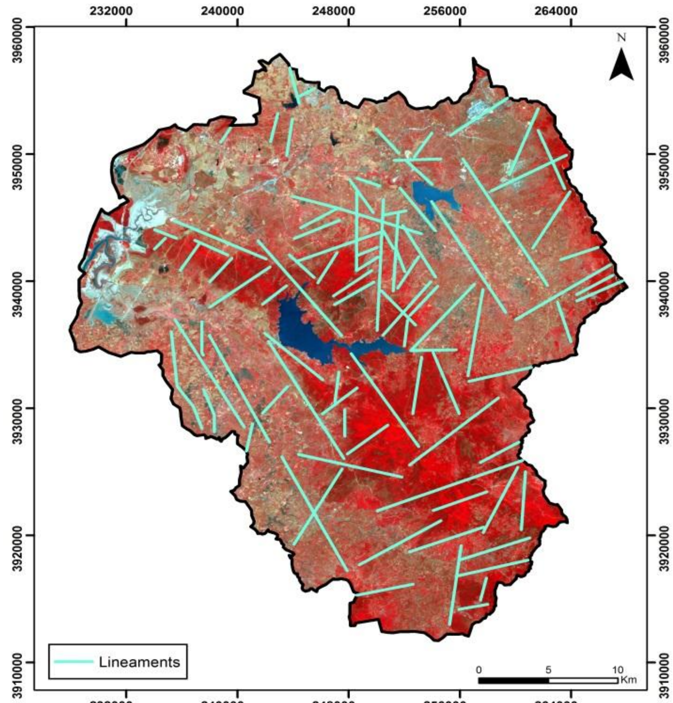


Figure5. Lineaments extracted from Landsat8 ETM imagery

HYDROGRAPHICAL NETWORK OF TAHADDART BASIN

Climatic data

The climate of the study area is sub-wet to wet (El Kharim, 2002; Achab, 2011). Precipitations are important, according to the average annual rainfall distribution diagram (meteorological stations of Tangier; Fig 2, 6), the low values of 197mm were recorded in 2012, while the heavy rainfall reach up to 668mm in 2010. Moreover ombrothermic diagram of last eleven years (2002 to 2012; Fig7), shows an inhomogeneous monthly rainfall distribution with higher values during wet seasons (October to April) and lower during dry seasons (May to September). However, the temperature distribution curve (Fig 7) shows normal evolution with maxima values of 24°C in July and August (summer season) and minima of 12°C in January (winter season). If we consider these most and least rainy years (2010 and 2012), we notice in both of them a huge heterogeneous monthly rainfall distribution (Fig 8, 9). Those climatic data mainly the rainfall distribution indicate a seasonal torrential regime of the Tahaddart basin streams.

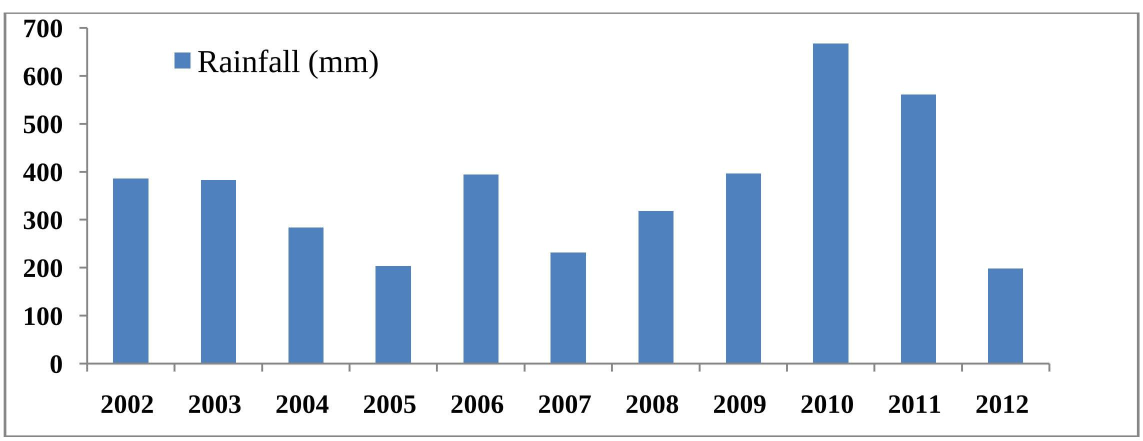


Figure6. Average annual rainfall distribution in Tahaddart basin from 2002 to 2012 recorded in Tangier stations.

