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Integrated elaboration of priority planning of vulnerable areas to soil erosion hazard using Remote Sensing and GIS techniques: A pilot case of the Oued Beht Watershed (Morocco)

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Abstract
The study deals with the implementation of spatial tools to analyze the socio-ecological information that allows developing strategic orientations linked to the spatial planning of Oued Beht watershed. Thus, the obtained interactive mode is based on a spatial autocorrelation approach and focuses on the geoprocessing of statistical information to delimit areas that require priority planning and to provide significant visual results for the manager. The spatial structure modelling obtained, as z-score, expresses the interactions between erosion hazard and boundary conditions which will be modified by the proposed action plan. The results are synthesized in decisional maps using Hot Spots Analysis. Indeed, the integration of the priority areas in the obtained geographic information system (GIS) offer an excellent tool for monitoring soil degradation and erosion control development adapted to local conditions. The socio-ecological vulnerability characterizes 32% of watershed and the priority areas are generally occupied by soils with strong erosion risks. Specifically, the final development map is used to highlight actions to be taken in areas requiring priority management. Therefore, the spatial analysis of all results led to define efficient biological actions for erosion control such as fruit trees plantation, reforestation in degraded areas; and to identify mechanical measures (terracing, benches, ditches and correcting ravines) in order to mitigate the negative impacts of water and soil losses.

Keywords: erosion control, watershed, hazard, remote sensing, spatial autocorrelation, Morocco.

1. Introduction
The soil erosion characterizes the majority of Morocco reliefs and a spectacular expansion of erosion processes reveals more disturbing aspects. Hence, the soil degradation, upstream of the catchments, is the origin of dam siltation phenomenon and decreasing storage capacities of Moroccan dams with 75 million m^3/year [1]. Moreover, the human context is difficult and generally characterized by high density of rural population [2-3]. Therefore, the erosion hazard imposes significant costs on the Moroccan economy by reducing soil productivity and the consequences are manifested by dam siltation.
In this work, the first results obtained have analyzed the importance of erosion in the Oued Beht watershed and revealed that combined erosion forms are meaningful (sheet, rill and gully) and many factors, both physical and human, promote erosion risk [4-5]. Thus, the soil erosion hazard evaluation presents moderate to high risk areas with 28% and unstable environments are dispersed in different slopes [4-5]. Indeed, the bathymetric data has shown that the El Kansra dam siltation average is 3 million m^3/year [6].
Therefore, the objective of this paper is to investigate an integrated roadmap of biophysical, hydrological and socioeconomic backgrounds and to develop a dynamic methodology that will identify and visualize development scenarios. Thus, the specific objectives are:

- to analyze the biophysical and social context and highlight the environmental constraints ;
- to develop the spatial modeling of soil and water degradation processes with integration of empirical models in a GIS environment to determine the potential soil loss ;
- to prescribe the strategic orientations of a master plan management linked to erosion control ;
- to define the action plan to be used in priority areas (hot spots) and identify the biological and mechanical actions to be implemented in order to mitigate negative effects of erosion hazard.

2. Materials and methods

The main objective of this study is to improve knowledge about the hydrogeomorphological processes in order to help decision makers on good environmental governance and a better long-term cohabitation with soil erosion impacts. Indeed, the preparation of input data and spatial analysis of erosion hazard in the Oued Beht watershed are produced in GIS environment tool. Therefore, the simulation of biophysical and hydrometeorological data is based on empirical models (Universal Soil Loss model, Gradex model and Francou-Rodier method) to analyse and produce decisional maps, which are useful for the prevention of soil loss and El Kansra dam siltation. Thus, the present vulnerability assessment is qualitative, not integrate temporal variations. This is primarily due to insufficient data on vulnerability, particularly related to the lack of historical information about potential damage. Hence, the socio-economic analysis is obtained using surveys data to prepare a reference situation for future environmental and socio-economic projects.

2.1. Study Area

The Oued Beht Watershed is located upstream of El Kansra dam (85 km east from Rabat), it acrosses the Central Highlands and the Middle Atlas of Morocco. The main stream is Oued Beht, affluent of Sebou river one of the most important Watershed in the kingdom. Thus, the Watershed overlaps the administrative territory erected into five provinces and twenty six Rural Communes (Figure 1). It owns a developed urban system, occupying a central place in socio-economic activities; it is Khémisset city (542,000 inhabitants), Azrou (47,540 inhabitants) and urban centres of Agourai and Ain Leuh [7].

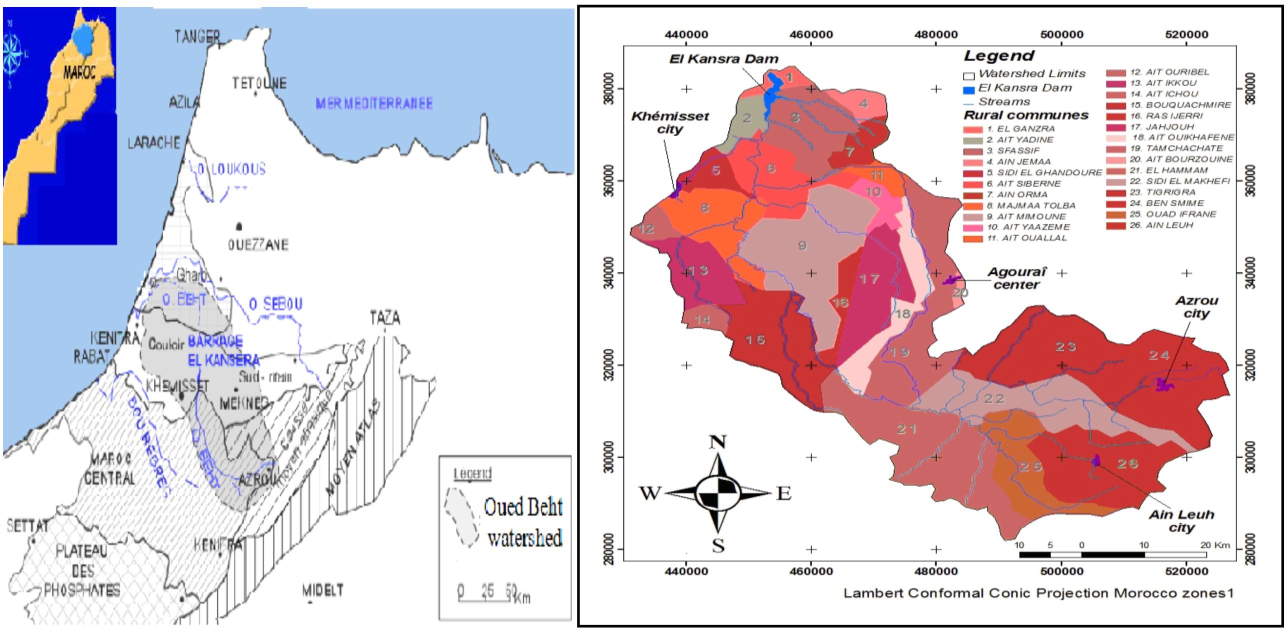


Figure 1: Geographic location of the Oued Beht watershed.

The mapping of the Watershed in the Geographic Information System (GIS) provides a total area of 430,728 ha with an elongated form (Figure 1). Concerning climate context, the Oued Beht watershed has characteristics of the Mediterranean climate with a rainy winter and a dry summer [6].

2.2. Methodological context

The guidelines of the watershed management is based on critical analysis of the current situation and the definition of predictive interventions to revitalize natural ecosystems and to support the local population needs of forage and fuelwood. Thus, the implementation of the spatial aggregate functions is used to identify priority areas by statistics combination of significant values (hot spots) in the GIS database. The Hot Spots analysis is used to calculate the Getis-Ord Gi statistics for each pixel from neighboring entities in spatial data set [8].

2.2.1. Mapping of erosion susceptibility

The input data preparation and spatial analysis of projected actions to control loss soil hazard are performed in the GIS environment. Therefore, the biophysical and hydro meteorological data assessment is based on empirical models to produce decisional maps of the priority areas to be developed.

. *Biophysical and hydrometeorological data*

The data used for the susceptibility analysis are grouped into five groups of explanatory variables linked to climatic, topography (gradient/length slopes), geological and geomorphological data, hydrographic parameters (river density) and soil occupation. Thus, thematic maps are produced by geoprocessing of obtained information.

