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Proposal of Installations to Protect watersheds in the Lower Valley of the Medjerda, Tunisia

Gader Khouloud[1], Gara Ahlem[1] and Mahjoub Mohamed Raouf[2]
[1]University of Carthage/ Laboratory of Sciences and techniques of waters/ National Institute of Agronomy in Tunis, TUNISIA
[2]University of Jendouba/ IRESA / Higher School of Rural Equipment Enginering of Medjez el beb, TUNISIA

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Abstract

This work concerns the catchment area of Sidi Thabet which is a region of the lower valley of the Medjerda basin in Tunisia. Our aim in this study is to quantify the water erosion of the soil and to develop a management plan. The development of the sensitivity map to runoff has led us to estimate the coefficients of runoff, the volumes of the floods (of period of return 26 years) are estimated by the application of the Sokolovsky model. The specific erosion "Es" at all sub-watersheds is the same. Specific erosion is in equal to 2669,5 t/km²/year. The responsible factor of the risk of erosion in the study area is the maximum monthly rainfall which is 227.3 mm. This value has a return period equal at 26 years. The proposed and planified installations are defined based on the map of risk of erosion and existing structures hydraulic.

Keywords: Medjerda, Tunisia, Water erosion, Sokolovsky model, Watershed management.

Introduction

In Tunisia, the predominance of little resistant rocks at the surface, the irregularity of the climate, the torrential stream flow, the low density of vegetation cover and the over exploitation of the land are particularly favorable to the acceleration of the phenomenon of water erosion which seriously threatens the potential water and soil. If it is possible to significantly reduce the water erosion by using appropriate techniques, such as the implantation of land terraces, it must first define the areas of high erosion requiring priority intervention[1].

The degradation of the soil under the effect of water erosion is recognized throughout the world, particularly in the arid and semi-arid regions[2].

The erosion can be regarded as a major problem in Tunisia particularly in the catchment area of the Medjerda basin[3]. Erosion can be a slow and unsuspected process, or take alarming proportions, involving an enormous loss of the arable sol[4].

It is an essential factor that must be taken into account in the development of the territory, because the degree of erosion is a major indicator of the sustainability of a layout diagram of the territory.

For planning, development and as a help tool to decision of makers; GIS was be used in our study. It integrates both management techniques on the spatial data, as well as the tools to capture, storage, analysis and display of these data[5, 6, 7].

The topography of the study area is an important factor for water erosion indeed the runoff is generally strong and fast on steep slopes thus causing a very serious water erosion[8].

To quantify the water soil erosion, several factors are used: topography, the pedology, geology, land use and land cover. The quantification of hydric soil erosion represent the goal of this article.

Material and Methods

Study Area: The study area is located in the lower valley of the Medjerda basin in the North east of Tunisia. It covers a total area of 151.88 km² which is divided into two watersheds, the watershed of Hessiene with an area equal to 105.93 km², and the watershed of Meleh with an area of 45.95 km². It is characterized by a moderate relief to strong enough and under a moderate climate. From the hydrographic network and altitudes, it is possible to divide the area into six sub-basins, such that the watershed of Hessiene is divided into four sub-basins while that of Meleh is divided into two sub-basins.

In semi-arid zones characterized by often intense rainfall, climatic factors have a considerable influence on soil loss[9]. Given this importance, a study of the reliability and the homogeneity of the different existing stations in the study area was performed and confirmed that the station Cherfech CRGR may be regarded as the reference station.

The exceptional floods are often produced by the maximum monthly rainfalls which allow the saturation of the superficial parts of soils[3]. In order to estimate the runoff responsible for the risk of erosion and flooding in this region, the adjustment of the maximum monthly rainfall series with a period of observations of 45 years is performed and has determined the return period for the maximum monthly observed for the station Cherfech CRGR which is 227.3 mm of return period 26 years.

