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# STATISTICAL ANALYSIS OF MORPHOMETRIC AND HYDROLOGICAL CHARACTERISTIC OF SMALL WATERSHED IN TUNISIA

**Hajji Olfa and Abidi Sahar**
PhD student, Rural Engineering; Water and Forest
National Agronomy Institute-Tunis INAT, Tunis, Tunisia
sahar.abidi@yahoo.fr – olfa.hajji@yahoo.fr

**Habaieb Hamadi**
General Director
National research Institute of rural engineering, Water and Forests (INRGREF) Ariana, Tunisia
habaieb.hamadi@yahoo.fr

**Mahjoub M^ed Raouf**
Professor in hydrology
Higher Engineering and Rural Equipment School (ESIER), Medjez El Bab, Tunisia
Mahjoub_raouf@yahoo.fr

**Abstract— Water erosion affects, in Tunisia, nearly 3 million hectares of agricultural land, and constitutes a threat to the sustainability of small lakes in the hilly regions. Twenty six lakes have been identified in the central part of Tunisia covering the Ridge area and Cap Bon. To predict the siltation in these lakes, we proposed a simple and practical model classification assessing the sediment fluxes at the outlet of the small watersheds and the sediment load of the receiving lakes. We further explored the links between the sediment prediction model parameters and various terrain attributes of the contributing catchments. Three statistical methods are used for the data analysis: the Principal Component Analysis method (PCA), the hierarchical classification method, and finally the step wise linear regression analysis. We identified three different classes of lakes. The first class is less vulnerable to the silting risk and is located on the southern and eastern borders, west of the ridge and the coastal plains. The lakes of this group are characterized by a low rate of silting, a large drainage area, a low relief, a relatively hierarchical hydrographic network and an effect of precipitation and little intense runoff. A second class which is the most degraded environments covers almost the entire semi-arid zone of Central Tunisia. This class has a very abrasive potential watershed, explained by high flow coefficients related, mainly to higher erosive rainfall intensities associated with a moderate or accentuate topography, structure of soil over marl and poor drainage and unimproved surface. The third class exists in the north and south of the Ridge. The catchments of this class are characterized by a moderate to high sedimentation rate which is governed by a more or less marl soil structure and an intense hydrodynamic compounded by the steep slopes of these basins. The represented lake will server to quantify and predict the sedimentation.**

**Index Terms— Silting, Hilly Lake, Principal Components Analysis, Hierarchic Classification, Linear regression, Typology.**

## I. INTRODUCTION

Dams and reservoirs created behind them have represented a domain of interest for geomorphology and resulted in various economical, hydrological and ecological benefits. However, sedimentation is the major problem which endangers the sustainability of reservoirs resulting in slowing down agricultural development and reducing thereby live storage of many existing reservoirs coupled with the limitations of the existing sediment control measures.

Alarming rates of storage depletion have been reported worldwide. The estimated annual loss in storage capacity of the world's water reservoirs due to sediment deposition is around 0.5- 1% [1]. Nevertheless, for North African countries, annual sedimentation rates are much higher and can go up to 4% or 5%, such that they lose the majority of their capacity after only 25–30 years [2]. In Tunisia, the quantity of sediment trapped in the different hydraulic structures of the country occupied 20% of their initial global capacity [3]. Important erosion and sediment transport in this region is highly influenced by the intermittent stream flow and erratic rainfall regimes on a steep topography with fragile soils and sparse vegetation cover.

The phenomenon of filling reservoirs depends on the condition of the soil erosion and deposition processes that are managed by the geological properties, soil, physiographic, hydrographic and anthropogenic watershed as well as hydro-rainfall characteristics. We explain the theory and the results of statistical tools we have used to shape and define the different classes of hill lakes. Our study is done on a sample of 26 hill lakes of different morphometric and hydrological characteristics. The choice of this region is justified by the fact that the study area is considered the heart of Tunisia, which has a remarkable succession of mountainous alignments. It suffers from both low economic development and environmental degradation in association with increased pressure on natural resources.

In this study, a multivariate statistical approach was used to identify the dominant factors which contribute to sediment yield variability in various semi-arid mountainous areas located in Central Tunisia. The main objective of this paper is to form different classes of hilly Lakes, by using statistical method, and to define a representative lake of each class.

