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Haiji, Olfa; Abidi, Sahar; Habaieb, Hamadi; Mahjoub, Mohammed Raouf

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Regionalization and Contribution to the Study of Reservoirs Sedimentation: Lakes of Cape Bon and the Tunisia Central

O. Hajji, S. Abidi & H. Habaieb
National Agronomy Institute of Tunis, Tunisia

M.R. Mahjoub
Hydraulics and Environment Higher Engineering and Rural Equipment School (ESIER) Medjez El Bab, Tunisia

ABSTRACT: In Tunisia, during the last two decades, the hilly Lakes occupy an important place in national strategies for water and soils Conservation (WSC). In addition to their role as protection of the environment, the hilly lakes appear as local reserves of water available for agriculture. Nevertheless these hydraulic infrastructures are rather sensitive to sedimentation due to solid contributions. In Tunisia, water erosion affects nearly 3 million hectares of agricultural land, and constitutes a threat to the sustainability of these hilly reserves. 26 hilly lakes are distributed in the Tunisia central and the Ridge until the Cap Bon. To conserve these reserves, we have research to find a simple and practical methodology which allows assessing the relative contribution of water erosion in sediment fluxes at the outlet of the small watersheds and to seek preferential links between the various explanatory attributes of sedimentation. To achieve this aims, extract a typology of the sedimentation variability of 26 hilly Lakes, is required.
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. Based on the correlation table, the correlations between different variables are interpreted. Then three methods of analysis are used: the ACP; a descriptive analysis method to synthesize the most relevant information of the data, the hierarchical Classification to quantify the effect of the data in prioritizing different watersheds and the linear regression type 'Step wise' or 'Step by step' to finally get a relationship that expresses the parameters affecting the erosive process. By crossing the different results we try to identify a typology of hilly Lakes and to explain the reasons for such assemblies. The results deduct three classes. The first group is the less vulnerable to the silting risk and is located on the southern and eastern borders West of the ridge and on the coastal plains. The lakes of this group are characterized by a low rate of silting, a large drainage area, a low relief, hydrographic network relatively hierarchical and an effect of precipitation and little intense runoff. A second group includes the most degraded environments cover almost the entire of the semi-arid zone of Central Tunisia. This group have 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 a drainage non occupied and unimproved surface. A third group extends share and other sides north and south of the Ridge, has the catchment 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 This study permitted to extract the preferential links between the various explanatory attributes of siltation, and to develop a typology of the reservoir siltation variability. Although the generated results have clarified the study of conditional factors of silting, it is remarkable that this phenomenon remains as complex to the point that it cannot be apprehended by the integration of multiple attributes at the same time. This suggests not only the complexity of monitoring of clogging of the hilly Lakes deductions, but also its non-linear character. In order to overcome such a problem, the use of other non-parametric techniques, such as the application of artificial intelligence, is recommended.

Keywords: Silting, Hilly Lake, Principal Components Analysis, Hierarchic Classification, Linear regression, Typology

1 INTRODUCTION

Tunisia is among, in North Africa, the most affected by the seriousness of the problem of siltation, including its central part country. In fact, Central Tunisia, playing an important role in the hydrology of the country is characterized by the extent of water erosion which generates a fairly high rate of filling (about 1.27%). Early studies of siltation of small reservoirs were emerged in 1993 with a network of hydrological observations and monitoring of small lakes in partnership between the Directorate General of District Water Conservation and Soil and Research Institute Development to ensure better monitoring and control of small lakes. Although these small artificial ponds are good sediment traps, their storage capacities are also inexorably condemned to rapid filling, estimated at 5 tonnes / ha / year, resulting in a consequent reduction in their lifetime in the medium to long term (Boufaroua, 2006).

Since the sedimentation process is "temporal and spatial discontinuity", characterization and numerical prediction or mapping of the phenomenon of siltation are imposed as a tool for decision support for rational management and sustainable water resources and soil. In this context, the use of statistical processing multi-varied proves to be an effective means, first, to define the critical between hydromorphological and anthropogenic factors and the sedimentation process interactions, and other part, for the development of a typology of the spatial variability of siltation. It is in this prospective study is that the contribution and the regionalization of siltation of 26 small lakes located in the semi-arid zone of Central Tunisia, using a multivariate parametric analysis (correlation matrix analysis principal component regression and hierarchical classification) revealed that the process of sedimentation and siltation.

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. Based on the correlation table, the correlations between different variables are interpreted. Then three methods of analysis are used: the ACP; a descriptive analysis method to synthesize the most relevant information of the data, the hierarchical Classification to quantify the effect of the data in prioritizing different watersheds and the linear regression type 'Step wise' or 'Step by step' to finally get a relationship that expresses the parameters affecting the erosive process.

2 MATERIALS & METHODS

2.1 *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 (figure 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 600 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.