The map of climatic aggressiveness (R) is based on the spatialization of climatic data available in the stations characterized by long observation periods more than 20 years [9]. Therefore, the topographic parameters (LS) are derived from the Digital Elevation Model (DEM Aster) and the planimetric and altimetric accuracies are respectively 30 m and 20 m.

The interpretation of the soil characteristics is used to classify soils in the Wischmeier Abacus and to approach erodibility factor [10-11-12-13]. Thus, the land cover map is extracted from SPOT satellite images (resolution is 20 m) combined with recent Landsat ETM+ imagery through the supervised classification method.

. *Decisional maps*

Soils susceptibility assessment (A) corresponds to the spatial occurrence of soil loss (number of pixels) that has taken place under the impact of local environmental conditions. The soil susceptibility is simulated by the Universal Soil Loss model [14-15] considered as the most robust approach for spatial assessment of the soil erosion hazard.

$$A = R . K . LS . C . P \tag{1}$$

A: Average annual soil loss (ton/ha/year).
R: Rainfall erosivity factor.
K: Soil erodibility factor.
LS: Topographical factor with slope length and slope gradient.
C: Land cover factor.
P: Erosion control practices factor.

In the Oued Beht watershed, the study of the biophysical environment shows the absence of erosion control practices in agriculture and fruit trees lands, therefore the P-factor takes the value of 1.

Secondly, hydrometeorological analysis is used to deal with flood sites. Thus, the Gradex model determines the flood flows characteristics and return period in the gauged station (Ouljet Sultan station) located in the watershed Strait [16]. Thus, the obtained data are extrapolated to the other sub-catchments by Francou-Rodier method based on the regional coefficient (k_T) calculated in the Ouljet Soltane station [17]:

$$Q(T) = 10^6 . \left(\frac{S.SBV}{10^8}\right)^{1-(k_T/10)} \tag{2}$$

Q(T): Flood flow in ungauged sub-catchment for return period (T).
S.SBV: Area of ungauged sub-catchment (Km²).
k_T: Regional coefficient that characterizes the gauged Ouljet Soltane station for return period (T).

$$k_T = 10 \,.\, (1 - \frac{\ln Q_A / 10^6}{\ln S_A / 10^8}) \qquad (3)$$

Q_A: Flood flow in gauged sub-catchment for return period (T).
S_A: Area of gauged sub-catchment of Ouljet Soltane (Km²).
The final map is the result of geoprocessing and spatial crossing of information linked to soils degradation and flood power which contribute to El Kansra dam siltation located downstream. Thus, the production of this qualitative map is used to provide a systematic vision to identify priority areas with homogeneous environmental characteristics and to study the alternatives of development strategies of the catchment.

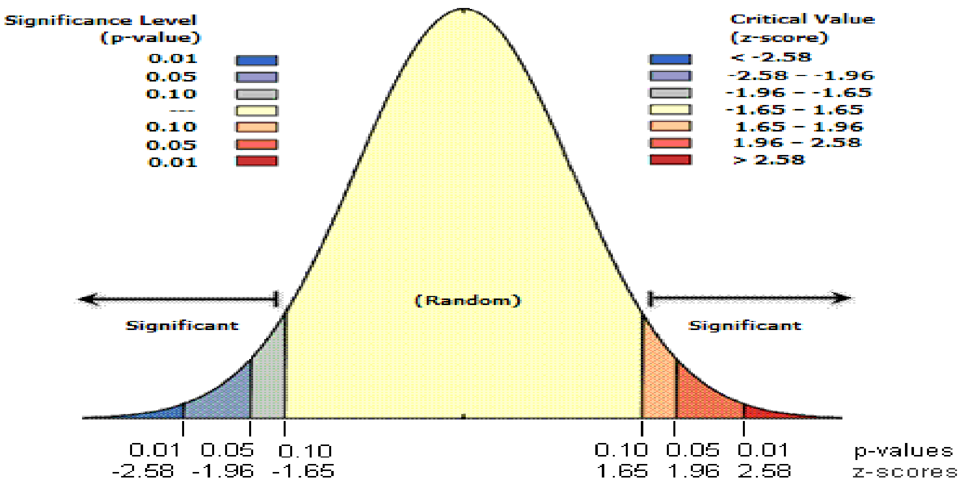
2.2.2. Socio-economic analysis

The methodological protocol used to characterize the socio-economic aspect is based on surveys data [2-3]. Thus, the analysis of mechanisms essentially linked to lifestyle, needs and household incomes are used to better understand the socio-economic vulnerability. The aim is to prepare a reference situation for future socio-economic or environmental projects.
The surveys are conducted through homogeneous area (called Douar) using a direct conversations form with surveyed groups (Focus-group), with a freedom to structure the interview to better understand the population profile, their real needs and to identify constraints that limit wealth production (biophysical constraints, land structures, income composition). The farms distribution is selected using a stratified sampling plan with 5% error and 95% confidence level. The randomness of the « Douars » is made from the list available in the General Agricultural Census [18]. Thus, in order to reduce the heterogeneity linked to Utilised Agricultural Land (SAU), which represents a discriminatory factor for management the techniques and income sources, the stratification is performed according to farm size and three classes are selected: SAU < 5 ha, 5 ha <SAU< 15 ha and SAU > 15 ha.
Moreover, the social vulnerability is assessed using the analysis of household incomes compared to the average poverty rate which is 22,700 dhs/ household/year; the poverty level is 3,569 dhs/person/year and the average household size is 6.36 person/ household [19-20-21].

2.2.3. Watershed Management Plan

The identification of the package of management actions is based on the diagnosis results of biophysical and socio-economic backgrounds. Thus, the management of priority areas is based on biological actions to protect soil and technical actions that are compatible with the intrinsic characteristics [22]. The aim is to promote the bioengineering techniques for soil erosion protection and slope stabilization to conserve soils and to protect El Kansra dam against siltation.
. *Strategic Planning*
The interventions program includes the conservation actions and environmental rehabilitation across the whole of the watershed area. Hence, the main measures selected are grouped into the following categories: Agricultural land use, Rangelands management, Forest management and Rivers protection and correcting ravines.
. *Priority Planning*
The « Optimized Hot Spot Analysis » is used to identify the priority areas through the use of the statistical method “Getis-Ord Gi” which allows the analysis of each pixel in relation with neighborhood in the spatial dataset [8]. Hence, the obtained results, related to the "z-score" (standard deviation) and "p-value" (independence probability), are used to measure the statistical significance of spatial auto correlation.
This dynamic approach tells us if we may reject or not the null hypothesis Complete spatial Randomness (CSR) that expresses the absence of spatial correlation between soil losses and factors that will be modified by the action plan. Thus, the biological actions are planned in areas with strong spatial correlation between erosion hazard and vegetation cover; and mechanical actions correspond specially to areas with high spatial auto

correlation between the natural hazard and topographic factors. The « Optimized Hot Spot Analysis » is used to measure the spatial correlation between natural hazard and factors linked to slopes and vegetation cover.
For confidence level 90%, the critical z-score are respectively "-1.65" and "+1.65" and the critical p-value is "0.10" (Figure 2). If the "z-score" obtained is between "-1.65" and "+1.65", the probability of independence (p-value) will be automatically higher than "0.10" and the null hypothesis of independence is not rejected [23].
In this particular case, the z-scores used correspond to the values that are higher than "+1.65", or lower than "-1.65", to define entities with strong spatial correlation (hot spots) between the soil erosion hazard and the factor that the proposed development plan will change by biological and mechanical actions. Both z-scores and p-values are associated with the standard normal distribution as shown below (Figure 2).



Source: ESRI, 2014. (http:// help.arcgis.com/fr/arcgisdesktop/10.0/help)
Figure 2: Distribution of spatial autocorrelation indicators.