## II. STUDY AREA

The present study focuses on 26 hill lakes in Central Tunisia, along the Dorsal and Cap Bon area of great contrasts on all scales (Fig.1). The study area is a semi-arid mountainous region that extends from the Algerian border in the West to the Cap Bon in the North-East. Implemented at the outlets of relatively small mountainous catchments, these artificial reservoirs are affected by water erosion.

The climate of the study area is Mediterranean type characterized by dry summers followed by intense autumn rainfall. The precipitation regime is very irregular and has an erratic distribution combining scarcity with tendency to fall in torrents. Annual rainfall gradient generally varies between 250 mm and 550 mm while mean annual temperature varies between 18 and 20°C. Indeed, the mountains of the dorsal constitute a climatic barrier, where the South Eastern zones are drier than those of the North West.

We conclude from the morphometric study that the majority of sites of hill lakes developed in the semi-arid ridges, mostly defined by topography and mountain terrain, generally have elongated shapes with areas ranging from a few hectares to a few tens of kilometers square and moderated to high relief.

The land watershed consists mainly of farmland (Arboriculture, market gardening, cereal), representing 40-70 % of the area under the watershed. We also note the presence of forests in some regions especially in the Cap Bon and north of the Ridge with a rate up to 35%.

The predominance of climate irregularity, torrential flows, moderated to high relief, low densities of vegetation cover and land overuse are all factors that promote soil erosion in our region. Then to reduce this effect, it becomes necessary to implement erosion control facilities whose purpose is to reduce soil loss and keep the soil in place. The density of such arrangements must not affect the good filling reservoirs. Physical factors in our study area are all in favor of an emphasis liquid intake and an acceleration of the phenomenon of erosion.

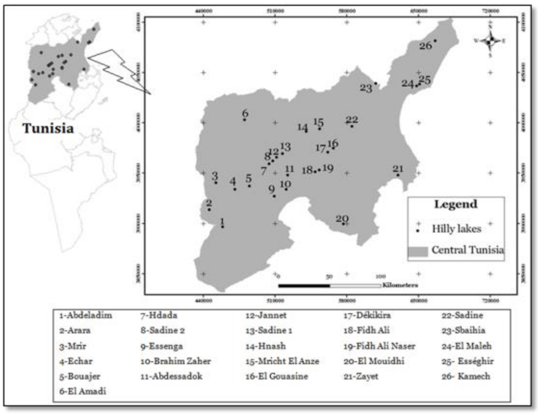


Fig. 1. **Location map of the hilly lakes**

## III. Statistical Analysis of Morphometric and Hydrological Characteristics

Spatial variability of sediment yield in this study is controlled by morphometric catchment characteristics which were derived from digitalized maps (topographic map, drainage network map, geologic map, land use and vegetation cover map) developed within the HYDROMED research program [4]. Major topographic attributes used are drainage area (A), compacity index (Ci) and a relief parameter known as the overall index slope (Gi).

Another important parameter that may influence sediment yield is the total drainage length (Ltw). Hydro-climatic factors such as maximum rainfall intensity in 30 minutes (I30), runoff depth (Rd), runoff coefficient (Rc) and the ratio of dam initial capacity to inter-annual flow contribution (C/A), were obtained from DGACTA reports (1994-2006) and were considered to characterize the flow erosion potential. Anthropogenic activities and land use pattern are represented in this study by the fraction of cultivated by forest land (Ar/Fr) and the percentage of soil conservation works (WSCW). Finally, soils and surface lithology represented by the fraction of clayish marl area (ERL) could also serve as a proxy to describe the erodibility potential.

In this work, we will rely on statistical analysis of multivariate types to manage the information provided by the used parameters. Multivariate analysis is a useful technique for identifying common patterns in data distribution, leading to a reduction of the initial dimension of data sets and facilitating their interpretation [5]. Statistical analyses were carried out by the statistical software (XLSTAT 2013). So after visually interpret the correlations between variables, using the correlation matrix, we will use three methods of analysis. The first is the Principal Component Analysis (PCA) method of descriptive analysis to synthesize the most relevant information of the data used. The Hierarchical Classification method (HC) will, in turn, quantify the effect of these factors in prioritizing the different watersheds. Then we will use the linear regression of "Step wise" or Type "step by step" to finally get a relationship that expresses the parameters on the erosive process. By comparing the different results, we will try to identify a typology of hill lakes and explain the reasons for such assemblies.