Evaluation of runoff: The runoff is a determinant of the rate of weathering and erosion[10]. The determination of the runoff coefficient is of great importance in any hydrological study, as well for a better assessment of runoff; it has used the method of multi-criteria evaluation.

This method is essentially based on the crossing of information layers (themes) using software (ArcGis 9.3) used as a tool of GIS.

Digital Elevation Model and map of slopes: By employing the satellite images SRTM, the vectoring of curves of level allowed us to produce a Digital Elevation Model (DEM) who presented finely the forms of watersheds constituting our study area. The latter was used to produce the map of slopes given essential in the phenomena of runoff. It has carried out a subdivision of classes of slopes: 0 to 2 %; 2 to 7% and superior than 7 %.

Soil Map: The nature of the soils is a major parameter in the runoff since the surface water flow depends directly on the properties of the soil. It gives a weight to each homogeneous zone of the viewpoint of pedology and of the viewpoint of classes of slopes and by subsequently give an attribute to each layer of information.

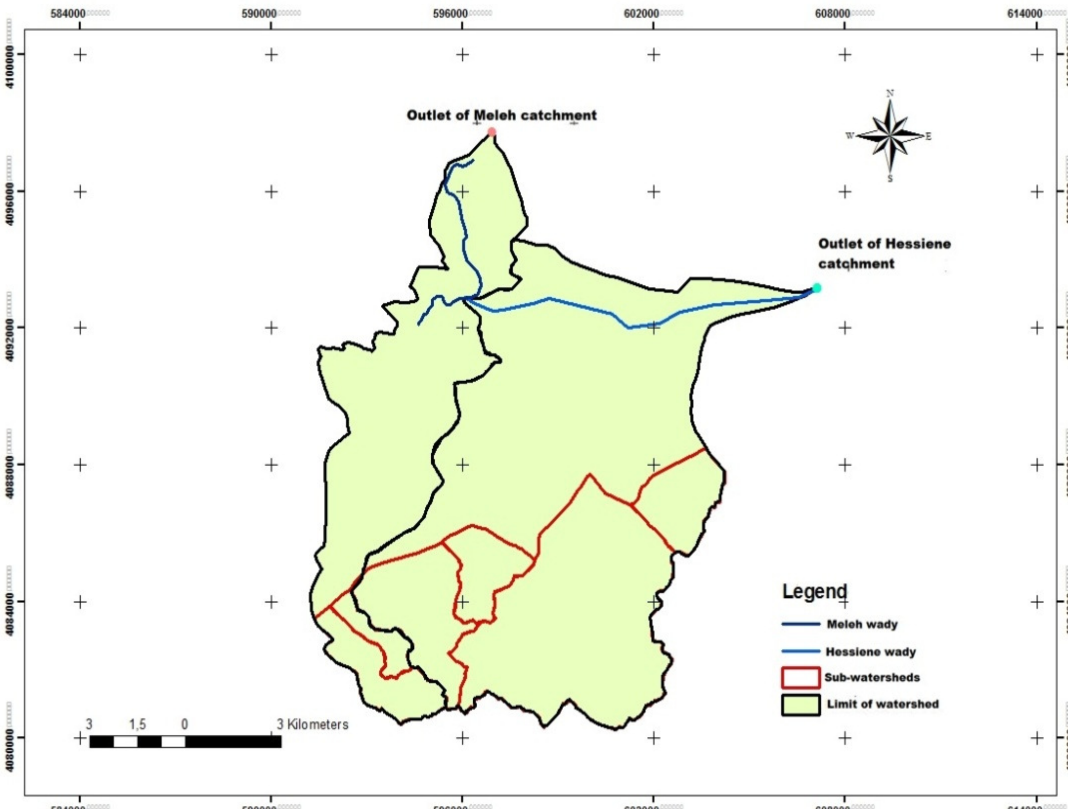

Figure-1
Map of the watersheds delimitation

Table-1
The weights assigned to the layers of information (pedology and slopes)