3. Results and discussion

3.1. Biophysical factors Analysis

. Topographic context

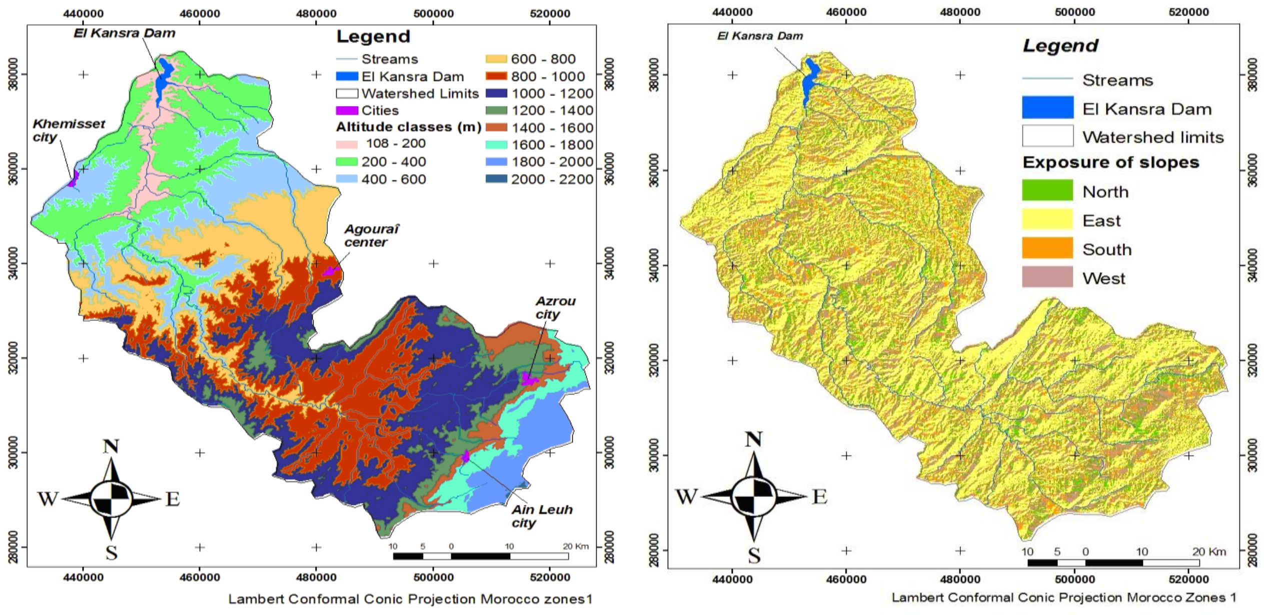
The topography of the Oued Beht watershed is analyzed by factor combination involving topographic effect of altitudinal amplitudes, exposure, slope gradient and slope length:

a. Hypsometric analysis: The spatial analysis of the Digital Elevation Model (DEM) shows that the watershed has a regularly altitudinal distribution along its elongated form. Thus, the altitudes classes follow a decreasing gradient, from upstream to downstream, in perpendicular bands to the axis, which coincides with the flow direction of the Oued Beht representing the low elevation (Figure 3a). The watershed presents a high altitudinal range, between the highest point 2,121 m and the lowest point 108 m, which is coinciding with the level of the El Kansra dam. Thus, the total length midline crossing the watershed is 177 km and the altitude difference of 2,013 m. Therefore, the topographic factor (2 013 m / 177 km) indicates that the whole surface has a very low slope factor (1.14%) and it does not present a real hydrologic indicator that promotes erosive process.

b. Exposure of slopes: The distribution of soil aspects shows that east slopes dominate, particularly at upstream part (38%). The other directions are almost equal 20% (Figure 3b). Furthermore, the areas representing a flat field are limited and localized mainly in the small depressions or hilltops. Moreover, the northern and western slopes present a humid character. Hence, the exposure map gives an idea about the potential cover land.

c. Slope gradient analysis: The DEM spatial analysis shows that the low slopes (less than 15%) are dispersed and occupy more than half of the watershed (57%). Thus, steep slopes are concentrated in central and upstream (Figure 4a). The obtained map of the slope length classes gives an indication of the transport distance traveled by soil detached particles. Thus, the slope lengths distribution shows that almost half of the watershed (55%) is

less than 1000 meters with a majority (30%) lower than 500 meters (Figure 4b). Therefore, the spatial distribution of the slopes length classes is heterogeneous and no zone is characterized by a single slope lengths



(a) **(b)**

Figure 3: (a) Hypsometric map ; (b) Aspect map.

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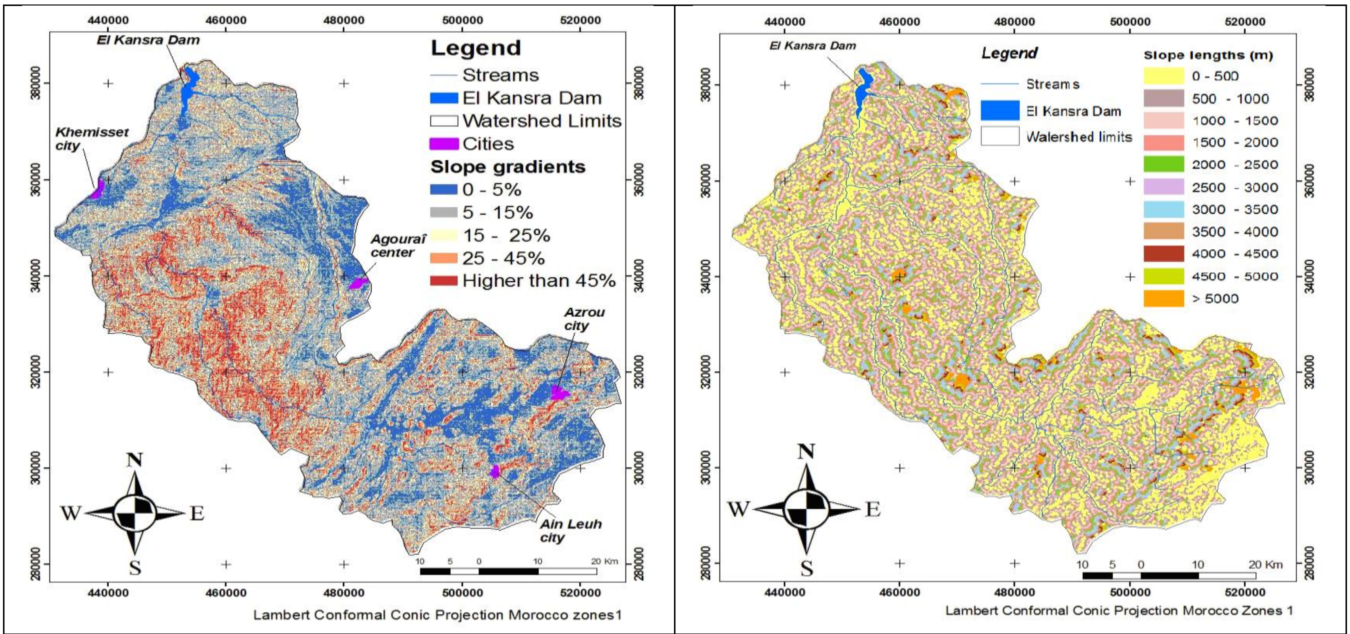


a **b**

Figure 4: (a) Slope gradient map ; (b) Slope length map.

. Soil resources

The soil analysis shows a strong dominance (45%) of slightly developed soils. Thus, this soil type is dispersed and used for agriculture, forestry, but especially in rangelands. Moreover, Brown soils are concentrated at the upstream where the forests are developed (6%). This kind of soil is enriched by the litter decomposition (Figure 5a, b). Generally, the poor soils, characterized by the bedrock outcrop, are located near El Kansra dam.