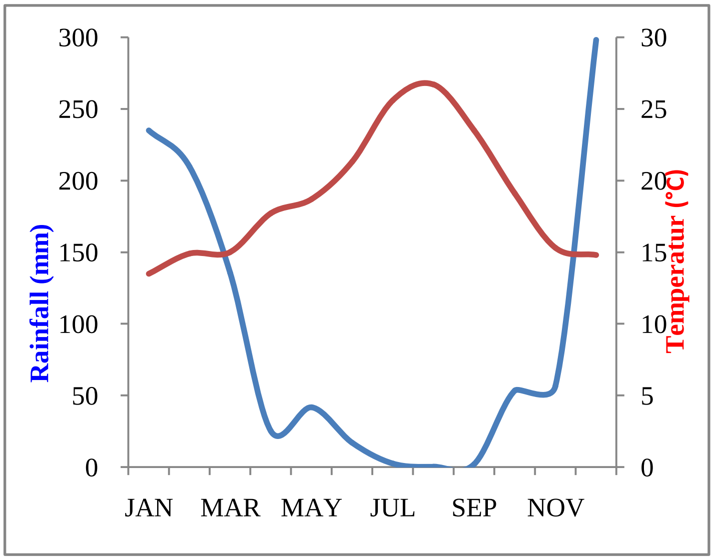


Figure7. Ombrothermic diagram for the period 2002 to 2012 recorded at Tangier station

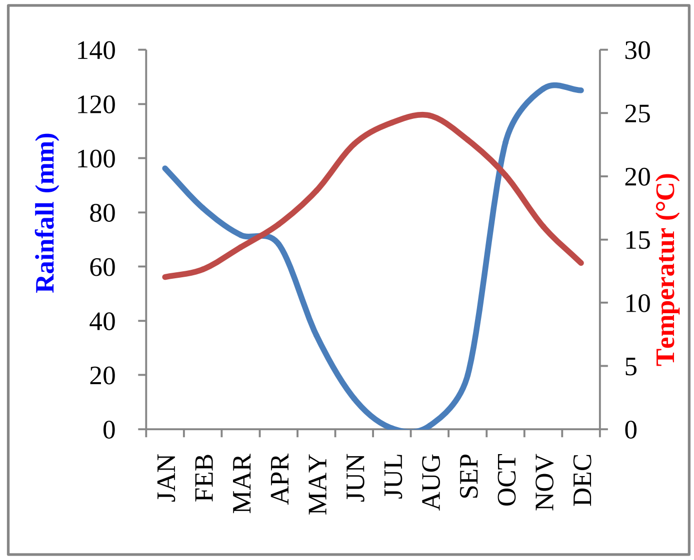


Figure8. Ombrothermic diagram of the rainiest year (2010) recorded at Tangier station

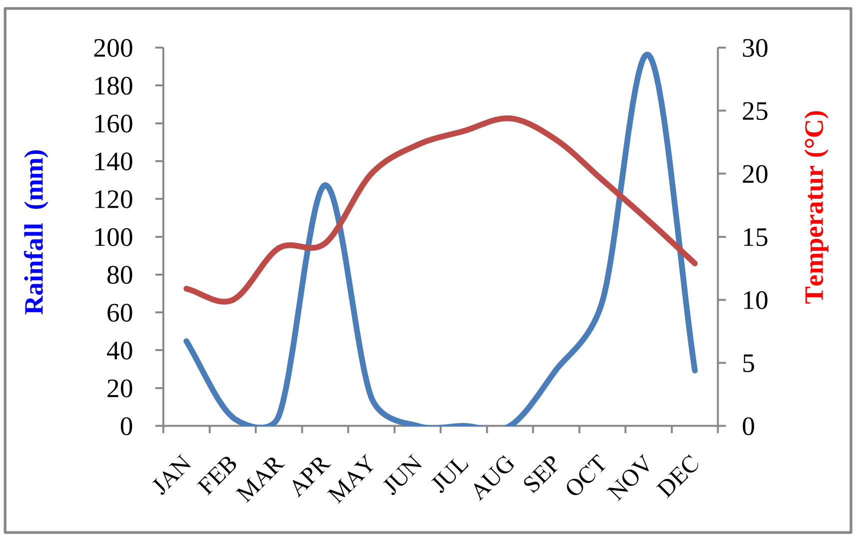


Figure9. Ombrothermic diagram of the least rainy year (2012) recorded at Tangier station.