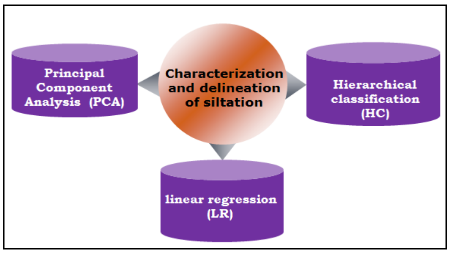


Fig. 2. **Methods of statistical analysis**

## IV. Results and Discussion

### *A. Characterization of siltation based on the hierarchical tree*

The fundamental objective is to define stable and homogeneous groups of small lakes monitored while combining similar elements. Each level represents a class hierarchy [6]. It is, in fact, a tree whose terminal elements are the elements classified. Each intersection of this tree is a node. This node represents a class that decomposes itself into two subclasses, the eldest and the youngest, according to the Euclidean distances between them.

The hierarchical classification is applied on 26 lakes hillside reservoirs of Tunisia in central function of 7 variables hydro-morphometric following falling within the physiography of watersheds: the index of overall slope (Gi), the index of compactness (Ci), the length of the settle (Ltw), the nature of runoff and drainage (Rc, Rd) and climatic erosivity of acid (I30) as well as the rate of abrasion (Ta) as the dependent variable.

Of first view, it is clear from the figure below that the taxonomy developed is virtually compatible with the one edited by the analysis of different methods (correlation matrix, ACP and linear regression). In addition, a growing ability and contradictory to the dynamics of the siltation of withholding of lakes hillside reservoirs is observed ranging from the class (1) to (3), of the low to the high potential of abrasion.

The typology unveiled pleaded in favor of the identification of three classes of lakes hillside reservoirs. In effect, the hilly lake 'El Gouazine' (N°16) paints to the larger surface area of drainage and the lowest rate of abrasion. Unlike the hilly lake Dekikira (N°17) is characterized by a catchment whose shape is the more elongated which allows the coalescence of nets of water and the formation of gullies accentuating the ablation of earth. In addition the hilly lake Sadine (N°22) may designate the court or the central core which is governed the spatial variability of the phenomenon of siltation in the study area.

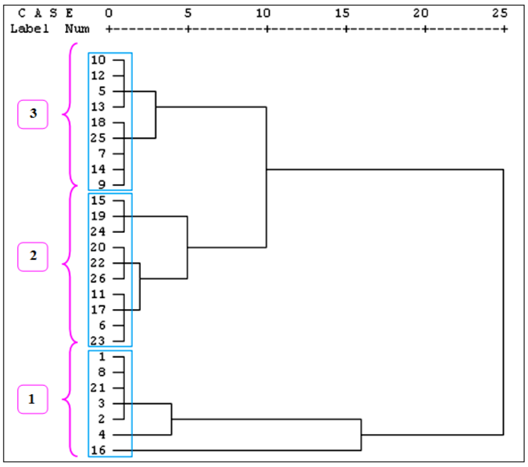


Fig. 3. **Dendrogramme resulting from the hierarchical classification of hilly lakes**

- **Class I:** includes the lakes number 1, 8, 21, 3, 2, 4 and 16, characterized by a low rate of siltation, a low relief and a little intense runoff.
- **Class II:** includes the lakes number 15, 19, 24, 20, 22, 26, 11, 17, 6 and 23, characterized by high rate of sedimentation, high flow mostly associated with most high intensities erosive rainfall coupled to topography moderate or high.
- **Class III:** includes the lakes number 10, 12, 5, 13, 18, 25, 7, 14 and 9, characterized by moderate to high rate of sedimentation. This character is governed by an intense hydrodynamic aggravated especially by the steep slopes of watersheds.

*B. Principal component analysis*

Graphical representations from the principal component analysis allowed to subdivide basins studied in 3 groups (Fig.4):

The first group "the less vulnerable to the risk of silting" locates on the southern and eastern borders of the West Ridge and also on the coastal plains (colorated in pink). It includes the lakes number 1, 3, 4, 5, 16, 21 and 25 which are characterized by a low rate of siltation, a large surface drainage, low relief drainage system relatively hierarchical and an effect of precipitation and runoff little intense . This class is also slightly affected by the various forms of erosion, due to the multiplication of the conservation of soil and water in combination with continuous vegetation cover which contribute significantly to fold the abrasion rate of these lakes. As such, some watersheds (as El Gouazine N°16) show the effectiveness of anti-erosion benches.