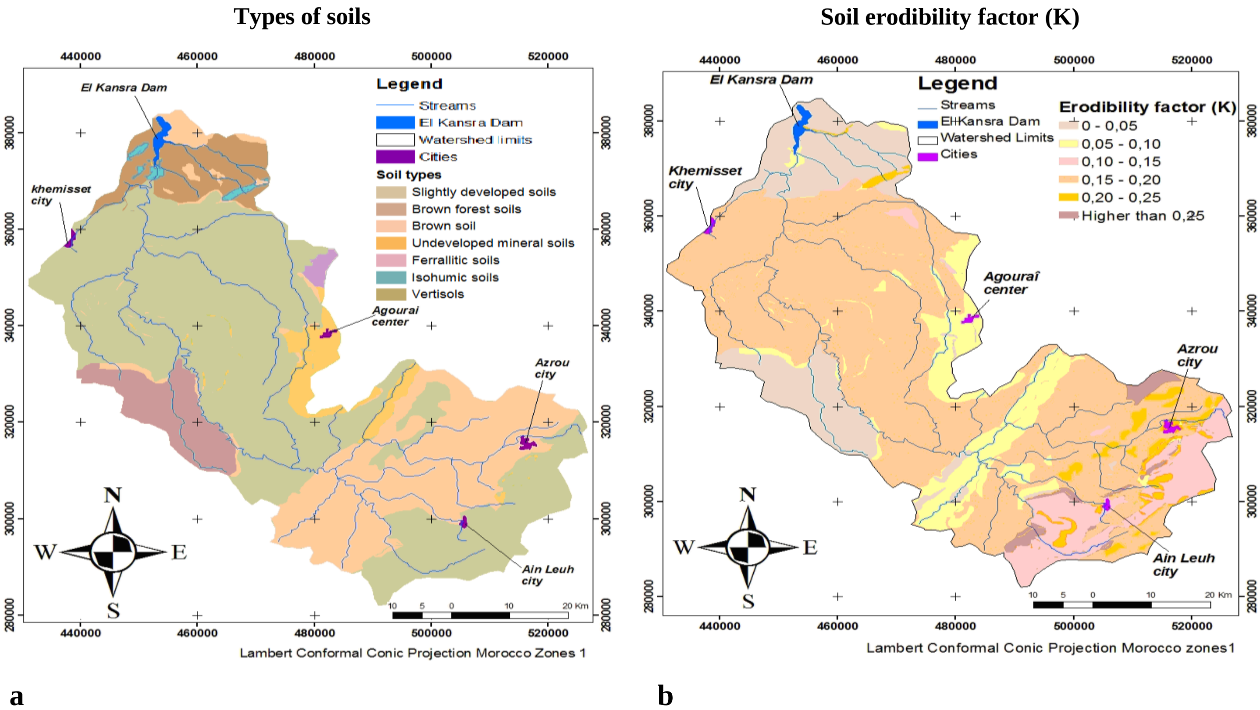


Figure 5: (a) Soils map ; (b) K- factor distribution.

In conclusion, the watershed soil analysis shows the diversity and heterogeneity of pedogenesis factors. This diversification of soils is mainly due to bedrock types and their degree of friability, morphology, topography, climate aggression and land use.

. Hydrometeorological analysis

The geographical distribution of climate stations presents good spatial coverage and long periods of observation that allow an eminent climate analysis in the watershed (Figure 6a).

a. Average rainfall: The precipitation distribution analysis shows that the watershed has a rainy winter and a dry summer period. Thus, the rainfall regime is irregular and the rainy period is concentrated between October and May (Figure 7). Therefore, the upland areas (Mountains) are wetter than the areas near to the sea. Thus, the altitude effect on rainfall (R-factor) is more dominant than the approximation near the sea (Figure 8a).

b. Thermal regimes: The weather stations used to characterize the thermal regime and to deduce bioclimatic classes are the stations of El Kansra, Khemisset and Ifrane (Figure 6a). Thus, the continentality is quite significant with a net decrease in temperature associated with increasing altitude. Moreover, the thermal regime is characterized by temperatures that vary between 10°C in the East and 26°C in the North and North West.

c. Bioclimatic synthesis: Bioclimatic data Analysis is based on quotient Emberger index (Q_2) which is well adapted to the Mediterranean regions [24]. Hence, the Oued Beht watershed is characterized by several bioclimatic architectures. Thus, in the north and northwest, the climate is semi-arid with temperate winter and in the center, it is sub humid with temperate winter. Moreover, the east of watershed presents a humid climate with cold winter.

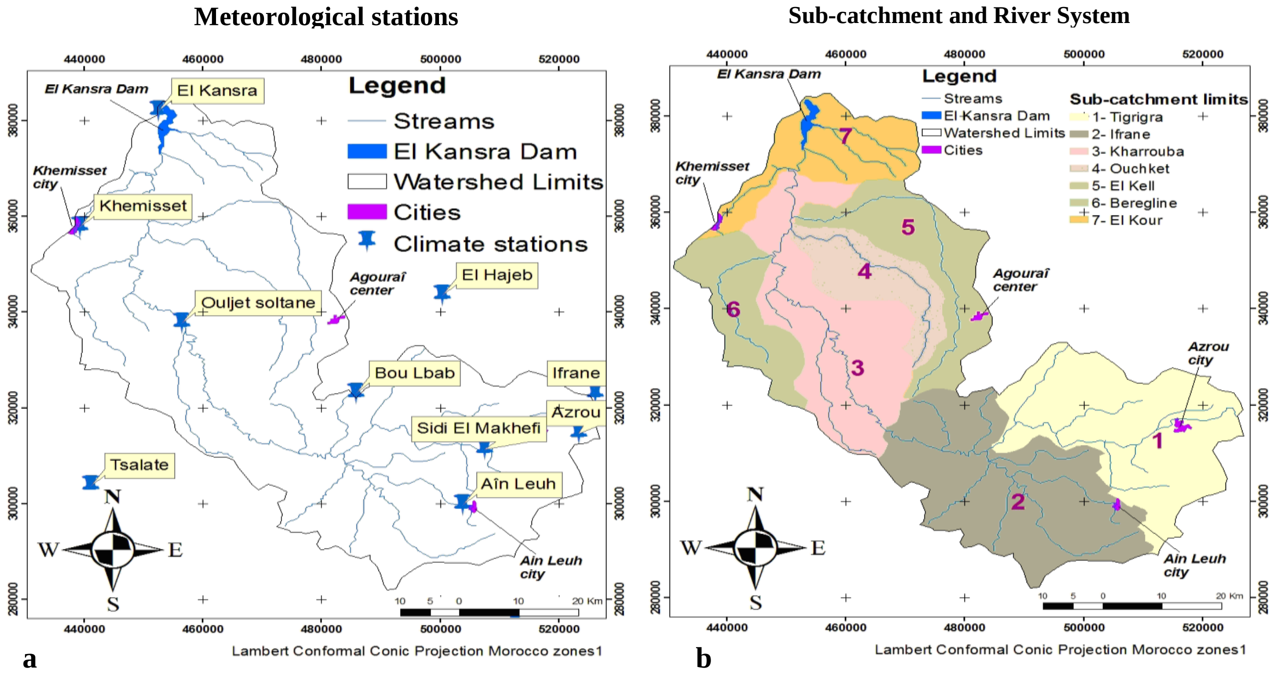


Figure 6: (a) Distribution of meteorological stations ; (b) Sub-catchment mapping.

In conclusion, in addition to the data linked to altitudinal impact (2,013 meters), the watershed hydrological context is conditioned by a bioclimatic changes affecting the nature of the developed vegetation, the resilience of ecosystems and intensity of erosion hazard.

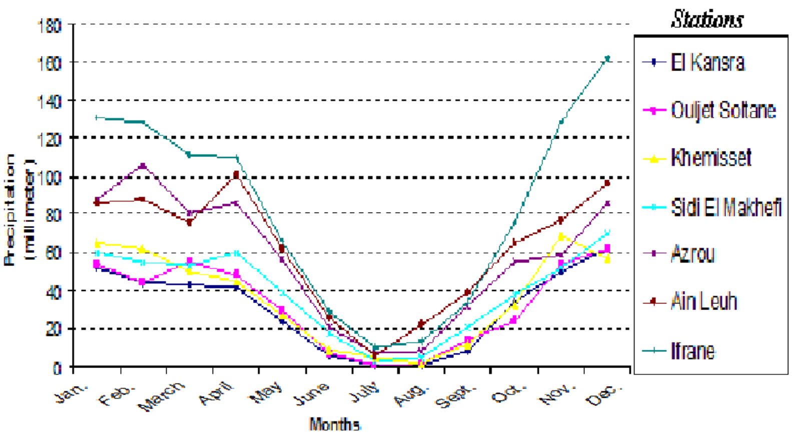


Figure 7: Average monthly rainfall data.

d. Rainfall aggressiveness (R):

The rainfall power is calculated by the formula developed by Rango A and Arnoldus H.M.J (1987) using data of average monthly and annual rainfall in the selected stations [9-25]. The results show that the rainfall aggressiveness (R) is between 64 and 130 respectively recorded at El Kansra and Ifrane stations. Thus, the interpolated values are modeled by spatial analysis (Kriging tools) which gives the best linear unbiased prediction of the intermediate values. The interpolation is obtained using map of isohyets and climate data.

Moreover, in the East the rainfall are more aggressive than at the north and west. Also, the upstream area shows the higher rainfall aggressiveness indexes (Figure 8a).

