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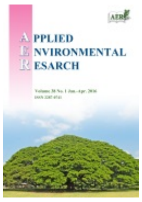

Evaluation of Meskat System Functionality as Water Harvesting at Wadi Hamdoun Watershed (Sousse, Tunisia) Using the Geographic Information System

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Abstract

In the Sahel of Tunisia, areas were characterized by complex landforms like hills and depression with active and alternation of the geographical processes between bare hilly limestones and fertile soils. These landforms consist of the Meskat system. It represents the commonly used micro-catchment of water harvesting for olive tree groves as traditional soil and water conservation technique. However, in recent years, this system seems to be increasingly neglected. The present study aims to determine the current functionality of the Meskat system in the watershed of Wadi Hamdoun through the use of a geographic information system (GIS) as well as field's investigation. Results reveal the presence of areas that do not respect the standards corresponding to the Meskat system implementation, and which most likely are the principal cause of its decreasing performance degree. For instance, the main reasons for the system dysfunction due to the urban area expansion, the densification of the roads network, and the planting of impluvium. The urbanization is manifested in the sub-basins of Wadi Ed Diq (WD) and Wadi Haj Abid (WHA), with affected areas reaching 1.86 and 1.05 km^2 respectively. In addition, satellite images show that the impluvium of Borjin Sub-catchment and Bellani Wadi Sub-basin are being used for growing olives, with planted area of around 0.81 and 0.56 km^2 respectively. Moreover, the destruction of Mankaas is most felt in Hmadet El Borijin and Wadi Bin Shahed sub-basins, with coverage area of 0.77 and 0.66 km^2, respectively.

Keywords: Soil erosion; Water harvesting practices; Wadi Hamdoun; Meskat system

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Introduction

In North African regions, the water availability has become a limiting factor for agricultural practices, where water scarcity is always the main problem [1-2]. In Tunisia, rainfall shortage is unevenly distributed in space and irregular in time [3]. In fact, two-thirds of the country precipitation ranges between 50 and 350 mm a^{-1} [4]. In arid and semi-arid regions, natural resources are affected by severe erosive phenomena [5]. The predominance of vulnerable soils, the torrential flows in stream, the low density of the vegetation cover, the over-exploitation of farming fields, and the growing demographic development are the main factors speeding the deterioration of water and soil [6]. In Tunisian territories, 50% of arable lands are severely affected by water erosion, which is, basically, around three million hectares. Approximately, half of that area is subject to medium and strong erosion occurrences. This is a significant constraint to ensure sustainable agricultural development and to improve the Tunisian economy. The struggle against these phenomena began long ago with our ancestors [7] who kept improvising new ways and techniques to better manage runoff and to preserve the soil against erosion. In order to control erosion, the Ministry of Agriculture implemented two national strategies for soil and water conservation for the decade (1991-2001 and 2002-2011) based on management of agricultural land in steeply sloped areas, mobilization of surface runoff through the realization of hydraulic structures in the waterways and stream network; the aforementioned soil conservation techniques are aiming towards a sustainable agriculture development and valorization of traditional erosion control practices.

In Tunisia, a specific traditional erosion control practices were developed considering natural context as well as socio-economic constraints. The spatial distribution of these structures depends, primarily, on the climatic characteristics of each region. In the Northern part of the country (sub-humid zone), the authorities and the agrarian associations are promoting the use of forest stands, protect the forest by assistance from territorial staff, and the construction of dams and hill small dams [8-9]. In the central part of the country (semi-arid zone), the contour ridge benches are used to intercept runoff, increase crop yield, and improve soil fertility. In the Tunisian Sahel, the runoff harvesting is done through Meskat system. Whereas, in the southern part of Tunisia (arid zone), farmers have adopted the Jessour system to meet up their water needs [10]. In 1984, the Water and Soil Conservation Services, from the Ministry of Agriculture, was founded; its main device is to implement strategies that ensure the integrated development of watersheds [11]. Its assignment is to promote the construction of erosion control structures in regard to the specific topographical and environmental conditions of each region, including their suitability with the natural landscape. The main aims of these structures are to wisely manage the natural resources, maintain or improve the living conditions for rural inhabitants, and to preserve the storage capacity of hydraulic structures, such as large dams, in order to improve agricultural productivity [12].

Many researchers studied the importance, the benefits, and the performance of different erosion control structures through numerous approaches [13-14], in particular, the Geographic Information System (GIS) approach [15]. According to Joliveau, the GIS can provide the user with a more realistic spatial representation of a specific area [16]. For example, Bouchnak et al. used GIS tools in their study of the changes occurring in ravines located in Central Tunisia [17]. They identified the most vulnerable lithologic units to water erosion agents and determined the different existing geologic formations. Baccari et al. also used GIS tools to determine the risk analysis of the breaches occurring in the contour ridge benches located in the Tunisian semi-arid region [18]. Identification of erosion control practices with the use of GIS was conducted also by Anane et al. who mainly focused on sites that had been landscaped by small hill dams [19]. With the aim of increasing farmer awareness to the importance of the Jessour system (mounds of compacted soil along Talwegs that make up mountainous streams), Abdelli et al. identified, using remote sensing, 94% and 87% of the Jessour at Wadi Jir and Wadi Hallouf's Watersheds indicating these types of data to locate such hydraulic structures [20]. GIS and remote sensing have also been used to diagnose abnormalities affecting water and soil conservation practices (WSP). In the same context, Fourati et al. proceeded to the visual interpretation of high-resolution satellite images to detect operation anomalies in the WSP in the Sfax region [21].