			Classes of slopes (%)		
			0% To 2%	2% To 7%	>7%
		Weight	0	5	10
Nature of the soil	Land sandy to clayey	1	1	6	11
	Silt and clay	2	2	7	12
Frame Ground (Waterproof)		3	3	8	13

According to these coefficients of weights (table-1) and subsequently to the superposition of the two themes (pedology and classes of slopes), it has been classified these areas according to the values of the coefficients of weights in three classes of sensitivities and achieve a sensitivity map to runoff

Study of inputs: Study of flood: model of sokolovsky: The study of flood is an important part of surface water hydrology for comprehensive water resources planning, management and development[11]. The flood flow is used for the design and sizing of hydraulic works. The problem arises when lack of hydrometric observations and pluviographic recordings of exceptional real events.

For these reasons we will use the model of Sokolovsky for the replenishment of on hydrographs flood warning for each sub catchment and for different return periods, and by following the calculation of volumes of floods.

The determination of on hydrographs of Sokolovsky is based on the following equations:
For the rise of the flood

$$Q(t) = Q_{max}\left(\frac{t_i}{t_m}\right)^2 \quad (1)$$

With: Q (t): Instantaneous flow rate (m3/s), Qmax: The maximum flow rate calculated by the rational formula, t_i: time snapshot (hours), t_m: the rise time of the flood (hours)

For the floodwaters : $Q(t) = Q_{max}\frac{(t_d - t_i)^3}{t_d^3}$ (m^3/s) (2)

Q_{max}: The maximum flow rate calculated by the rational formula (m^3/s)
T_d: The time of decayed (hour)

The determination of time of flood and that of decayed depends on the shape of the hydrograph to adopt:
Triangular Hydrograph: $t_m = t_c$ and $t_d = 2t_c$ $t_b = 3t_c$ (3)
Parabolic Hydrograph: $t_m = t_c$ and $t_d = 4t_c$ $t_b = 5t_c$ (4)

The unit hydrographs of sokolovsky obtained for each watershed and for the different return periods will be refined to obtain on hydrographs rounded according to the formula:

$$Q(t) = Q_T \frac{t}{t_m} e^{\left(1-\frac{t}{t_m}\right)} \ (m^3/s) \quad (5)$$

With: Q_T: The maximum flow rate for the return period T (m^3/s)
T_m: rise time which is equal to the time of concentration t_c(s)

The volume of flooding was determined from the traces on hydrographs, in effect the calculation of the volume of flooding for each return period is done according to the following method:

The hydrograph is divided into N equal installments along the axis of time due to a selected time step

$$\mathbf{N = \frac{4t_c}{\Delta t}} \quad (6)$$

With: Δt: time step, T_C: rise time which is equal to the time of concentration.

For a tranche i (i ranging from 0 up to N) we calculate the volume, by applying the following formula:

$$\mathbf{V_i = \frac{Q_i + Q_{i-1}}{2}\Delta t} \quad (7)$$

Then $\mathbf{V_{i+1} = \left(\frac{Q_{i+1} + Q_i}{2}\Delta t\right) + V_i}$ (8)

For i =N, one obtains the total volume of floods which is V_N.

Study of solid transport: To estimate the solid transport, it was used of empirical equations developed by exploitation of the measures carried out at the level of certain stations of observation, or measures of siltation of certain deductions of water.

From the specific erosion, it was determined the average annual erosion of land (t/year) land in each sub-basin, which is transformed into strong transportation by the waters of floods. It was also determined the volumes of solid transport in function of liquid volumes by using the formula of STER:

$$\mathbf{Rate\ (T/Km^2/year) = 458V^{0,15} \times S^{-0,15}} \quad (9)$$

$$\text{Pt annual average (T/year)} = 458V^{0,15} \times S^{0,85} \quad (10)$$

Study of the status of erosion: The mapping of erosion is a fundamental tool for understanding the distribution and the geographical extent of the phenomenon, as well as to its qualitative characterization.