Streams

The hydrographical network of Tahaddart basin was extracted from four sheets of the topographic maps of Morocco (1/50000) mentioned above. The Tahaddart wadi/estuary is the largest stream/river of the area. Its tributaries show two main entities (Fig 2): 1- The Mharhar River located to the north part of the basin (on which was built the Ibn Batouta dam) whose name changes eastbound becoming El Kebir and Sania rivers. 2- El Hachef river occupies the southern part and has two major tributaries, the Haricha river (on which was built the 9th April 1947 dam) and the Kharrouba river to the SE locally named Kebir river (Fig 2).

Hydrographical network ranking

To classify the different streams component of a river, we assign a number (an order or class) to each section of the stream/river according to a codification, including that of Strahler (1952) and Deffontaines (1990). In the Tahaddart basin, all the streams are considered, the main permanent rivers and their tributaries, the permanent and temporary ravins. The hierarchy of the considered hydrographic network was simplified considering only the decreasing importance of its elements (even if they have different toponymies by sectors) from the main collector up to upstream ramifications. So, the class1 groups permanent main streams (main collectors) as Mharhar, El Hachef, and Tahaddart rivers; the class2, associates the 1th permanent and/or temporary tributaries of the classe1; the class 3 includes all the temporary tributaries of the class 2 (Fig 2, 10). They have extremely varied directions: NW-SE (25%), NE-SW (19%), NNW-SSE (17%), NNE-SSW (12%), E-W (9%), ENE-WSW (8%), WNW-ESE (6%) and N-S (4%), E-W (9%), ENE-WSW (7%), WNW-ESE (5%) et N-S (17%). The pattern drainage of the Class 3 is presented in three main forms (Fig 10): trellis-sub-angular (60 %), dendritic (20 %) and sub-Parallel (20 %).

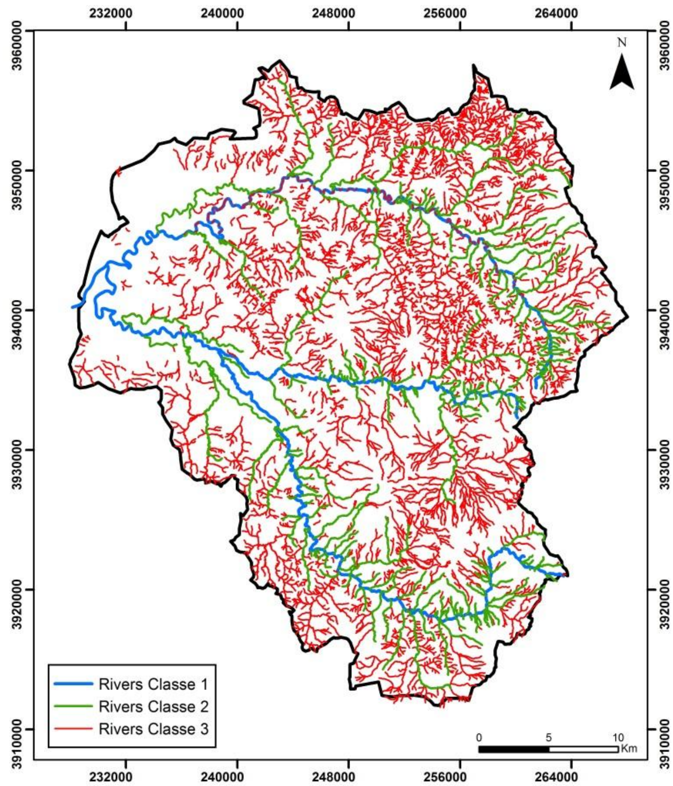


Figure10. Different Classes of the Tahaddart basin hydrographic network.