The main aim of this work is to assess the dysfunction of Meskat system through historical topographic maps and very high-resolution satellite imageries freely available from Google Earth combined and a cross-survey with field visits.

Material and methods

1) Meskat system

The Meskat system is a traditional erosion control structure which is most widespread in the Tunisian Eastern coastal region (Sahel). This practice is a long-time established, extended largely since the Roman period [22]. It relies, essentially, on intercepting runoff flow from the impluvium, then redirecting it to the farmed fields (Figure 1). This runoff is directed through distributors to irrigate the olive trees grown in downstream plots, called “Mankaas”. At this level, the water is intercepted by mounds known as “Tabias” and directed from one plot to another through a small earthen outlet, commonly called “Majref”.

The proper functioning of the Meskat system essentially depends on the ratio between the size of the impluvium and that of the “Mankaas”. The optimal ratio is 2/3 for the first and 1/3 for the second. The impluvium is characterized by the dominance of the limestone layer, the development of sparse spontaneous vegetation such as *Artemisia herba alba*, *Rosmarinus officinalis*, *Stipa tenacissima*, etc. and the existence of old runoff harvesting structures such as “Fesguias” or “Majels”. These structures are dug under the houses or in the garden. The “Majel” is deeper, four to eight meters deep, against three to four meters for the “Fesguia”. They recover rainwater from the surfaces of the lime roofs of the main house.

The “Mankaas” are mainly occupied by olive trees groves. The impluvium sizing essentially depends on rainfall and amount of runoff. Its slope varies between 3% and 10%, while the general slope of the “Mankaas” is 1 to 2%. The alternation between impluvium and “Mankaas” surfaces forms a mosaic.

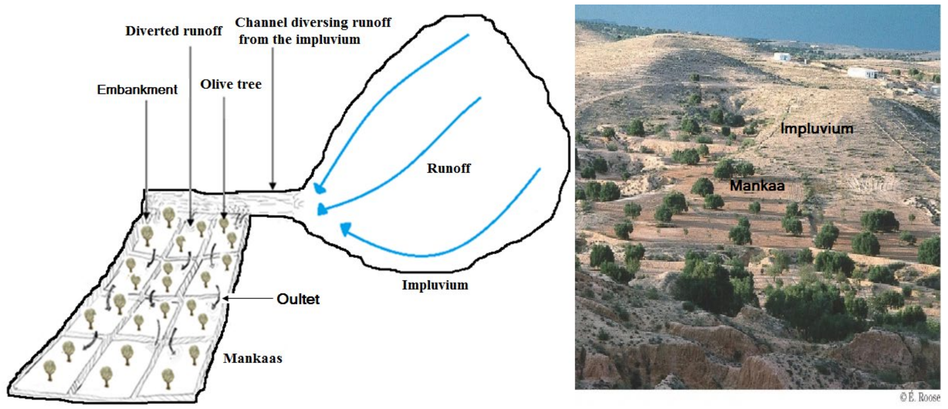

Figure 1 Design of the Meskat system intercepting runoff and its components.

2) Study site

The study zone corresponds to the Wadi Hamdoun basin, which belongs to both the governorate of Sousse and that of Monastir with an area of around 315 km^2 (Figure 2). M'saken, Sousse-Erriadh, Sousse-Medina, Sousse-Sidi Abdelhamid and Sousse-Jawhara are the urbanized area of the watershed. The Wadi Hamdoun basin is limited by the Wadi Laya basin in the North-West, Sidi El Hani catchment in the South-West, Wadi Khnis basin in the South-East and the Mediterranean Sea in the North-East. Its corresponding geographic coordinates are 35°47' N and 10°41' E. Wadi Hamdoun basin is characterized by a high variability of land use. In fact, its coastline is highly urbanized with an area reaching the 27 km^2, whilst the area dedicated to planting, particularly olive trees, is around 143 km^2 and that dedicated to roads is around 65 km^2.

With a length of around 14 km, Wadi Hamdoun is the main tributary of the basin's stream network. Its main affluents are Wadi El Maleh, Wadi Bellani, Wadi El Hijeb, Wadi Jouabi, and Wadi Cherki. Wadi Hamdoun receives flow from Karaat El Knaiyes, during floods, through an artificial channel. The slope of Wadi Hamdoun varies between 3% and 15%. Hills are, usually, used as impluvium for runoff harvesting to allow an additional water supply for olive trees. The study area is part of the Middle Pleistocene and upper continental and is characterized by the fragility of its structures. The soil of this catchment mainly characterized by calcareous soil partially contained salty clay to sandy clay texture with the sparse vegetation cover.

The analysis of the stream network showed some dissymmetry between the left and right bank of Wadi Hamdoun basin. The flows are often widespread and most wadis are not marked in the landscape. The basin is divided into 21 sub-basins such as As-Sidryya (S), Bou Akwa (A), El Borjin (B), El Knaiyes 1 (K1), El Knaiyes 2 (K2), El Qisba (Q), Ghiryan (G), Hmadet el Borjin (H), M'saken (M), Wadi Ad Abiq (WD), Wadi Ballani (WB), Wadi bin Shahid (WS), Wadi El Bey (WE), Wadi el Haj Abid (WHA), Wadi el Jibs (WEJ), Wadi el Maleh (WM), Wadi Ghrab (WG), Wadi Hamdoun 1 (WH1), Wadi Hamdoun 2 (WH2), Wadi Jwabi (WJ) and Wadi Offim (WO), with each one taking the name of its main tributary or the name of the nearest location.