The extent of soil erosion also constitutes a solid basis for the conservation and planning of water resources because the erosion has a deep impact on the quality and the water regime. The fine particles of soil that are transported in suspension in the water the more far away are the polluting agents the most widely spread and serve as a vector to other organic contaminants and to chemicals. The erosion is so intimately related to flooding especially in the Mediterranean area, that any study of the causes of floods and of prevention, must take into account the phenomena of erosion, it is deemed necessary to develop a map of risk of erosion.

Remote sensing is an authoritative tool to keep an update of universal inventories[12]. The Geographic Information System (GIS) and Remote Sensing technique are a very useful tool[13]. They provide efficient methods for analysis of land use issues and tools for land use planning and modelling[14].

The methodology to be followed based on satellite, topographical and geological data. These data were integrated and analyzed in a GIS environment for the refund and the mapping of areas exposed to water erosion: i. Topographic Data:

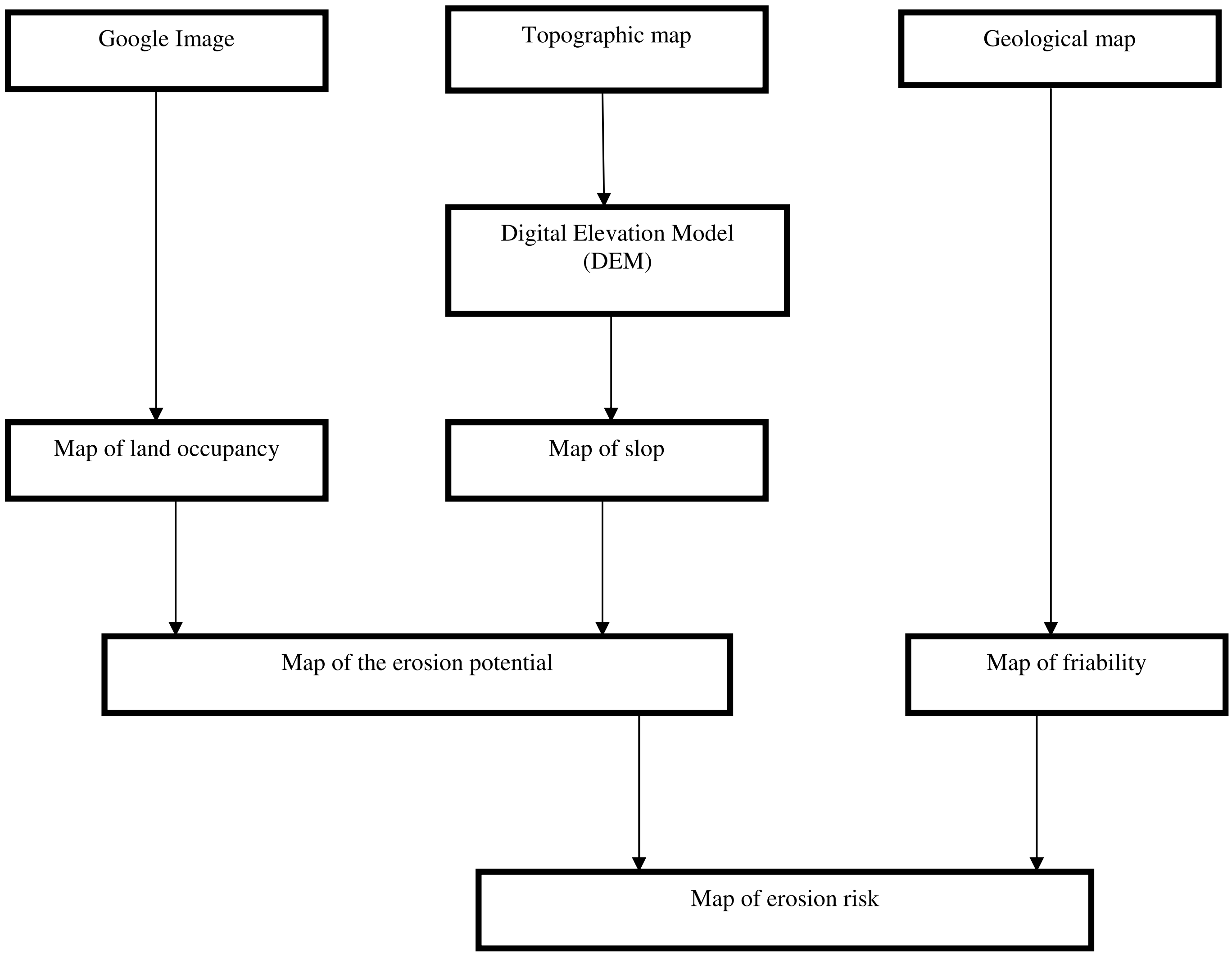

Figure-2
Flowchart of the methodology followed for the development of the card of the erosion risk