In conclusion, the rainfall aggressiveness, associated with the heterogeneity of the rainfall distribution, is spatially variable and adheres to erosion processes.

. Land uses

The analysis of the vegetation cover has shown that the watershed has a variety of land uses related to the bioclimatic variation and topo-edaphical diversity. Thus, the rangelands area is the most common type of land cover (44%). Forests represent second place with 29%, reflecting the sylvopastoral character of the watershed (Figure 8b). Moreover, the forestry formations are mainly concentrated in the central and upstream parts. Furthermore, we note the presence of unplanted lands, covered by rocks, which are generally concentrated near the El Kansra dam.

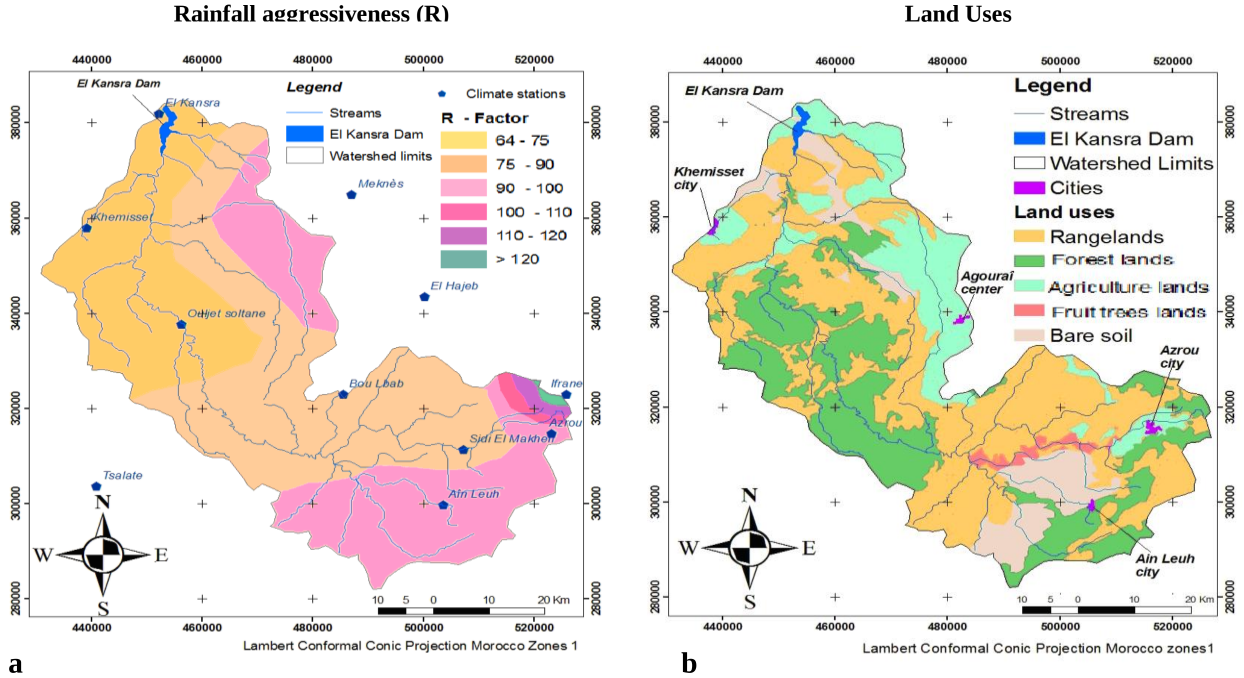


Figure 8: (a) R- factor distribution ; (b) Land use map.

. Vegetation Index

The analysis of NDVI index (normalized difference vegetation index) shows that the recovery rate is characterized by a dominance of the low class grouping generally rangelands and crop fields. Thus, both classes "low" and "very low" represent 72% of the total area. This indicator reflects the low coverage capacity, even if the land cover is almost complete and denuded soils rate is only 9.5% (Figure 9b).

The agricultural lands are based on cereals and annual crops with short growing cycles. Hence, the rangelands consist on perennial grass vegetation with short development cycle, especially during periods of low rain.

The establishment of the C-factor map is performed by crossing maps of land uses and recovery rates. Moreover, the interpolated values of C-factor are modeled using default values, developed by Wischmeier & Smith (1978), for different vegetal formations in the watershed.

Thus, the statistical data obtained shows that the average C-factor is 0.42 which varies from 0.1 "good soil protection" (Forest lands) to 1 "very low soil protection" (Bare soils). Furthermore, the C-factor map shows the absence of the first class (< 0.1) corresponding to the dense forests "very good soil protection" (Figure 9a).

Indeed, the analysis of vegetation cover (C-factor) shows that more than half of the Oued Beht watershed (55%) has a C-factor exceeding 0.5, and 72% having values greater than 0.2 (Figure 9a). Hence, these results are consistent with the biophysical analysis describing the low recovery rate.

In conclusion, the C-factor has a detrimental effect on the erosion process by developing sediments production in low soil coverage; and especially if it is combined with other determinants factors.

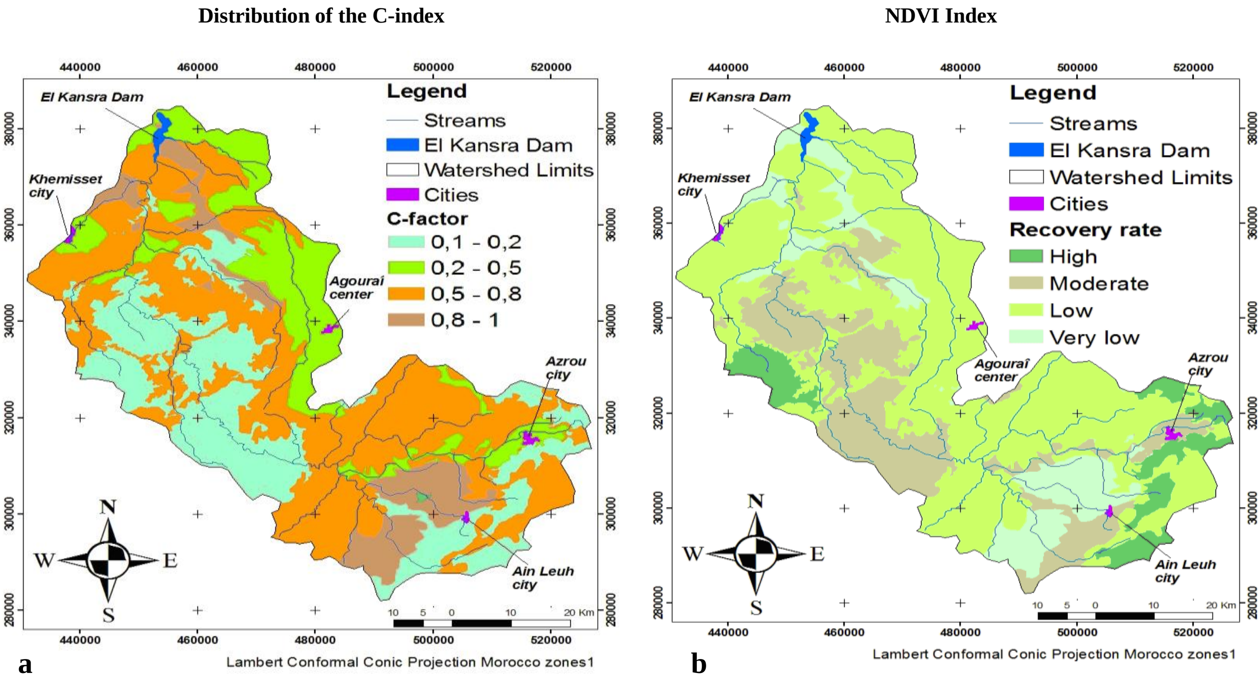


Figure 9: (a) C- factor distribution ; (b) Normalized Difference Vegetation Index map.