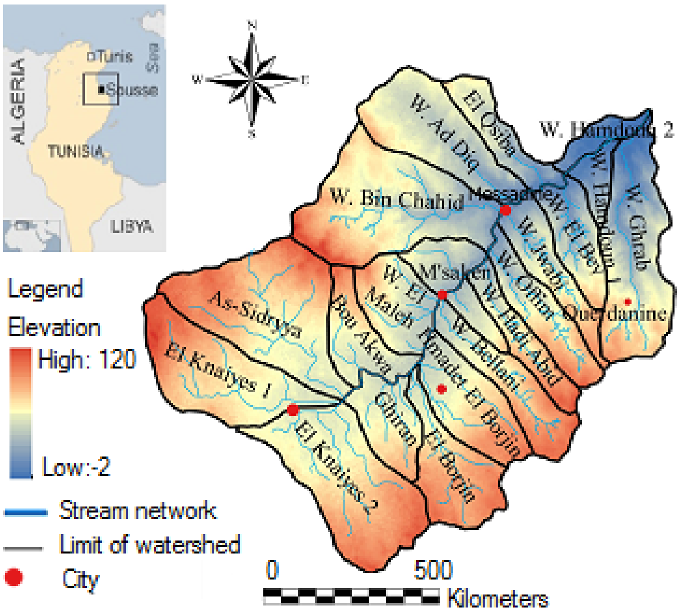

Figure 2 Geographic location of Wadi Hamdoun basin and its delineation into sub-basin.

3) Used tools

To fulfill the aim of this work, a number of maps and GIS tools were employed. These tools were used for mapping the study site and functionality transformations of Meskat system between 2003 and 2013. The used topographic maps are that of Sousse and of Monastir with a 1/50000 and 1/25000 scales in order to study and identify the Meskat systems and to compare its functionality at different date. In addition, a high-resolution satellite image was extracted from Google Earth, dating from 2003 and 2013. The extracted images were geographically referenced using Global Mapper. Then, we used Arc-view 3.2 to create information database and analyze the geographic information. The statistical processing has been done in this study with SPSS 16 software.

4) Assessed variables

The methodology adopted in this study is based on the processing of the cartographic and the survey data. The different steps are summarized in the Figure 3 and Supplementary Material (SM) 1.

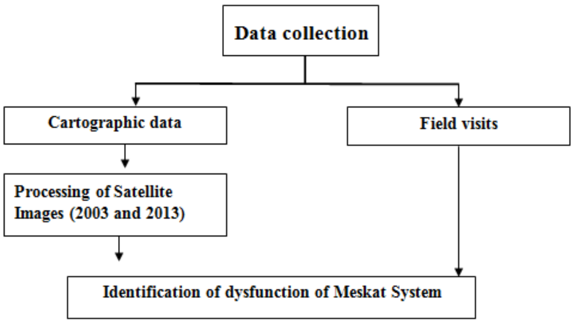

Figure 3 Synoptic diagram of the methodology adopted to assess the dysfunction of the Meskat system.

The methodology adopted in this study is composed, of five steps. The first one consists of collecting and building the most exhaustive database of maps. The second step consists of pre-treating of the different collected data, for example georeferenced the maps was applied using the GIS tools. In this study, we projected the maps according to the Universal Transverse Mercator (UTM) system. This step was carried out using Global Mapper program. For example, we used the Swipe function offered by the program to verify that maps, as well as a satellite image, are being correctly georeferenced. The third step is the spatial pattern of the Meskat system, which was realized through the different topographical maps and the satellite image downloaded through Google Earth. It consists of digitizing, particularly the impluvium and Mankaa plots of the Meskat system, by creating and/or modifying vector layers in shapefile format through the Arc View program. This work consists to identify the main components of Meskat such as impluvium and mankaa based on the topographic maps and satellite images which were been referenced. The fourth step consists of creating attribute tables containing detailed information of each sub-basins, such as the order, the length, the affected features, the surface, the perimeter, etc. The last step is the creation of thematic maps. For instance, the dysfunctional features in the Meskat system were spatially illustrated. In addition, many visits were made in the field to take pictures of the basins in which the Meskat systems were degraded.

The compactness index (Kc) of the different sub-basins is defined by Eq. 1.

$$Kc = 0.28\frac{P}{\sqrt{S}} \qquad \text{(Eq. 1)}$$

Where, P and S denote the perimeter (km) and surface (km^2) of the sub-basins, respectively.

Results and discussion

1) Physical characterization of Wadi Hamdoun Basin

The basin I divided into 21 sub-basins such as As-Sidryya (S), Bou Akwa (A), El Borjin (B), El Knaiyes 1 (K1), El Knaiyes 2 (K2), El Qisba (Q), Ghiryan (G), Hmadet el Borjin (H), M’saken (M), Wadi Ad Abiq (WD), Wadi Ballani (WB), Wadi bin Shahid (WS), Wadi El Bey (WE), Wadi el Haj Abid (WHA), Wadi el Jibs (WEJ), Wadi el Maleh (WM), Wadi Ghrab (WG), Wadi Hamdoun 1 (WH1), Wadi Hamdoun 2 (WH2), Wadi Jwabi (WJ) and Wadi Offim (WO), with each one taking the name of its main tributary or the name of the nearest location.