For the achievement of the MNT and by following the map of slopes. ii. Satellite Data (Google Image): For the realization of the Map of land, and after the overlay with the card of the slopes, you will have the map of erosion potential. iii. Geological Data: For having the map of friability of materials, with the map of erosion potential will be the card of the risk of erosion.

Preparation of a management plan: To ensure the protection of the areas affected by the erosion, it is indispensable to a hand to perform a diagnosis of the current state of facilities to maintain and safeguard the existing developments and assess their influence on the flow rates of the floods, on the other hand the implementation of a development complementary program.

Results and Discussion

Estimation of the Runoff coefficient: Due to the superposition of the two themes (pedology and classes of slopes) and the coefficients of weights assigned to each homogeneous zone, it was able to close these areas into three classes of sensitivities and achieve a sensitivity map to runoff.

Similarly the superposition of the two themes Map of land and Sensitivity to runoff allows you to realize the map of potential runoff.

The calculation of the coefficient of runoff then gives a coefficient of runoff for the entire study area of 0.3 and of the coefficients of runoff for each sub-basin shown in table-2

Table-2
Coefficient of runoff

Under basin	sub-basin 1	sub-basin 2	sub-basin 3	sub-basin 4	sub-basin 5	sub-basin 6
CR	0.28	0.25	0.27	0.22	0.26	0.26