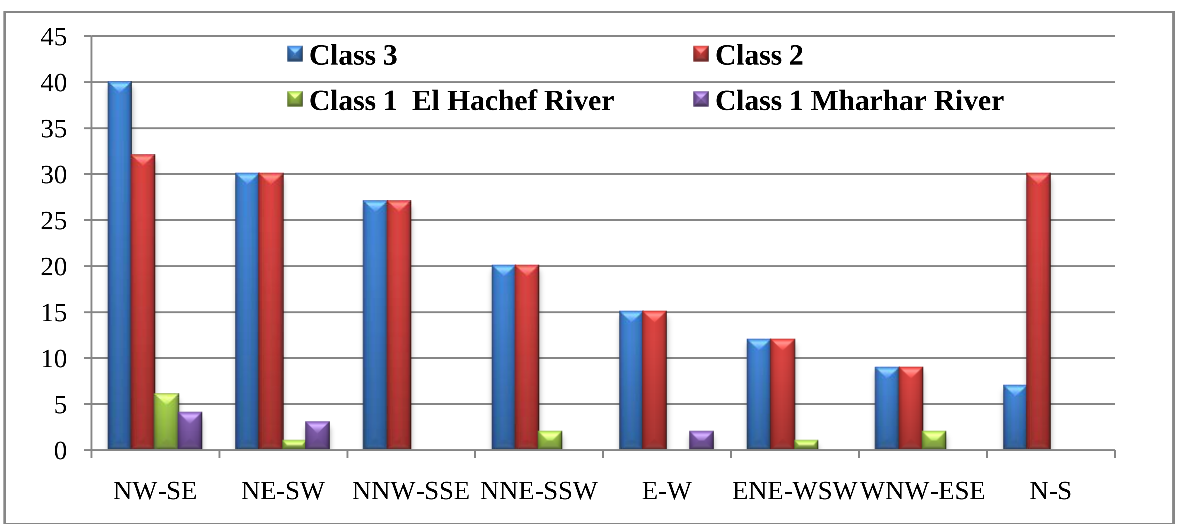
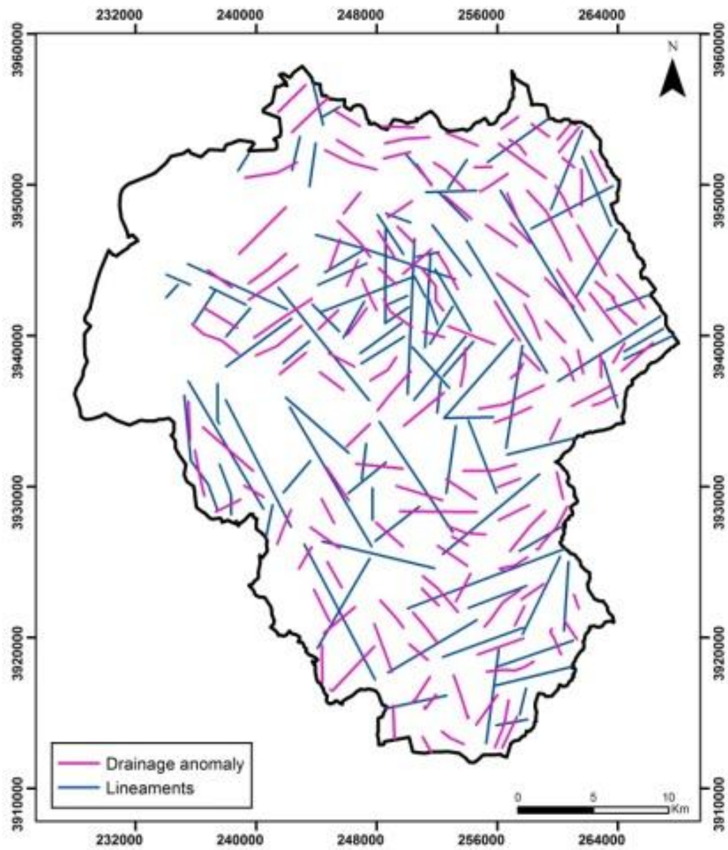


Figure11. Flow directions of the Tahaddart basin hydrographical network.