The largest areas correspond to the sub-basin of Wadi As-Sidryya (33 km^2) and that of WS (33.5 km^2). However, WEJ and WH1 sub-basins have the smallest areas, respectively, 4.50 and 4.96 km^2. All sub-basins but (WM) have an elongated shape with a Kc varying between 1.12 and 1.64 (Table 1).

Table 1 Morphological parameters of sub-basins

Sub-basins	Area (km^2)	Perimeter (km)	Kc
S	33.20	25.86	1.26
A	11.39	17.59	1.46
B	15.95	20.78	1.46
K1	24.62	24.28	1.37
K2	31.24	25.46	1.28
Q	9.80	17.48	1.56
G	10.30	16.08	1.40
H	15.35	17.10	1.22
M	7.23	13.36	1.39
WD	20.54	20.92	1.29
WS	33.56	26.70	1.29
WB	10.11	15.90	1.40
WM	11.79	19.89	1.62
WE	4.51	9.87	1.30
WHA	11.77	13.68	1.12
WG	25.69	26.85	1.48
WH1	5.18	11.46	1.41
WH2	4.96	12.46	1.57
WJ	12.91	21.03	1.64
WO	14.26	20.08	1.49

1) Factors affecting the functionality of the Meskat system

The field investigations realized in this study revealed that several aspects of the management do not conform to the standards for the Meskat system. For instance, the expansion of urban areas, the division of the farming fields, the neglect of maintenance, the planting of the impluvium, the destruction of the embankment of the Mankaa, and the densification of the road network explain mainly the dysfunctionality of Meskat system.

1.1) Urbanization

The expansion of urban areas in WH Basin is quite clear, essentially, in the vicinity of M'saken City (Figure 2 and SM 2). The increase of the inhabitants might be explained by the growing number of immigrants coming back mostly from France. This seems to be related to the overall improvement of their livelihoods few years after their establishment in the region. New agglomerations, stores, national and international companies are increasingly being built in agricultural lands. This situation affected negatively the performance of the Meskat system [12]. It is to be noted through that the laws 83 to 87 written on the 11th November 1983 which stipulate that the construction of buildings on arable lands is prohibited and shall be allowed only in the case of extreme need. It is to be noted, though, that the impluvium is considered as a non-fertile land. However, according to the JORT (Official Journal of the Tunisian Republic), several agricultural lands of the Sousse region were subject to vocation changes. Statistics reveal that, especially after the revolution, increasing rhythms of vocation changing requests have been registered. In fact, between 1998 and 2010, a total of 26 changing of vocation operations were realized, with the area being 8× 10^{-3} and 82×10^{-2} km^2.

1.2) Field segmentation and neglect

The construction and maintenance of the Meskat system require appropriate benching engines as well as labor. This can no longer mobilize the necessary funds and do not interest labor since other economic sectors are more attractive. Thus, the maintenance of the

Meskat system is made through efforts of the families that own agricultural fields ensuring the harmony between the different family members. However, nowadays, due to the conflicts between inheritors, the agricultural fields are being continuously partitioned. Thus, the area of the farming land to be inherited is increasingly decreasing. This growing phenomenon of continuously dividing the agricultural land resulted in the neglect of these fields since its area is increasingly reduced, and consequently, the deterioration of the Meskat system (Figure 4).

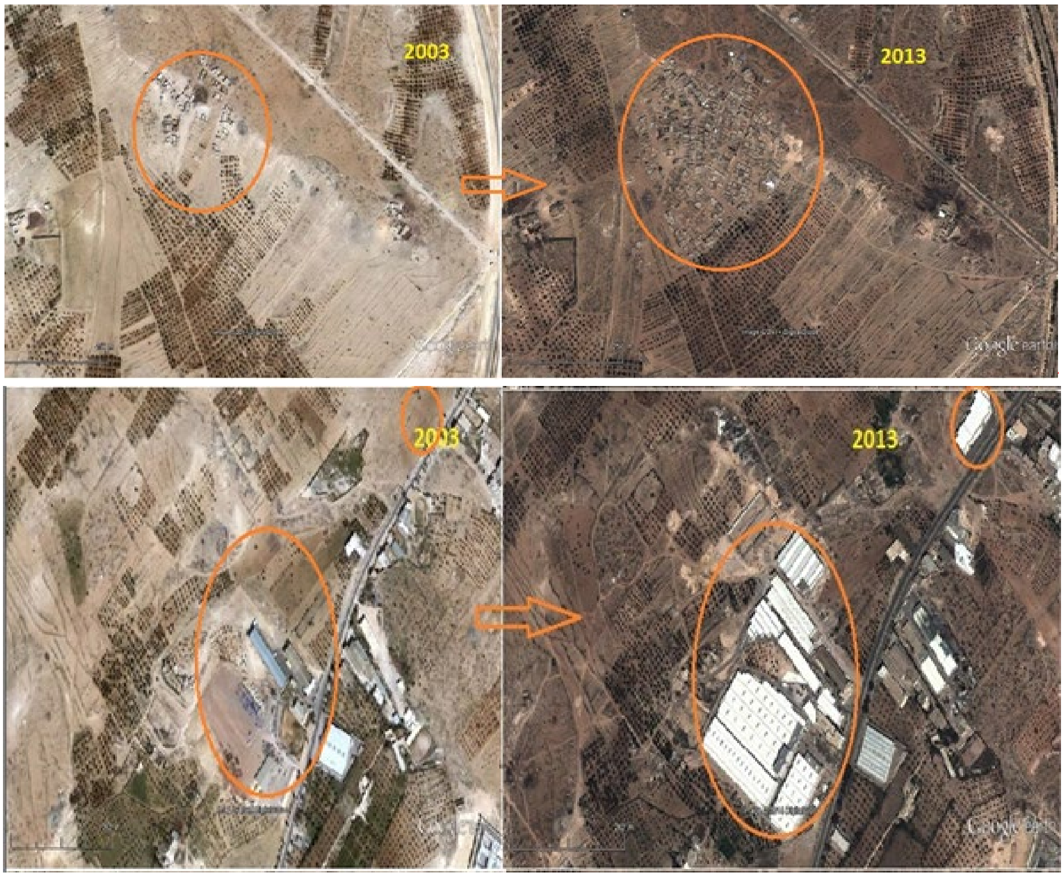

Figure 3 Expansion of urban areas to the impluvium occurred between 2003 and 2013 observed in the region of El Borjin.