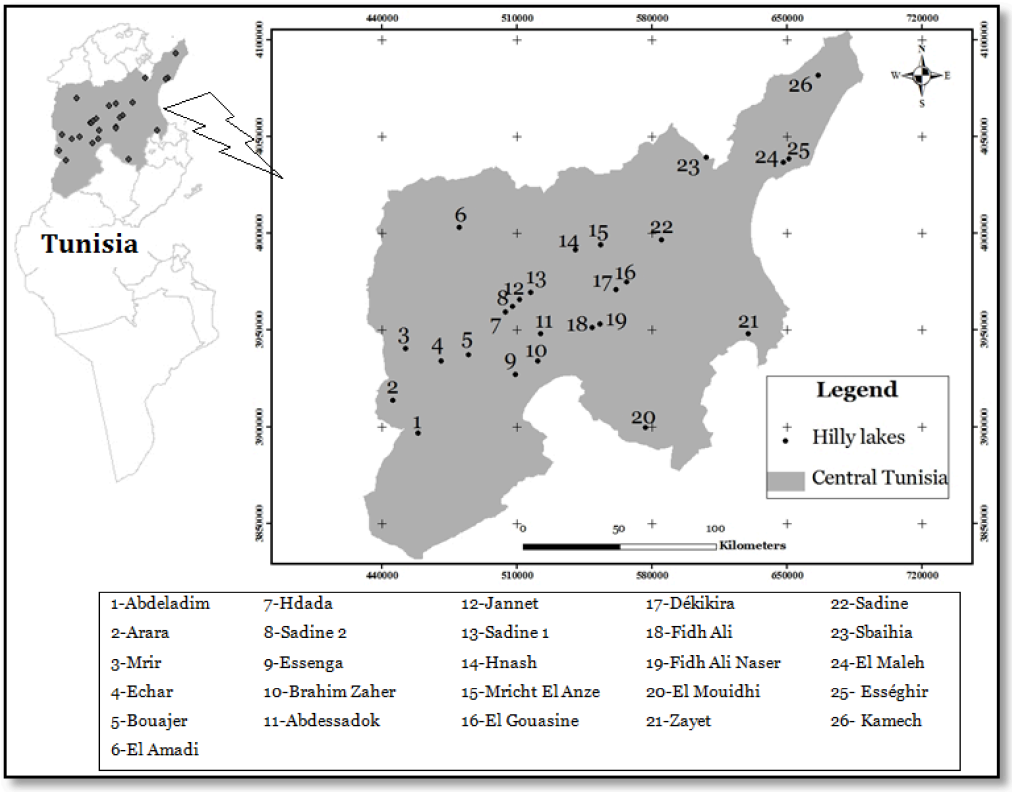

Figure 1. Location map of the hilly lakes

The majority of information used was collected from publications (directories hydrological) of the Directorate General for Development and Conservation of Agricultural Land (Ministry of Agriculture, DG / ACTA) in cooperation with the Research Institute for Development (RID-Tunisia). These publications were developed during the period between 1994 and 2006 as part of the research project HYDROMED on small lakes in the Mediterranean (Albergel et al., 2001).

2.2 *Methodology and analysis approach*

A purpose of identifying the main factors that influence the variability of erosion and siltation of small dams, a multivariate analysis of different process parameters hydromorphométriques watershed is maintained through various parametric multivariate analyzes. The study was apprehended by the statistical software XLSTAT (2013) for 216 observations of 26 people (small lakes) and 15 variables. We will rely on the multivariate statistical analysis types to manage the information provided by the parameters used. Multivariate analysis is a useful technique to identify common patterns in the data distribution, which leads to a reduction in the initial size of the data sets and facilitate their interpretation (Castellano et al, 2007). After visually interpreting the correlations between variables, using the correlation matrix, we use three methods of analysis. The method Principal Component Analysis (PCA) of the descriptive analysis to synthesize the most relevant information of the data used. The hierarchical clustering method (HC), in turn, to quantify the effect of these factors in the prioritization of different watersheds. Then, we use linear regression to "Step wise" or "step by step" type to finally get a relationship that expresses the parameters on the erosion process. By comparing the different results, we will try to identify a typology of hill and explain the reasons for these meetings lakes.

The spatial variability of sediment in this study is controlled by morphometric characteristics watersheds were calculated from digitized maps (topographic map, map of drainage, geological map, land use and land cover map) developed in the research program HYDROMED (Albergel et al, 2001). Major topographic attributes used are the drainage area (A), the compactness index (Ci) and a parameter known as the terrain slope of the overall index (Gi).