A second group comprises "the most degraded" cover almost all the semi-arid zone of Central Tunisia (clorated in yellow). This group includes the lakes number 6, 8, 13, 15, 17, 18, 19, 20, 22, 24 and 26. It is characterized by abrasive potential, explained by high flow coefficients related especially at the highest erosive rainfall intensities, moderate or severe topography, soil structure more marl and surface drainage unoccupied and undeveloped. We deduce, therefore, that in this class, raises the erosion and sediment dynamics and yielding large quantities of soil particles to concentrate at a specific core of the Dorsal (case watershed Sadine N°22). Therefore, this class must be taken as a priority area of intervention to fight against the scourge of clogging.

A third group extends on either side of the North and South sides of the ridges, includes the lakes number 2, 7, 9, 10, 11, 12, 14 and 23. It is characterized by "moderate to high rate of sedimentation" (colorated in blue). This sedimentation rate is governed by a structure more or less marl soils and intense hydrodynamic compounded by the steep slopes. The evolution of surface exposed to the combined action of traditional farming practices, changes in land use (mechanized farming) and a very variable climate from north to south, may strongly condition the flow, infiltration, erosion and therefore, sedimentation (case of lake El Hnach N°14).

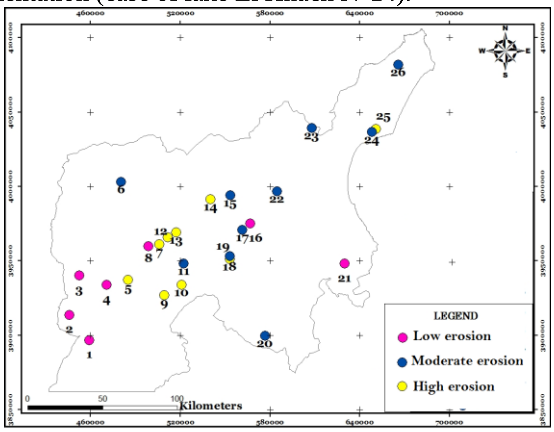


Fig. 4. **Map of geographical location of 3 groups**

*C. Characterization of the siltation based on linear regression*

After determining the affinities between the sedimentation and the dependent factors by the principal component analysis and the subdivision into groups of the basins studied, another step statistics has been affixed. To examine more the effect of weighting of the axis of the PCA and settings that they characterize, a linear regression (or Step wise) has been applied to the pins from the principal component analysis in function of the rate of siltation. In which we start from the best regression of a variable, in order to perceive if the introduction of the new explanatory variables step by step does not justify the elimination of variables already introduced in the model. It stops when no variable brings sufficient reduction of residual variation.

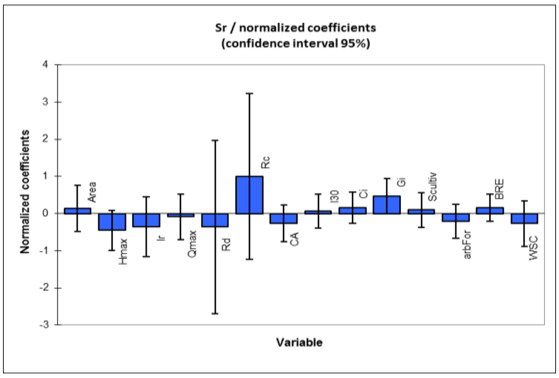


Fig. 5. **Variation of the siltation rate in function of the different variables**

The variables offering the best regressions are the index of slope (Gi) and the runoff coefficient (Rc). The sedimentation rate is given by the following equation:

$$Sr = 0,993\ Rc + 0,466\ Gi \qquad (1)$$

Based on the coefficients from this equation, introducing a coefficient of determination if important to the order of 78 %, it is demonstrated that the siltation rate is more sensitive to the fluctuation of the shape of the watershed and the hydrographic network. In addition, the analysis of the general trend of the siltation is due to natural effects and predominant of anthropogenic hydro-climatic conditions.