. Hydrological behavior

The establishment of the hydrological system map, based on DEM analysis, allows to determine the rivers directions (flow direction) and the accumulation of their flow (flow accumulation). Indeed, the obtained river system is ramified along the entire watershed. Thus, it consists of the main stream named Oued Beht which is powered by the waters of several tributaries: Beht, Tigrigra, Ifrane, El Kell, Ouchket, Kharrouba, Beregline and El Kour (Figure 6b).

a. Drainage density

The surface drainage in the watershed is assured by an arsenal of rivers. The drainage density is influenced by its topo-geological structure and relief. The river system is characterized by the distribution of its elements, since their original ramifications upstream, domiciled in the Middle Atlas chain, to the main collector which is the El Kansra dam. Therefore, the river system is characterized by a total length of 668 km with a low drainage density of 0.16 km/km². Thus, the ramification is centralized and presents limited development of ravines.

b. Concentration time

The time (tc) that is necessary for the farthest water particle to arrive at the watershed outlet is estimated by the Passini formula [26]. At the majority of sub-catchments, the concentration time (tc) is low and varies from 2:30 hours (sub-catchment of Kharrouba) to almost 5 hours (sub-catchment of Tigrigra).

In conclusion, the elongated form of the Oued Beht watershed and the low concentration time for the majority of sub-catchments are favorable conditions for the development of flood and river flow that cause sediment deposits in the stream beds and El Kansra dam.

. Floods study

The objective is the prioritization of sub-catchment (Figure 6b) presenting high floods risk and soil erosion. Data linked to maximum flood flows are obtained by calculating the extreme values gradient (Gradex method) from the decennial flow in reference station of Ouljet Sultan (Table 1).

Table 1: Statistical adjustment of annual maximum flows (Ouljet Soltane station)

T (year)	10	20	50	100	1 000
Q (m^3/s)	488	586	712	807	1 121

For the other neighboring ungauged sub catchments, the results obtained by Francou-Rodier formula (1967) shows that the flood flows are important (Table 2).

Table 2: Flood flows of the rivers (m^3/s)

Stream	**Area (Km²)**	**Qp (10)**	**Qp (20)**	**Qp (50)**	**Qp (100)**	**Qp (1 000)**
Tigrigra	909.37	241	294	364	417	597
Ifrane	1019.6	261	318	394	451	643
El Kell	487.2	154	190	238	275	401
Ouchket	326.53	115	143	181	210	310
El Kour	413.2	137	169	213	246	361
Kharrouba	798.12	219	268	333	382	549
Beregline	353.26	122	152	191	221	326

. Potential erosion assessment

The crossing of thematic layers linked to rainfall aggressiveness (R), soil erodibility (K) and the topographic data (LS) has allowed to synthesize potential erosion impacts and to appreciate the power of soils to produce sediments in the analyzed topological environment and under the rainfall hazard.

The results analysis shows that the potential average annual soil loss is 54 tons per hectare and the average annual quantity is 23.25 million tonnes per year. Moreover, the importance of soil loss differences between extreme values (pixel) shows the power of eminent soil units that produce sediments under the rainfall aggressiveness. Furthermore, two-thirds of the Oued Beht watershed is characterized by soil loss quantity which is less than 50 t/ha/an, while almost 30% corresponds to the potential erosion class between 50 and 300 t/ha/year.

On the sub-basins located in the upstream part (sub-catchment 1 and 2, Figure 6b), with steep slopes (exceed 25%), the potential erosion is high and values exceed 200 t/ha/year (Figure 10a). Moreover, the priority areas are characterized by high and medium soil vulnerability (Figure 10b).

Secondly, some priority areas near El Kansra dam (sub-catchment 3, 4 and 5, Figure 6b) present also high values of the potential erosion exceeding 200 t/ha/year (Figure 10a, 10b). These vulnerable sectors correspond mainly to northern sub-catchments with low altitudes (less than 400 m) and with high soil friability.

Therefore, the great erosive power of adjacent areas to El Kansra dam is a real danger that involves the dam siltation and compromises its service life. Additionally, the upstream part is also very sensitive to the potential erosion (as shown in Figure 10b). However, the presence of medium and high levels of vegetation cover, by location, can reduce the erosive potential. The priority areas mapping is performed through the spatial crossing of the specific degradation map, flood generation data and the map of sub catchment contribution to dam siltation (Figure 6b). Thus, we note that the obtained results reveal that the majority of identified areas and delineated as priority areas are generally occupied by soils with strong erosion risks. Therefore, the vulnerability linked to soil degradation characterizes 32% of Oued Beht watershed (Figure 10b). Hence, urgent biological and mechanical actions are needed in this region to control erosion impact.

Therefore, 24 rural communes are identified by high contribution to dam siltation and include areas with high erosion risks and high poverty level too. This spatial analysis is further developed by the socio economic vulnerability map (Figure 11b). Thus, the results obtained are based on the analysis of exploratory surveys data of farms selected in the douars chosen by systematic random sampling. It is a qualitative assessment of living standards of the watershed population using the farm incomes compared to the average poverty rate.

In conclusion, the results show that the entire watershed is composed of areas with a significant social vulnerability that is beyond 30%.

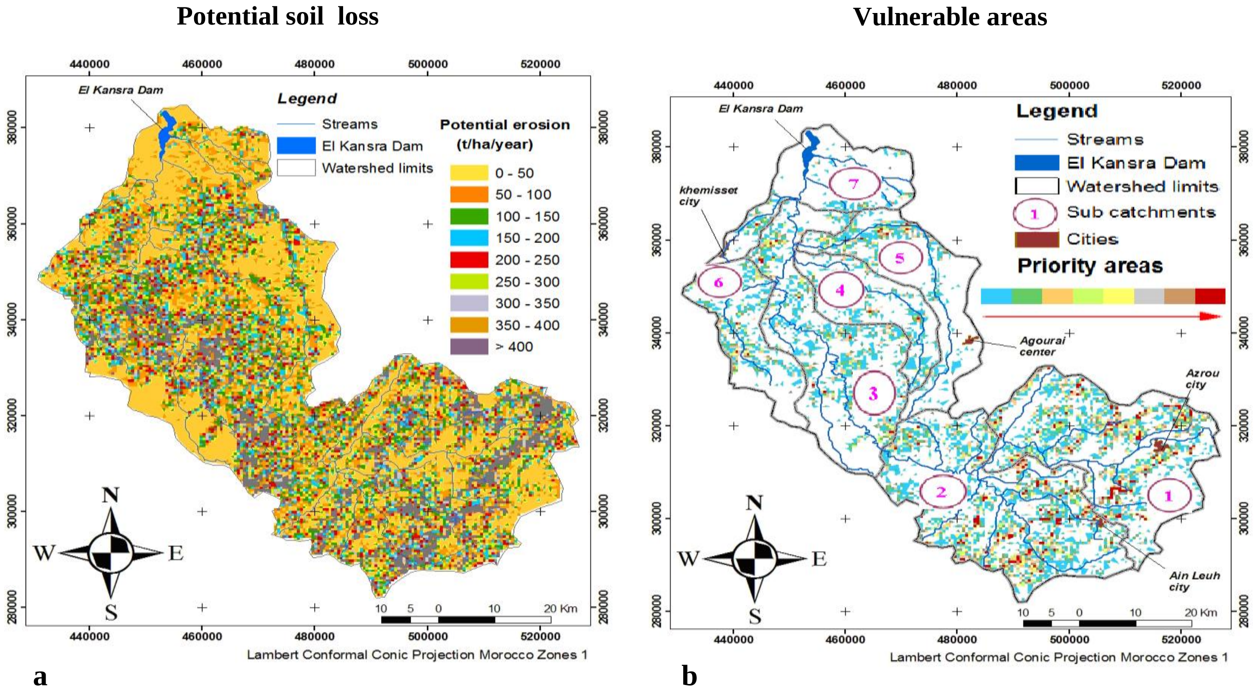


Figure 10: (a) Potential soil erosion map ; (b) Distribution of vulnerable areas.

3.2. Strategic Planning

The formulation of Strategic Action Programme (SAP) is based on the results linked to biophysical and socio economic analysis (Figure 11a, b). The Action Programme is translated into operational actions (biological and technical) which are compatible with the intrinsic possibilities of the studied watershed:

a. Agricultural Land Management

The agricultural development actions assist rural households in the watershed to develop their agricultural business according to the lithological, topographical and climatic constraints. Indeed, the agricultural lands, including arboriculture, cover an area of 74,577 ha, nearly 17% of the watershed. Moreover, the operating systems are basically extensive with the cultivation of a maximum surface whatever the slope (even in the steep slopes). Indeed, the socio economic analysis shows that 96% of rural population is conscious of the water and soils degradation. Thus, the adopted production systems are characterized generally by inappropriate farming practices that promote soil erosion.