Figure 4 Abandoned impluvium: construction waste (on the left) or fallowed farm colonized by pseudo-savanna (on the right).

The modernization of the agricultural activities by reinforcing the use of greenhouses and promoting the creation of irrigated areas may result in several transformations that negatively affected the traditional agricultural production systems. Moreover, due to the competition with the other economic sectors, namely the touristic and industrial sectors, an important decline in the traditional agricultural activities has occurred [12]. The olive groves in the Sahel are not able to escape the aftermath of these changes. Despite the incentives adopted by the authorities and the importance of the water harvesting systems, most landowners are still more attracted to non-agricultural occupations, due, primarily, to the advantage of higher and more stable incomes.

1.3) Farmed impluvia

The field investigations realized in WH Basin revealed that some impluvia are, currently, being farmed to grow fruit trees, to plow cereals, vegetables, alfalfa, etc (Figure 5). Despite the calcareous character of the soil, the farmers are still planting the impluvium. This situation strongly affects olives planted downstream by limiting the runoff flow into the Mankaa. Before the 1950s, the new olive tree plantations in the Sahel were in the olive groves owned for some time by the owners living in cities of Sahel [24]. However, the decline in agricultural land around urban areas coincided with an increase in the area planted with olive trees in the governorate of Sousse, between 1960 and 1994. In fact, the insufficiency of arable land has resulted in the emergence of pressure on the landscape by shifting pasture land as well as impluvium into the ploughed area. This pressure has been accentuated following a call by the authorities (the 1960s) encouraging the farmers to plant more trees throughout the country for subsidies to the farmers [7]. This shortage in agricultural land forced the farmers to plant all bare land in order to receive the subvention from authorities despite the misappropriation of the plantation. In fact, the olive plantations, and other fruit trees, have invaded the impluvium reserved for the runoff supply of the system and then the functionality of the Meskat system is disturbed and its effectiveness is reduced (see SM 3 and SM 4 in the supplementary).

1.4) Destruction of embankment in the Mankaa

The Meskat system can be efficient only it is collective, maintained and conceded from generation to generation. Nevertheless, this system, as best they can, seems today to be not considered by actual inhabitants in the urban or rural areas. This behavior manifests itself in the lack of maintenance of the Mankaa's embankment and sometimes by their destruction. The productivity of olive trees depends, primarily, on maintaining continuously the quality of the Meskat system. The soil plow, made to eliminate weeds and to improve soil hydraulic properties, is less applied nowadays which might result in reducing its capacity for storing water. The expense of traditional labor becomes high due, in a part, to the rarity of labor. Hence, farmers are using the plowing engines causing the destruction of embankment (tabia) and erosion (Figure 6). Due to the tractor passing between plots, the damage is being done to the tabia that play an important role in runoff storage, near olive trees. In addition, some tabias, which are essential for the runoff storage in the Mankaa, are cracked, without any repairs made by the farmers. This is explained by the lack of farm labor to other economic sectors. This contributes to more deterioration of the situation.

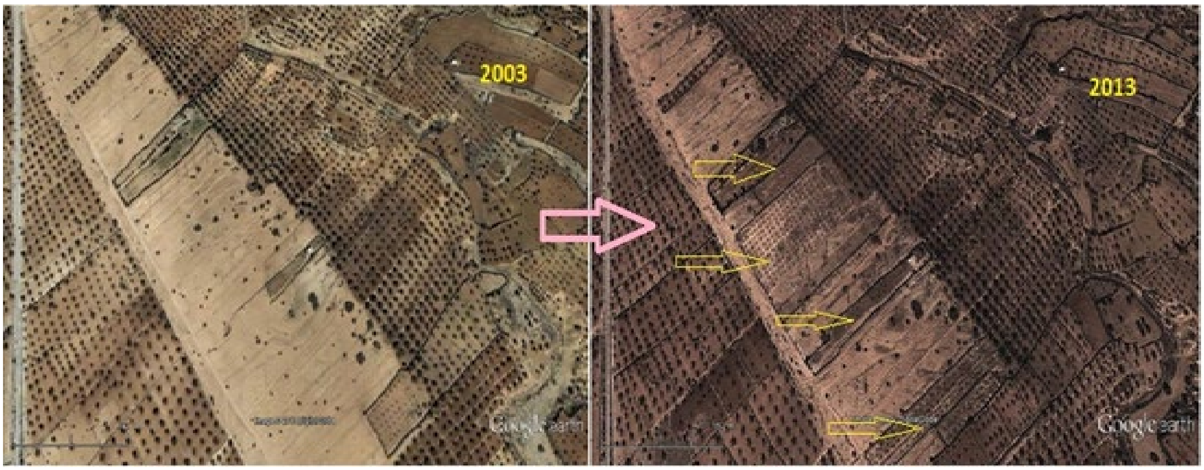

Figure 5 Dysfunctionality of the Meskat system due olive tree plantation in the impluvia, revealed by the landuse changes between 2003 and 2013 at the region of Ouerdanine.