This illustrate that, the variability of siltation rate depends on the variability of the factors which control the process of silting (shape of the basin, the density of the hydrographic network, the status of the vegetation cover, nature of the soil, anthropogenic activities and hydro-climatic conditions).

The graphic below gives the prediction of the silting rate of the different small lakes.

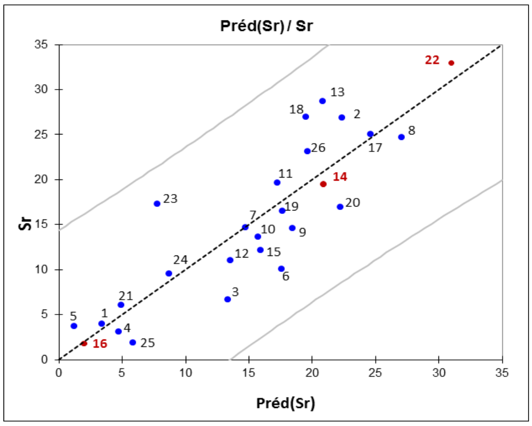


Fig. 6. **Prediction of the silting rate**

It proves also a special feature indicated by the location of the watershed El Gouazine (N° 16). This watershed is more distant than other watersheds. This can be explained by the importance of its drainage area that generates the reduction of siltation rate in the lake. In this context, this watershed displays the effectiveness of water and soil conservation technics.

The anti-erosive arrangements operates in favor of an overall reduction of erosion in the watershed and has a lifetime exceeding 100 years as three other lakes that are Echar, Abdeladim and Es Séghir.

Another particularity is indicated by Sadine (N° 22). This lake is characterized by its steepness (Gi> 100 m/km) and the most alarming siltation rate in the study area ((Sr) exceeding 31 tonnes/ha/year). The ability of abrasive Sadine Lake is especially enhanced by the susceptibility of marly soil erosion and the rain highly erosive (maximum recorded during the period 1994-2006 equal to 250 mm/h).

## V. Conclusion

A high spatial variation in area specific sediment yield among the 26 studied small dam reservoirs in Central Tunisia is observed. The average sediment yield is approximately of 15 t $ha^{-1}$ $y^{-1}$, which is relatively high compared to African average values.

Major factors affecting erosion and siltation were identified. The analysis indicates that there are morphological catchment properties, land use, soil lithology that are useful as aids to predict sedimentation rates. A single criterion cannot determine the erosion of soils on little catchments in the Tunisian mountain range.

Multivariate statistical analyses were performed to assess the role of different catchment variables in the sediment yield of reservoirs and to see the spatial distribution of reservoir sedimentation throughout mountainous areas located in various hydro-climatic, geologic and geomorphologic zones.

In the light of these analyzes, it appears that the study area was divided into three areas of different abilities may siltation:

The first class is less vulnerable to the silting risk and is located on the southern and eastern borders, west of the ridge and the coastal plains. The lakes of this group are characterized by a low rate of silting, a large drainage area, a low relief, a relatively hierarchical hydrographic network and an effect of precipitation and little intense runoff.

A second class consists of the most degraded environments and cover almost the entire the semi-arid zone of Central Tunisia. This class has a very abrasive potential watershed, explained by high flow coefficients related mainly to higher erosive rainfall intensities associated with a moderate or accentuate topography, structure of soil over marl and poor drainage and unimproved surface.

The third class exists in the north and south of the Ridge. The catchments of this class are characterized by a moderate to high sedimentation rate. The sedimentation rate is governed by a more or less marl soil structure and an intense hydrodynamic compounded by the steep slopes of these basins.

Indeed, it turned out that the most degraded areas cover almost all of the semi -arid zone of Central Tunisia and because of the altitude of the mountains, increasing continentality towards the West, increasing aridity southward and finally opposition sides. The semi-arid environment is far from being a homogeneous whole geomorphological and bioclimatic. Although the results generated have clarified the study of conditional factors siltation, it is remarkable that this phenomenon remains as complex as it can only be understood by integrating multiple attributes simultaneously. This suggests not only the complexity of monitoring clogging deductions hill reservoirs, but also its non- linear character. To overcome such a problem, the use of other non-parametric techniques, such as the application of artificial intelligence, is required.

## Acknowledgment

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