In this perspective, the selected actions aim to achieve a progressive evolution of production systems and land uses in accordance with soil vocation, with limitation of annual crops on steep slopes, the development of arboriculture and improving forage production for livestock.

The implementation of actions mentioned below (Figure 11a) will lead to increase agricultural incomes and establish a space management to ensure local sustainability according to the following practices:

- *Low to medium slopes (0-15%)*

The biophysical data analysis shows that the lands with low to medium slopes (0-15%) are subject to an erosive process due to sheet, rill and rarely gully erosion. Thus, the aggressive rainfall and inappropriate farming practices (soil tillage in the direction of the slope, overgrazing) are the main factors that increase soil erosion. Therefore, the correctional measures should include improving productivity through appropriate use of culture techniques, such as the soil tillage must follow the contours and combined with cultures in alternate bands. In order to maintain on this type of soil vegetation cover as long as possible during the year, it is necessary to develop culture associations. The rotations of « cereal-legume-forage » or « cereal-legume-cereal » are the rotations retained. For rangeland improvement, the vetch-oats, alfalfa and clover present important opportunities for pastoral production and contribute significantly to soil protection.

- *Steep slopes (higher than 15%)*

The results analysis shows that higher slopes are commonly used by cereal cultures which give low yields. Especially, in this case, the soil tillage in the direction of slopes causes ridges that eventually become water runoff channels (gullies) that quickly develop the gullies and ravines. Moreover, the tillage soils according to the slope direction increase soil erosion.

Finally, a sustainable soil management, on steep slopes, is necessary through the restoration of vegetation cover by planting of multiple use species following the contours. This plantation technique must be combined with isohypse structures (benches, ditches and cords) to conserve water and soil.

In the case of the Oued Beht watershed, fruit trees cultivation presents a promoter axis of the erosion control in the difficult terrain, which leads to the proposed tree species that depend on agro-ecological areas. This operation needs also the consultation with the concerned farmers to choose trees species. Moreover, the olive, fig and almond trees seem to be the most desired fruit trees by the population and the best adapted to the ecological conditions in the watershed.

b. Rangeland management

The socio-economic study shows that the actual animal demand is high compared to production potential. Moreover, the confrontation of the rangelands offer and livestock demand reveals an important deficit -31%. Thus, the results analysis shows that the three livestock types (sheep, cattle and goats) use intensively and continuously the rangelands. Generally, the state of rangelands is in an advanced degradation of vegetation resources (Figure 9b). This usage mode is accentuated firstly by the severity of soil and climatic conditions which are unfavourable; and secondly the nature land status (domanial regime, collective) which leads to non rational exploitation of forage justified by their gratuity.

In this situation, the pastoral improvement is fully justified by the need to implement an intervention program to save the pastoral resources in the watershed. Indeed, the following actions (Figure 11a) will change the pastoralist habits and support the incentive mechanisms related to fattening in order to reduce the pressure on the pastoral spaces:

- Deferred rotation grazing: The Deferred Rotation Grazing is proposed to restore the potential herbaceous and shrubs. It consists of prohibiting grazing in vulnerable areas to allow the natural regeneration with the development of herbaceous richness and of forage quantity. Thus, a short duration of the deferred grazing (2 to 4 years) is sufficient for the regeneration of herbaceous species and for the improvement of pastoral potential.

The limitation of rights to use rangelands will be able to generate a forage imbalance that will directly increase the pressure on the surrounding lands and cause the accentuation of their degradation. To resolve this problem, it is imperative to choose pastoral species with high nutrient supplies and to provide accompanying measures for population such as compensation system linked to unexploited forage units and development of forage crops irrigated.

- Planting shrubs: The surveys analysis shows clearly that fodder shrubs are highly attractive to farmers. The shrubs present the advantage to provide their production in a late period of the year when other forage crops (including herbaceous vegetation) are low or zero. Indeed, the introduction of tree plantations consists in soil tillage in the autumn before the first rains with the digging holes along the contour lines for planting shrubs and installing bleachers for planting cactus. This technique aims to improve water balance and protect soil against erosion. The shrubs species that are recommended here are: Atriplex numilaria, Medicago arborea, Opuntia ficus- indica. Moreover, the cactus plantation presents its pastoral role with the advantage of producing highly appreciated fruit that can provide revenue for the users.

c. Forests management

The implementation of actions linked to degraded natural ecosystems (*Thuya and Evergreen oak*) represent an economic and ecological importance. Thus, the proposed actions aim to protect the soil against erosion and to halt the Forest degradation (Figure 11a):

- Forest rehabilitation: The biophysical analysis shows that watershed forests are located generally in difficult areas upstream. These ligneous formations have good adaptability and resistance to the negative impacts of climate and anthropogenic pressure, but most of these forests suffer from a lack of natural regeneration.

As a result, this situation requires efforts in terms of natural regeneration with native species and the intervention program must give priority to the areas that have the potential for natural regeneration. Thus, these actions should be accompanied by water and soil conservation measures to reduce erosion and increase water storage capacity (benches and terracing).

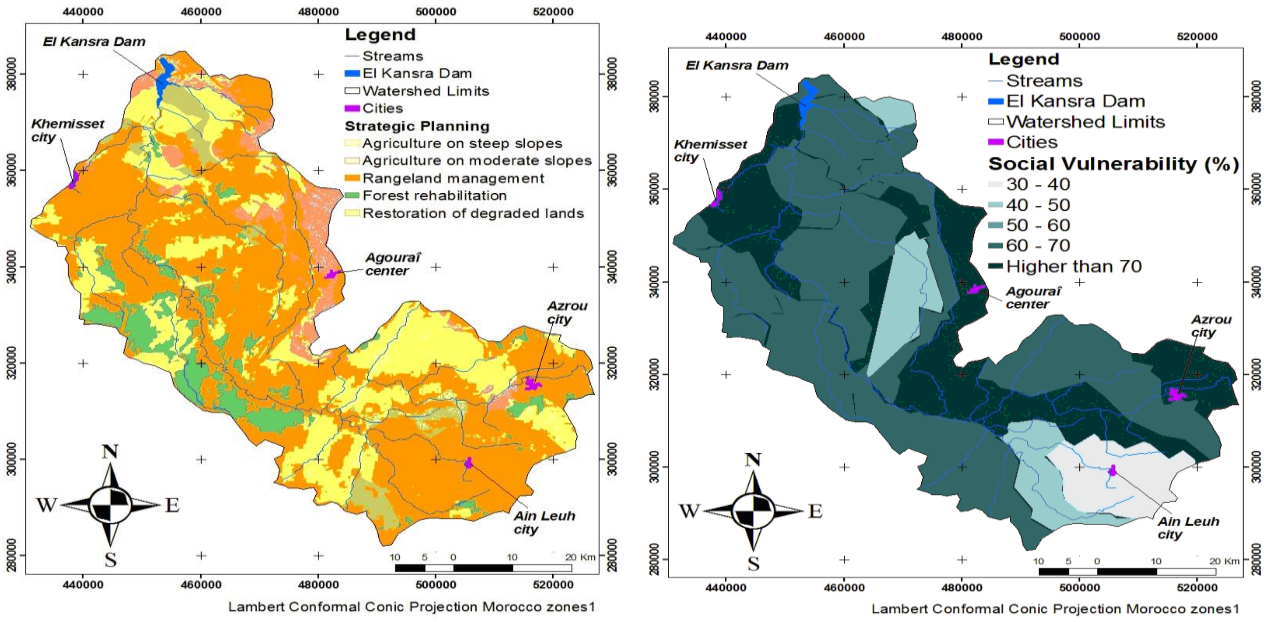
- Reforestation protection: In the denuded soils with forest vocation, the introduction of artificial plantations aims to protect the degraded soils through the reforestation actions. Considering the watershed bioclimatic conditions, the obtained spectrum of tree species proposed for reforestation is: Maritime Pine, Aleppo Pine, Brutia Pine, Cypress and Eucalyptus like gonphocephala, torquata and sideroxilon.

d. River system and badlands development

The hydrographic analysis has shown that the study area is characterized by high ratio density of river (Figure 6a). Hence, the soil losses are accentuated by this river system and the erosion is generally active on soft to moderately vulnerable areas. This phenomenon is strongly observed in the central part of the watershed, where the river system becomes increasingly ramified and individualized. The regressive evolution leads to a densification of ravines that can achieve the generalized gully erosion. Thus, this situation is clearly illustrated in the downstream part at the El Kansra dam (Figures 10a, b). The sediment quantities resulting from this erosion are mainly transported downstream and contribute significantly to the dam siltation.