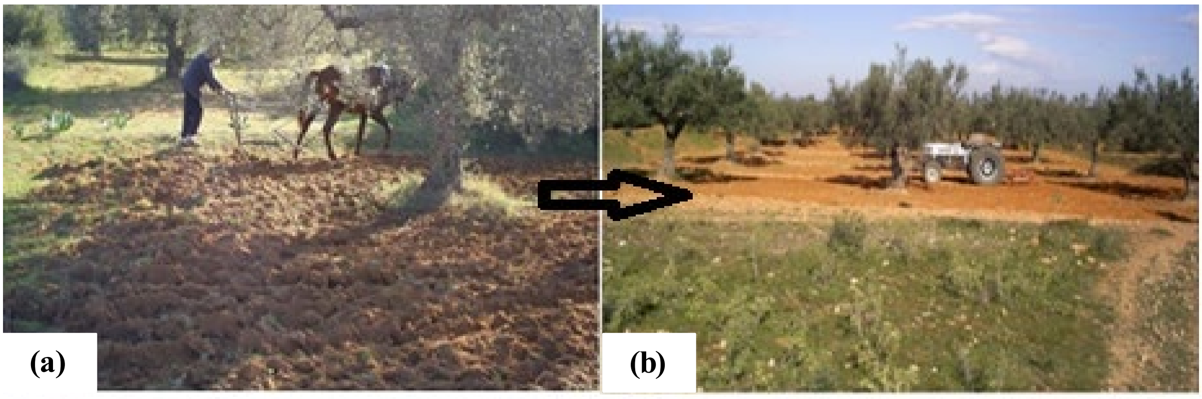

Figure 6 Soil plow in olive groves: animal traction (a) shifting to mechanical traction (b).

1.5) Densification of the road's network

The Meskat system degradation is amplified, among other causes already mentioned, by the new urban infrastructures (bypasses, highway, etc.) which, implemented on the system, disturbs its design, especially runoff routing and its harvesting. In fact, the road often leads to the division of land, the fragmentation of certain agricultural plots, the disruption of conditions and sometimes the devaluation of existing landscapes. There is a dense network of roads in Wadi Hamdoun Basin; these roads stretches to a total length of around 700 km. In fact, roads pass on several occasions across the impluvium, causing the runoff routing disturbance. According Houimli and Donadieu, roads always provoke the segmentation of agricultural fields, the disruption of the plow, and in some occasion the ruin of existing sceneries [24]. However, the biggest problem lies in destruction of the Meskat system and the disruption of the stream network. What is more, in Sousse Medina, the development of the touristic roads which cut the olive tree area in two surfaces, disturbing the runoff supply of the eastern part of the olive groves; the construction of the pavement is a real barrier to the runoff flow routing.

2) Regionalization of dysfunctional features

Figure 7 details the location of the Meskat that does not conform to the standard of the system. The most factors affecting negatively the functionality of the Meskat system in WH basin are the urbanization, the planting of impluvium, the destruction of plots, and the road's network densification.

The Meskat system stretches on the hole of the studied basin. In most cases, the system is located on the South-Western side of the WH Basin. Urbanization affects mainly the central part of the study area and near the sea, on the eastern side. Planted impluvia correspond, especially, to the regions near the boundaries with Monastir and Kairouan governorates. The destruction of the embankment in the Mankaa characterizes almost all sub-basins in WH Basin. Whereas, the degradation of the Meskat system due to the road's network is, particularly due to the Highway (M'saken-Sfax). The B sub-basin is the most affected by the crossing of the motorway.

The areas affected by urbanization vary between 39×10^{-4} and 1.678 km^2, in regard to sub-basin. These values correspond, respectively, to the sub-basin of WD and that of WE (Figure 8). On the other hand, by comparing the affected areas to those managed, it is founded that the sub-catchment areas of Q, WD and WM are the most affected by urbanization. Building on impluvium results on the decline of the impluvium/Mankaa ratio and the disruption of the stream network, affecting negatively the functionality of the Meskat system and, eventually, causing a runoff shortage for olive trees planted in Mankaa of Sidi El Hani (limited by Kairouan governorate) and of Wadi Khniss (Monastir governorate) are characterized by different soil texture, from a calcareous one to a more fertile soil. The most affected sub-basins are H (0.77 km^2) and of WS (0.66 km^2). This may be due to their areas and the different spatial repartition of the system disturbances. Planting of the impluvium is most apparent in the sub-basin of B and WB, with a respective affected area of 0.81 and 0.56 km^2. In this context, sub-basins of Sidi El Hani and Wadi Khniss are characterized by different type of soil texture. It ranges between calcareous and fertile soil.