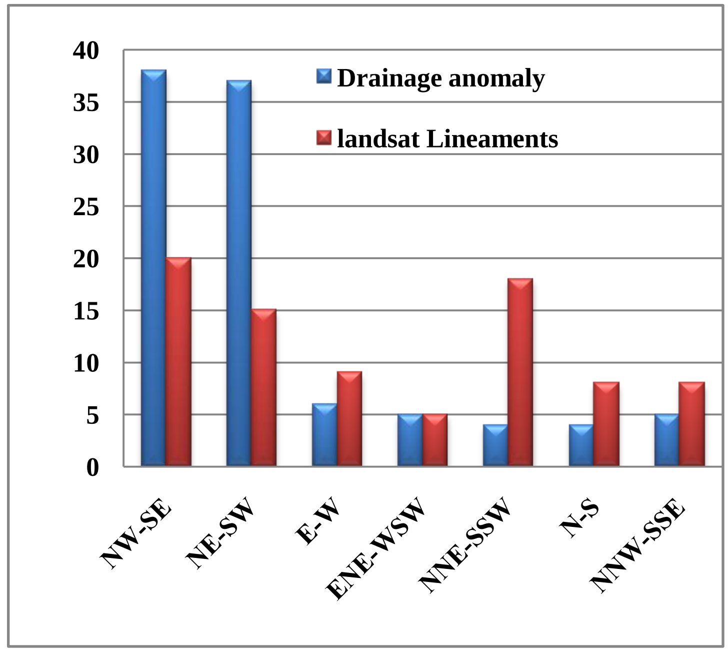


Figure12. Drainage anomalies of Tahaddart basin hydrographic network (right), comparison with Landsat lineaments (left)

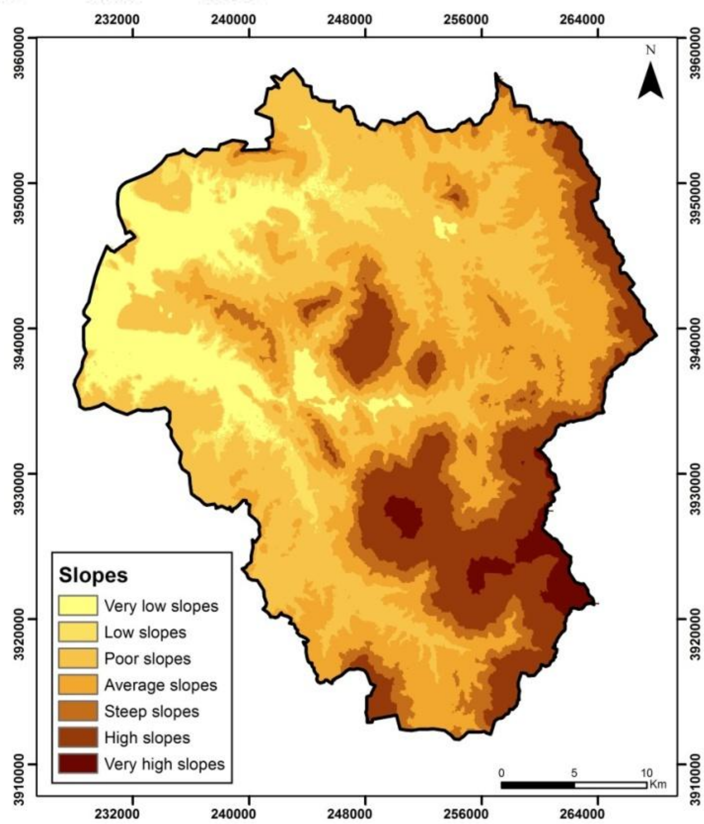


Figure13. Relief slopes of Tahaddart basin

Trending drainage

The permanent streams of Class 1 have varied drainage (Tahiri et al., 2013; Fig 11). In case of the Mharhar river, from eastern basin to the confluence with the Tahaddart river, it shows directions of NW-SE (40 %), sub EW (20 %), and NE-SW (40 %). El Hachef river shows from southeastern basin to the estuary directions of ENE-WSW (8%), NE-SW (8%), NNE-SSW (17%), NW-SE (50%) and ESE-WNW (17%). Streams of Class 2 often have an orthogonal or oblique direction sometimes parallel to the direction of the associated stream of Class1. These directions are NE-SW (17%), NNE-SSW (12%), NNW-SSE (15%), NW-SE (18%).
Several types of drainage anomalies have been described (Le Pape, 1994; Deffontaines et al., 1992); some have been recognized in the Tahaddart basin especially in streams of Class 3: the straightness, irregular pinching valleys, asymmetries confluences, abrupt changes. The drainage anomalies show varied directions (Tahiri et al., 2013; Fig 12): NW-SE (41%), NE-SW (39%), E-W (7%), ENE-WSW (5%), NNE-SSW (4%), N-S (4%).