In conclusion, the proposed development program gives special attention to the correcting ravines actions in vulnerable areas by the combination of two key actions: Biological fixation and mechanical correction of ravines (Figures 12a, b), both integrated actions promote the installation of vegetation and slope stabilization. This approach combines the benefits, not only to limit sediment yield, but also to promote the defense of infrastructures, good soils.

Strategic Plan **Social Vulnerability**



a b

Figure 11: (a) Master Plan of the Oued Beht watershed management ; (b) Social vulnerability.

3.3. Priority Planning

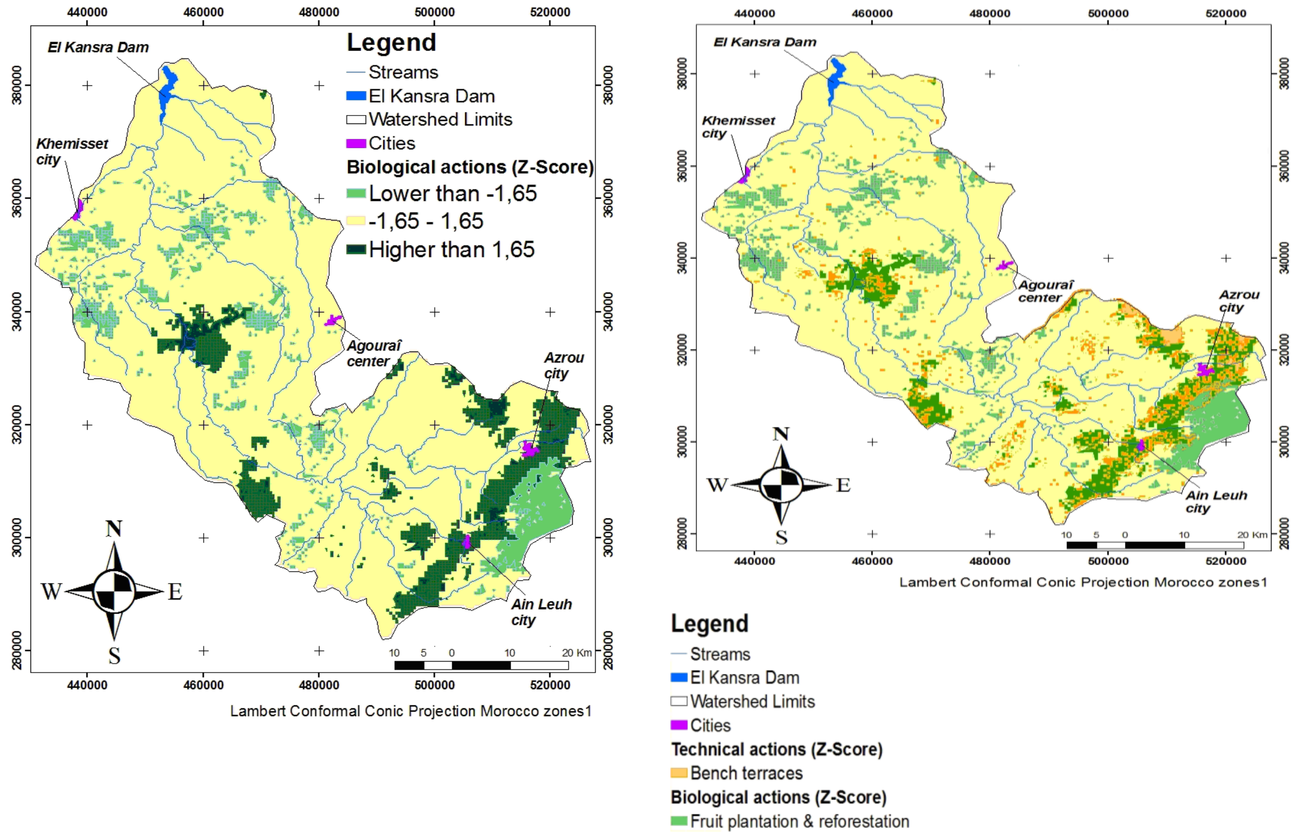
The auto correlation maps obtained are used to delineate the priority interventions which correspond to the z-scores statistically significant with values higher than 1.65 or less than -1.65 (Figures 12a, b). Moreover, the highest z-score shows the spatial auto correlation between the erosion hazard and variable to be modified by priority management program.

The biological actions in degraded soils (fruit plantation, regeneration and reforestation) are materialized in spaces with high spatial aggregation between the potential erosion and vegetation cover factor (Figure 12a). Thus, the results show that the area of biological actions represents 20% of the watershed with 87,351 ha. These biological actions are concentrated mainly in the sub catchments of Tigrigra, Ifrane and Kharrouba (Figure 6b).

On the other hand, the mechanical actions designed to reduce the slope effect consist in the establishment of benches, ditches and terracing. These structures are programmed in high spatial aggregation between the potential erosion and the topographic factor maps. Finally, the area of mechanical intervention is 22,753 ha; and consequently a quarter of biological interventions are combined with technical measures especially in the upstream part (Figure 12b).

In conclusion, this package of conservation techniques concerns agricultural and sylvopastoral areas, and is based of various types of soil tillage and vegetation cover with different types of terraces, stone bunds and check dams. Hence, in the mountainous regions (upstream), the terracing is the selected agricultural technique for collecting surface runoff water increasing infiltration and controlling water erosion.

actions for erosion control	Mechanical actions by terracing



(a) (b)

Figure 12: Action Plan maps (a) biological actions ; (b) mechanical actions.

Conclusion

The present study has shown a cartographic approach based on the integration of spatial remote sensing tools (GIS) and statistical analysis functionalities linked to the initial state of Oued Beht watershed to study vulnerable areas to erosion and how to protect the watershed. The objective is to define the guidelines of the planning master plan and management degraded soils. Moreover, although some studies have combined biophysical data and the constraints identified in the socio-economic analysis, they generally do not consider the spatial auto correlation and spatial statistics data (z-score) to develop strategy for priority management of the watershed.

In this perspective, this study provides a methodological contribution and shows also an approach based on the spatial autocorrelation analysis and the decisions mapping to study soils erosion, without trying to determine the causal directions between the variables analyzed in terms of spatial auto correlation. Thus, the cartographic restitution of spatial data obtained identifies priority areas and establishes the first interventions across the watershed. This spatial approach constitutes a real decisional tool to the choice of erosion control techniques in the vulnerable watersheds.

The obtained results, with respect of the spatial autocorrelation analysis concerning socio-ecological components, show that the priority actions are needed for almost 20% of the Oued Beht watershed. Thus, all priority areas identified are affected by the biological techniques (fruit plantation, regeneration and reforestation in degraded areas) that mitigate the factor which expresses the lack of vegetation cover (Figure 12a). Especially, the spatial aggregation maps shows that the mechanical actions correspond to a quarter of the priority areas. Hence, this category of mechanical intervention aims to reduce the negative effects of topographic factor with the establishment of terracing structures (Figure 12b). The main purpose of terracing application is to improve the usefulness of steep slope and to increase its agricultural potential. This function is realized by creating the level surfaces according to contour lines of transformed slope. The level, bench platform allows to spread the surface runoff water, decreases its speed and thus allows more time for water infiltration into soil profile.

We can conclude that this approach has allowed developing a planning program with successful techniques for soil erosion control in areas endangered by soil erosion resulting from combinations of steep slopes, climatic conditions and erodible soils.

It is obvious that this approach, based on ground measurements and combined with geographic information systems must be accompanied by a regular monitoring system, by updating continuously the part of the spatial model derived from remote sensing. Moreover, the stable part of the geospatial database consists of intrinsic factors (lithology, soil, drainage density, etc) and the dynamic part to control includes factors relating to the soil occupation and needs evolution of the local population.

Finally, although this analysis was conducted for the master plan of the watershed development, and has identified environmental constraints (soil and water degradation) characterizing priority areas, it is necessary to refine this analysis through a participatory action plan. Indeed, this zonal analysis will specify for each year the actions to be implemented and the financial package, by considering the needs and perspectives of the rural population. Moreover, the effectiveness of the proposed techniques can be limited, especially if the local population is opposed or, in some cases, found to be expensive to build and maintain.

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