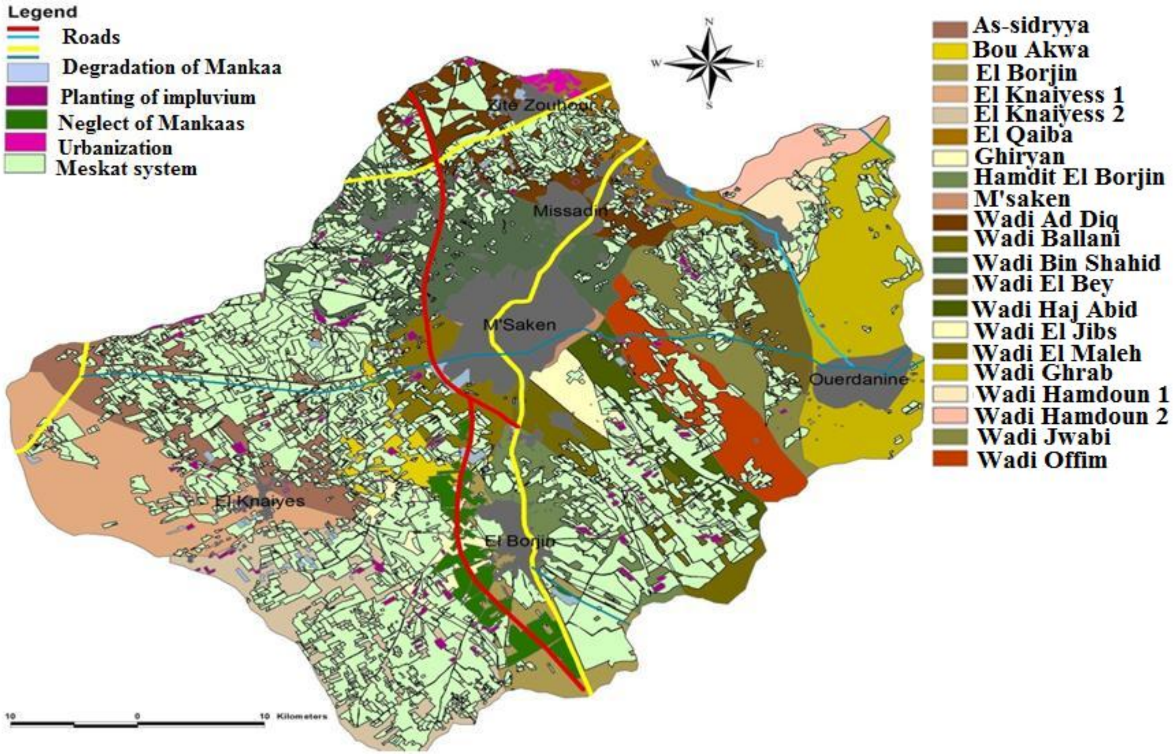

Figure 7 A spatial repartition map illustrating the dysfunctionality of the Meskat system in Wadi Hamdoun Basin.

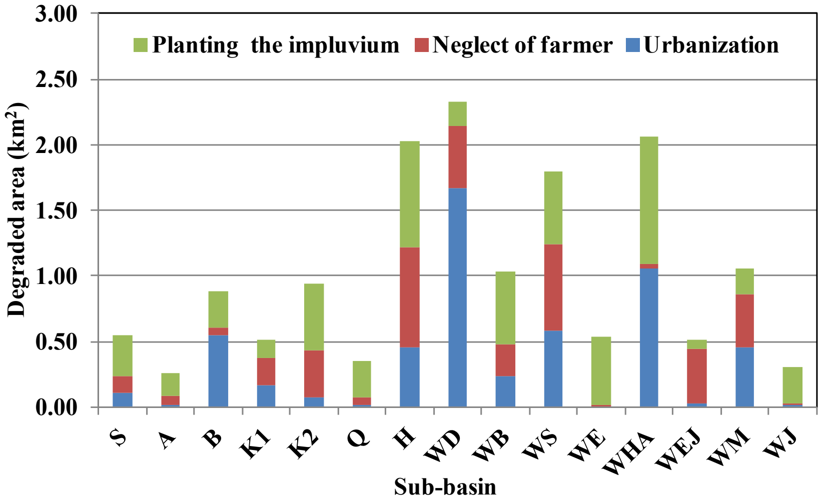

Figure 8 Form of degradation area of sub-basins.

Conclusion

The present work allowed us to study the different transformations that may affect the performance of the Meskat system in WH Basin. The analysis consists of using satellite images and topographical maps of the area to create a spatial repartition. Results proved the damage caused to some features of the Meskat system due to several reasons such as the expansion of urban areas, the planting of the impluvium, the destruction and the segmentation of agricultural fields due to the creation of new roads, neglect and lack of maintenance. The problem of urbanization affects mainly the sub-basins of WD and WHA, with affected area of 1.68 and 1.05 km^2 respectively. The planting of the impluvium affects mostly the sub-basins of B and WB with affected area of 81 and 56 km^2 respectively. The Mankaas destruction is observed in the sub-basins of H and of WS, with an affected area of around 0.77 and 0.66 km^2, respectively. In the long term, the disturbances of the Meskat system may, eventually, increase the vulnerability of the region to erosion and result in the deterioration of existing water harvesting structures. Thus, it is recommended to implement a more rigorous control and maintenance and to reinforce zones with high erosion or inundation vulnerability risks.

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References

[1] Lei, Y., Wang, J., Yue, Y., Yin, Y., Sheng, Z. How adjustments in land use patterns contribute to drought risk adaptation in a changing climate. A case study in China. Land Use Policy, 2014, 36, 577-584.

[2] Briassoulis, H. Combating land degradation and desertification: The land-use planning Quandary. Land Journal, 2019, 8(27), doi:10.3390/land8020027.

[3] Jaouadi, S., Lebreton, V., Bout-Roumazeilles, V., Siani, G., Lakhdar, R., Boussoffara, R., Dezileau, L., Kallel, N., Mannai-Tayech, B., Combourieu-Nebout, N. Environmental changes, climate and anthropogenic impact in south-east Tunisia during the last 8 kyr. Climate of the Past, 2016, 12, 1339-1359.