Another important parameter that can affect the sediment yield is the total length of drainage (LTW). Hydro-climatic factors such as the maximum intensity of rainfall in 30 minutes (I30), the depth of runoff (Rd), the runoff coefficient (Rc) and the report of the initial capacity of the dam contribution of interannual flow (C / A) were obtained from DGACTA reports (1994-2006) and were considered to characterize the potential for erosion of the stream. And anthropogenic land use model activities are represented in this study by the fraction of cultivated land by forest (Ar / Fr) and the percentage of soil conservation

works (WSCW). Finally, soils and lithology surface represented by the fraction of the surface of clay marl (BRE) could also serve as a proxy to describe the potential erodibility.

3 RESULTS AND DISCUSSION

3.1 *Characterization and delineation of siltation based on Principal Component Analysis (PCA)*

These are all methods to carry out linear transformations a large number of cross-correlated in order to obtain a relatively variables limited uncorrelated components called "main components" or axes, while keeping the maximum amount of information (Castellano et al, 2007).

The following figures show after the performance of individuals on the factorial plane formed by two axes (F1*F2) and (F1*F3) of the PCA. These figures allow us to distinguish between three main groups. Differentiation between these three groups is based on the effect of changes in natural factors (vegetation cover, soil type) and anthropogenic (WSCW) is personalized axis F2. Differentiation between these three groups is based on the impact of rainfall aggressiveness resulting in exceptional floods is personalized F3 axis.

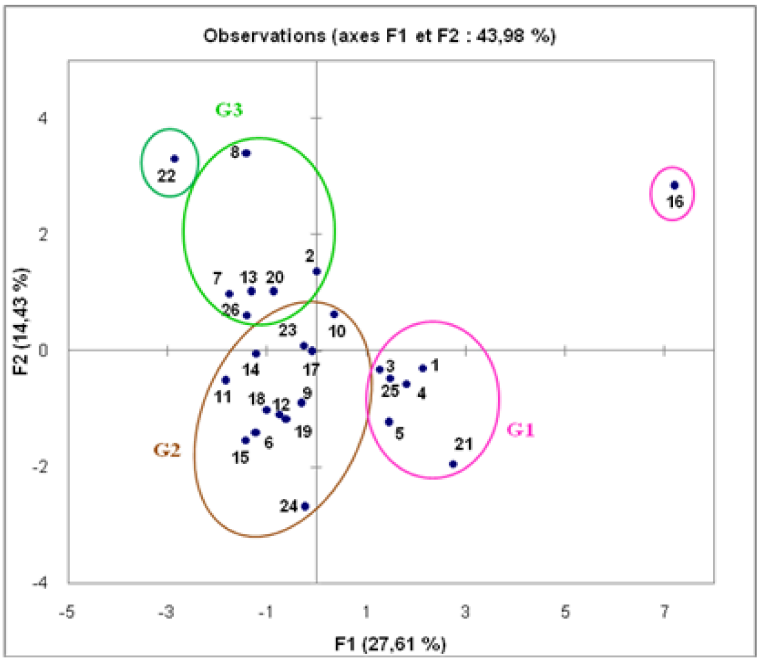

Figure 2. Individuals representation on the axes of PCA (F1* F2)

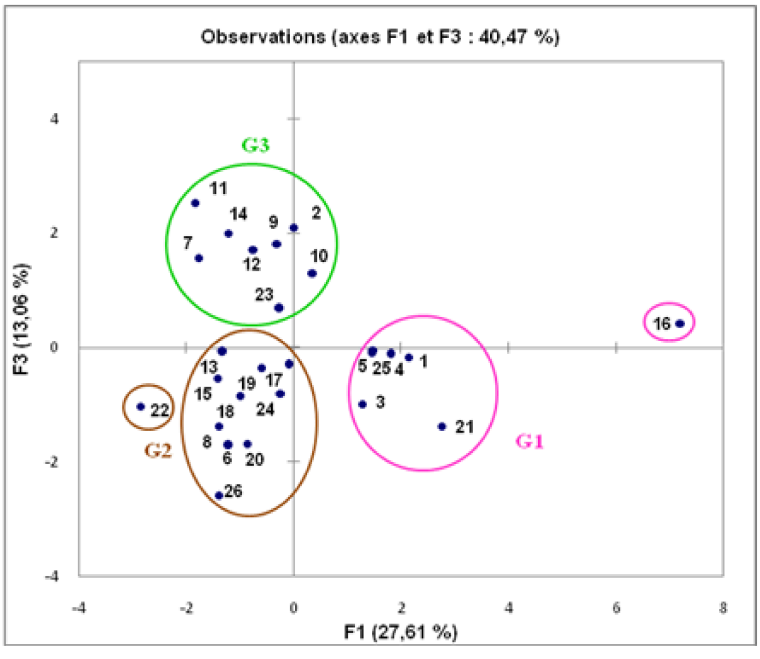

Figure 3. Individuals representation on the axes of PCA (F * F3)