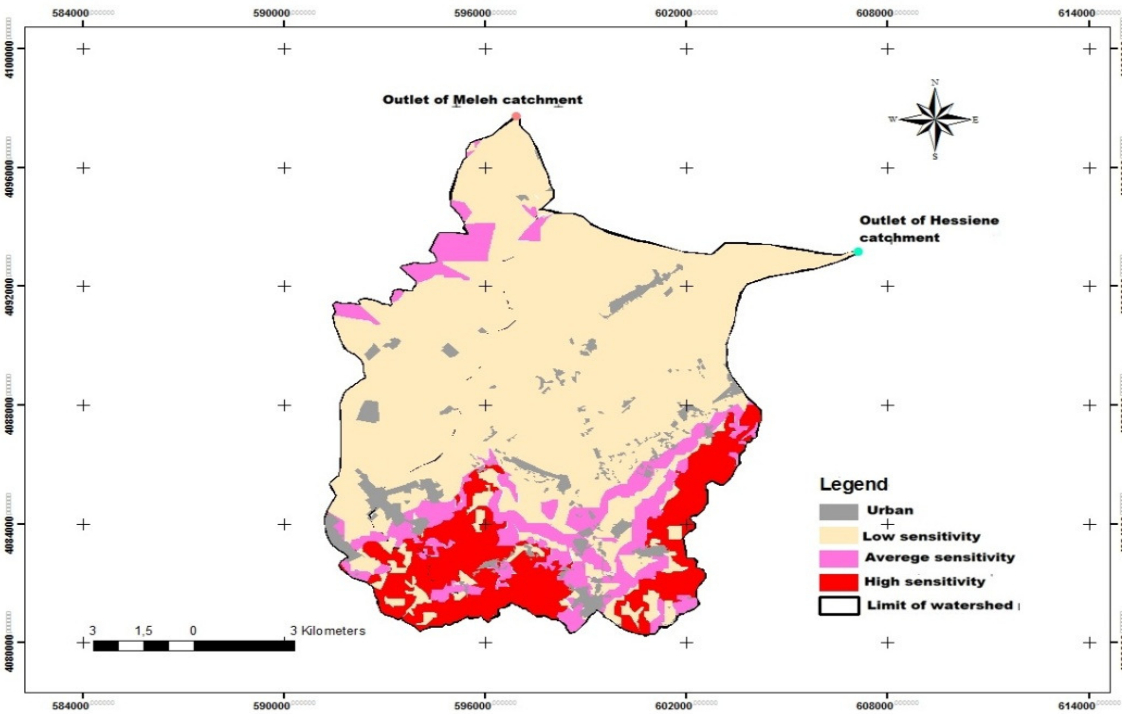

Figure-3
Map of the sensitivity to runoff

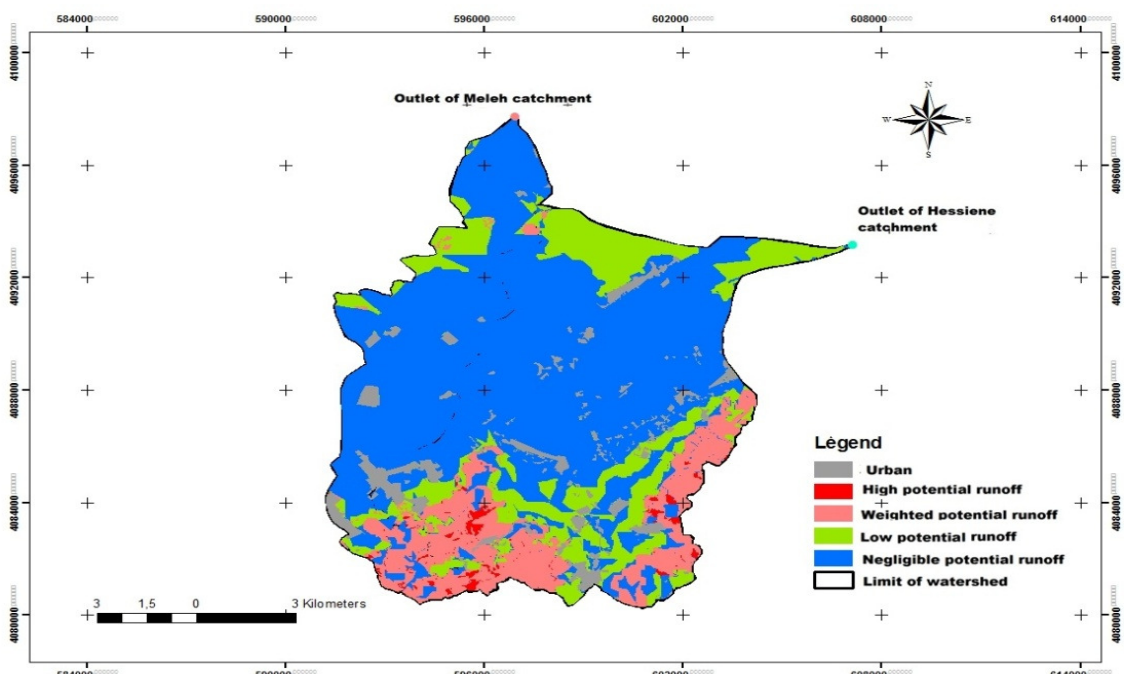

Figure-4
Map of potential runoff

Study of inputs : Study of flood: model of sokolovsky: Unit hydrographs of flooding. The flood flow is used for the design and sizing of hydraulic installations. The problem consists on the lack of hydrometric observations and rainfall data of exceptional events.