[4] Sahtout, N., El Amri, A., Fourati, M., Majdoub, R. Les facteurs de la pauvreté hydrique du Grand Sousse: Un déséquilibre en eau agricole en perspective? European

Journal of Scientific Research, 2015, 136 (3), 320-335.

[5] Bakker, M.M., Govers, G., Kosmas, C., Vanacker, V., Oost, K.V., Rounsevell, M. Soil erosion as a driver of land-use change. Agriculture, Ecosystems and Environment, 2005, 105, 467-481.

[6] Roose, E., Sabir, M., Arabi, M., Morsli, B., Mazour, M. Soixante années de recherches en coopération sur l'érosion hydrique et la lutte antiérosive au Maghreb. Physico-Géographie, 2012, 6, 43-69.

[7] El Amami, S. Une nouvelle conception des aménagements hydrauliques en Tunisie. Science et Société. Presse universitaires de France, 1983, 61-68.

[8] Boussaidi, N. Impact de l'action anthropique sur la subéraie Tunisienne: essai de projection dans le futur d'un écosystème (Cas de la subéraie de Kroumirie- Nord Ouest de la Tunisie. Thèse de doctorat. Institut National Agronomique de Tunisie, 2012.

[9] Nasri, S., Lamachère, J.M., Albergel, J. Impact des banquettes sur le ruissellement d'un petit bassin versant. Revue des sciences de l'eau, 2004, 17(2), 265.

[10] Ben Moussa, M., Solé, A.B., Canton, Y., Kouakbi, M., Chehbani, B. Conservation des eaux et des sols cas des Jessour de Braouka. monts des Matmata – Tunisie. Revue des Régions Arides, 2011, 26(2), 81-115.

[11] Achouri. M, La conservation des eaux et du sol en Tunisie: bilan et perspectives. Agriculture. Durabilité et environnement. CIHEAM. Cahiers Options Méditerranéennes, 1995, 9, 35-45.

[12] Houimli, E. Les facteurs de résistance et de fragilité de l'agriculture littorale face à l'urbanisation: Le cas de la région de Sousse Nord en Tunisie. Thèse de Doctorat. Ecole Nationale Supérieure du Paysage de Versailles, 2008, 239-263.

[13] Bouchiha, R., Besbes, K. Contribution of two methods of monitoring evolution of the urban area by Landsat imagery, application to the Tunisian Sahel region. Revue Français de la Photogrammetrie et de Télédetection, 2008, 190, 40-48.

[14] Khaledian, Y., Kiani, F., Ebrahimi, S., Brevik, E., Aitkenhead-Peterson, J. Assessment and monitoring of soil degradation during land use change using multivariate analysis. Land Degredation and Developement Journal, 2016, 28(1), 128-141.

[15] El Garouani, A., Chen, H., Lewis, L., Tribak, A., Abahrour, M. 2008. Mapping of land use and erosion from satellite images and IDRISI GIS in northeastern Morocco. Review of Remote Sensing. 2008, 8, 193-201.

[16] Joliveau, T. Géomatique et gestion environnementale du territoire. Recherches sur un usage géographique des SIG. Mémoire d'Habilitation à Diriger des Recherches en Sciences Humaines. Rouen. Université de Rouen, 2004.

[17] Bouchnak, H., Sfar Felfoul, M., Boussema, M.R., Snane, M.H. Étude de l'évolution du ravinement en fonction de la lithologie dans les bassins versant des Wadis el Hammam et Rmel en Tunisie Centrale. Télédétection, 2004, 4(1), 75-93.

[18] Baccari, N., Boussema, M.R., Lamachere, J.M., Nasri, S. Identification du risque de brèche des banquettes anti-érosives en région semi-aride Tunisienne à l'aide d'ortho-images aérienne et de données multisources dans un système d'information géographique. Télédétection, 2007, 7, 405-417.

[19] Anane, M., Masmoudi, M., Ben Mechilia, N., Oweis, T. Potential sites for hill reservoirs: An assessment methodology using GIS and Remote Sensing Tools. In: Proceeding of a Workshop Watershed

Management in the Dry Area, Jerba, Tunisia, 2008, 109-116.

[20] Abdelli, F., Ouessar, M., Khatteli, H. Méthodologie d'identification des ouvrages existants et des sites potentiels pour les jessours. Revue des sciences de l'eau, 2012, 25(3), 237-254.

[21] Fourati, M, Bouaziz, R., El Amri, A, Majdoub, R. Identification des anomalies de fonctionnement des ouvrages de conservation des eaux et du sol du bassin versant Sidi Salah. International Journal of Innovation and Applied Studies, 2015, 10 (1), 428-434.

[22] Majdoub, R., Brahim Zarrad, M., Khlifi, S., Ben Salem, A. Contribution à l'évaluation de l'effet des aménagements antiérosifs traditionnels sur certains paramètres chimiques du sol: cas du Meskat dans le Sahel Tunisien. European Journal of Scientific Research, 2012, 2, 250-259.

[23] Despois, J. La Tunisie orientale: Sahel et la basse steppe. Études géographiques, PUF, Paris, 1955.

[24] Houimli, E., Donadieu, P. Meskat, a hydraulic system of olive production threatened by urban sprawl; The case of the region of Sousse Nord (Tunisia). Proceedings of the seminar Stages of research in landscape, 2005, 7, 31-43.