The comparison between the two representations, visualizing the projection of the eigenvalues of individuals on the axes of the PCA (F1 * F2) and (F1 * F3) take depending on the filter variable, highlights mobility some watersheds on both sides of the second and third group. The new clan is sold off by the lake hill Sadine (N° 22), which is characterized, in addition to its steepness (Gi> 100 m / km), the most alarming in the study area siltation rate ((Sr) exceeding 31 tonnes / ha / year). The ability of abrasive Sadine lake is especially enhanced by the susceptibility of marly soil erosion. Indeed, these soils undergo the most significant rainfall intensities with the highest 30 minutes paroxysmal rainfall events (maximum recorded during the period 1994-2006 equal to 250 mm / h). These downpours highly erosive, runs off a watershed highly cultivated and undeveloped generating, therefore, prominent amounts of sediment deposited on the bottom of the reservoir lake and leading to his early clogging.

3.2 *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 (Saporta 1990). 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.

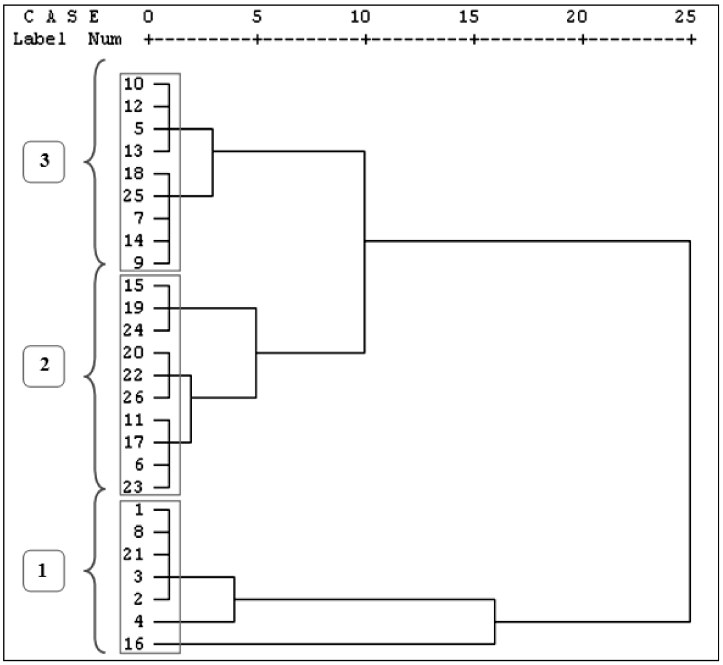

Figure 4. Dendrogramme resulting from the hierarchical classification of hilly lakes

- 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.

3.3 *Characterization of 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 better examine 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 share the best regression to a variable, in order to watch if the introduction of new explanatory variables does not justify the elimination of variables already introduced in the model. It stops when no variable brings sufficient reduction of residual variation.

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:

$$\mathbf{Sr = 0{,}993\ Rc + 0{,}466\ Gi} \quad (\text{With } R^2 = 0.78 \quad \text{and} \quad N = 26)$$

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, it is by fate that the analysis of the general trend of the siltation is due to natural effects and predominant anthropogenic the hydro-climatic conditions.

This shows that, as the has loosed Walling (1994), the variability of siltation rate depends on the variability of the factors which control the process of silting up (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 superposition of the different results of the multivariate analysis of hydrometric and hydrological parameters of the study area, have allowed us to regionalize these 26 small lakes in 3 groups (Figure 5):

First group less vulnerable to the risk of silting locates on the southern and eastern borders of the West Ridge and also on the coastal plains (square mark). 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 (triangle mark). 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 (circle mark). 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).

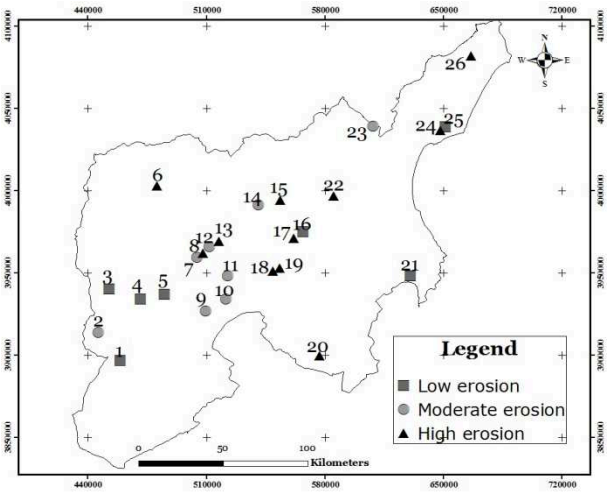

Figure 5. Map of geographical location of 3 groups

4 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. 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.

NOTATION

Sr : sedimentation rate
Rc : runoff coefficient
Gi : index of slope
R^2 : correlation coefficient

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