Relief slopes

The highest elevations up to 1000m are mainly localized SE of the Tahaddart basin. Westward appear low altitudes (50-228m), especially in coastal floodplains (Achab, 2011). The basin is characterized by stiff slopes in the upstream part (east and southeast) and by low slope in the downstream part (west). In addition, areas with stiff slope are fundamentally oriented in NW-SE directions in particular at the SE and east part of the basin (Fig13).

Land use and lithology

Hydrographic network also depends on land use especially the vegetation which has an impact on a process set: "it modifies evaporation and evapotranspiration, surface flows, soil humidity, ground waters recharges…"(Zhang and Schilling, 2006)."So more vegetation cover is dense more the surface flow is slowed down. On the contrary, a naked ground contributes to accelerate surface flows process"(Li et al., 2007).
In the Tahaddart basin, land use classification extracted from Landsat 8 imagery of 1999, 2003, 2009 and 2013 (Fig 14a,b,c,d) shows that the forest Lands occupy 50% of the basin surface, followed by agricultural lands (40%) and wet lands (≈10%).Wet zones identified are numerous and form an important complex constituted by basins of temporary fresh water, temporary salted lakes, reserved of dams, alluvial plains, estuary zones and sandy coastal zones, etc. Forest lands are found to be situated in high altitudes essentially in the NE, SE and central parts of the basin. 4 types of forests are distinguished according dominant species: the important one is Cork oak forest dominated by *Quercus suber* (*Arbutus unedo* and *Quercus canariensis* are rarely founded); reforestations of *Pinus halepensis*, *Pinus pinaster* and *Eucalyptus camaldulensis*. The remaining lands of moderate-low altitudes are occupied by agricultural and wetland areas. Mapping distribution of forest areas is similar especially to that of Numidian quartzites and Bni Ider sandstones. Agricultural and wetland areas are on the marly and clayey Tangier unit.

DATA ANALYSIS

In the Tahaddart basin, drained geological deposits belong to various tectonic thrust units (nappes) with various lithological sets and geological ages. Thrusting produced juxtaposition of different competence and lithological permeability (quartzitic and marly). The main lithological sets (of Melloussa, Bni Ider, Numidian and Tanger units) are mainly oriented NW-SE to NNW-SSE.
Mharhar and El Hachef rivers watersheds are mainly constituted at highest heights (stiff slopes) by quartzite and sandstone lithology (Numidian, Melloussa and Bni Ider Units; Fig 13). The drainage basin of the main rivers is located on the Tangier Unit of marl nature. Class1 rivers flow directions are generally sub parallel to the lithological sets direction (Fig 1, 10, 11). Class2 rivers directions are varied often parallel to the main strike slip faults for witch NW trending are abundant. Class3 rivers show a most varied direction witch NW-SE and NE-SW trending are privileged. However, all rivers class flow directions are similar to the highlighted remote sensing lineaments trending which are parallel to drainage anomalies directions (Fig 11, 12).
The majority of the class 1 streams (via their classes 2 and 3) originate from the NE and SE basin parts at the level of the mainly quartzitic lithological units (Melloussa, Bni Ider and Numidian Units). Class 2 and 3 streams originate from strong slope zones mainly constituted by the quartzitic lithological units.
Class 1 collector's drainage is made within the marl Tangier unit. At north, Mharhar river drainage curve around numidian quartzites in the central basin part according WNW-ESE and E-W trending until a NE-SW trending

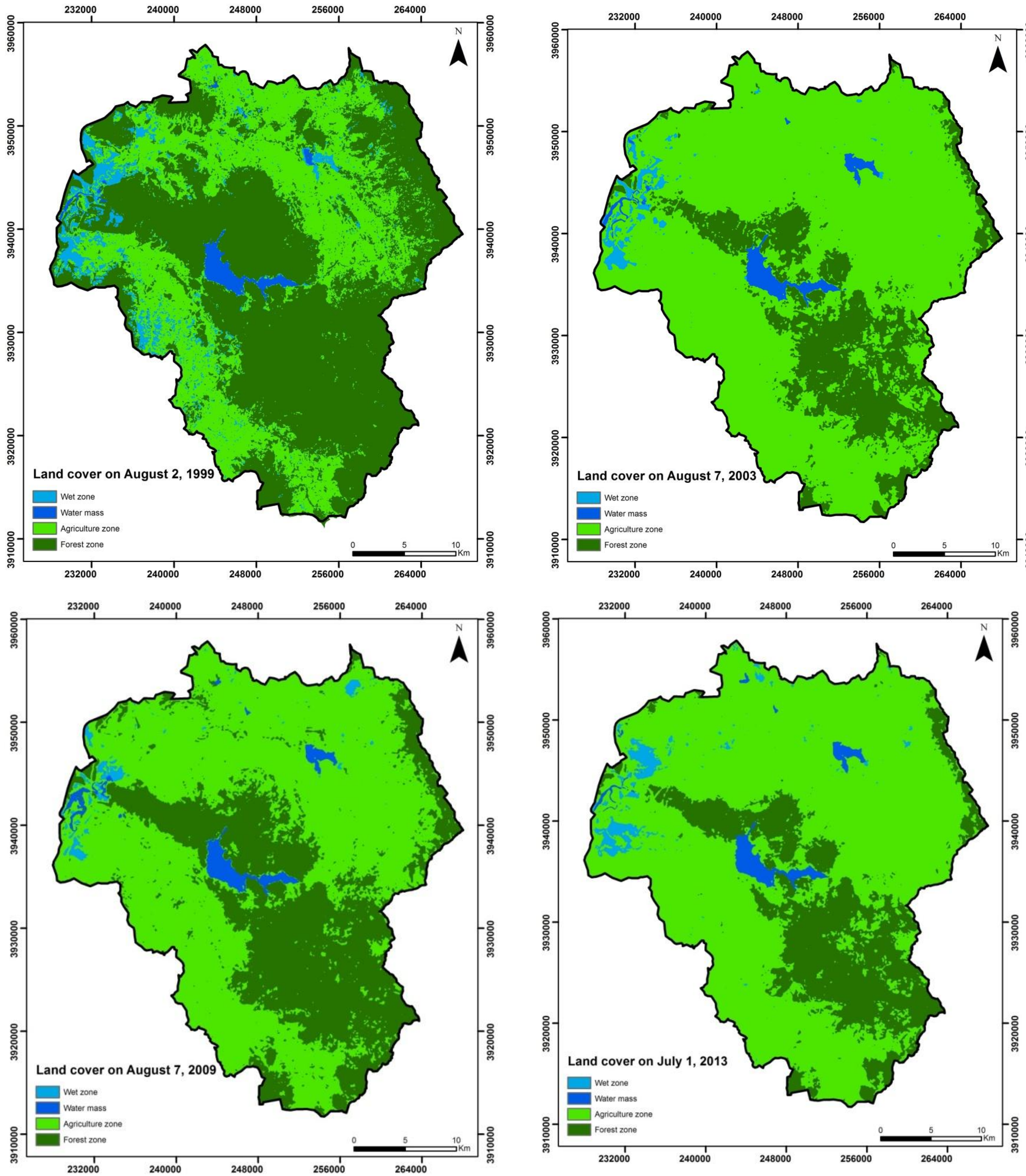


Figure14. Land use of the Tahaddart basin in 1999, 2003, 2009 and 2013

Tahaddart river. South, El Hachef river drainage is firstly WNW-ESE then NW-SE and curve around south westward a central basin numidian quartzites. The importance of fracturation in the distribution of lithological sets directions is proved (Tahiri et al., 2013).
The Use Land remote sensing classification show (Fig 14) Forest Lands (mainly Cork oak forest dominated by *Quercus suber*) within the mainly strong slope quartzitic lithological units (Melloussa, Bni Ider and Numidian Units) (Fig 1, 14). While agricultural lands correspond to Class1 rivers of low slopes and marl drainage zones (Tanger Unit).

CONCLUSIONS

The confrontation of the hydrographical network distribution and the lithology data of the Tahaddart basin reported in the GIS and joined to the contribution of the remote sensing allow establishing relations between these geological parameters and the main waters flows directions. The lithologies of geological formations of this northwestern rifain chain part represent one of the determining parameters which guide the drainage network. The tectonical evolution (thrusting) entailed contrasted permeability and competence juxtaposition of the complex ground-soil. This lithological distribution influence the Use Land in a way that forests occupy preferentially (competent) quartzitic zones and agricultural lands occupy marly zones.
The role of the lithology (and the tectonics) in the hydrographical network distribution shows the importance of the geological parameters which must be considered for the adoption of the most appropriate measures of the northern Moroccan hydraulic basin environmental management.

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