For these reasons, the model of Sokolovsky[15, 16] is used for the reconstitution flood hydrographs warning for each sub catchment and for different return periods, and by following the calculation of the volumes of the floods. Thus the following figures show the rounded unit floods hydrographs for each sub-basin and for different return periods.

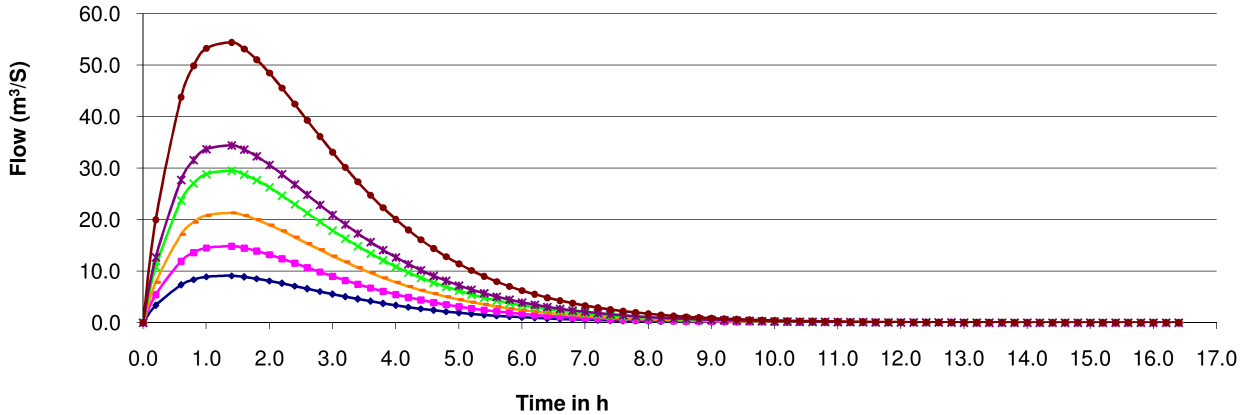

Figure-5
Rounded hydrograph flood (*sub-basin* 1)

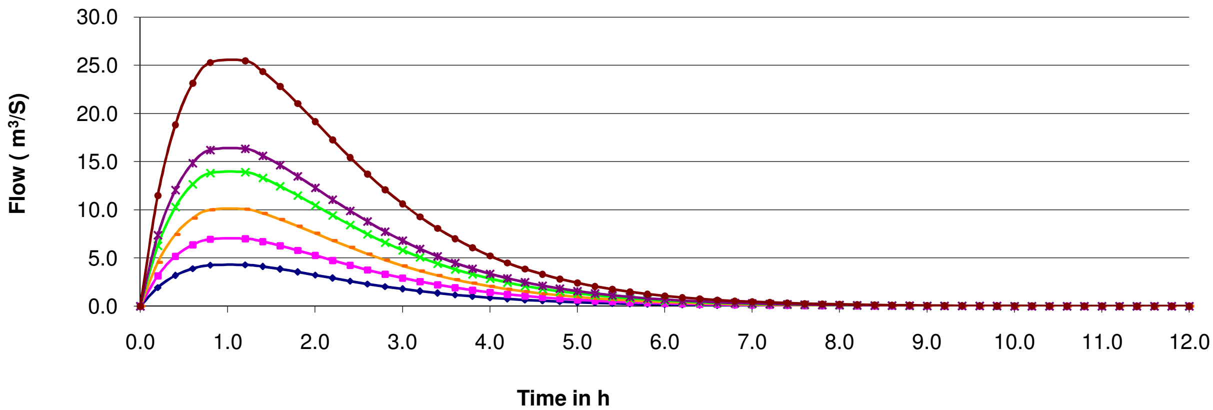

Figure-6
Rounded hydrograph flood (*sub-basin* 2)

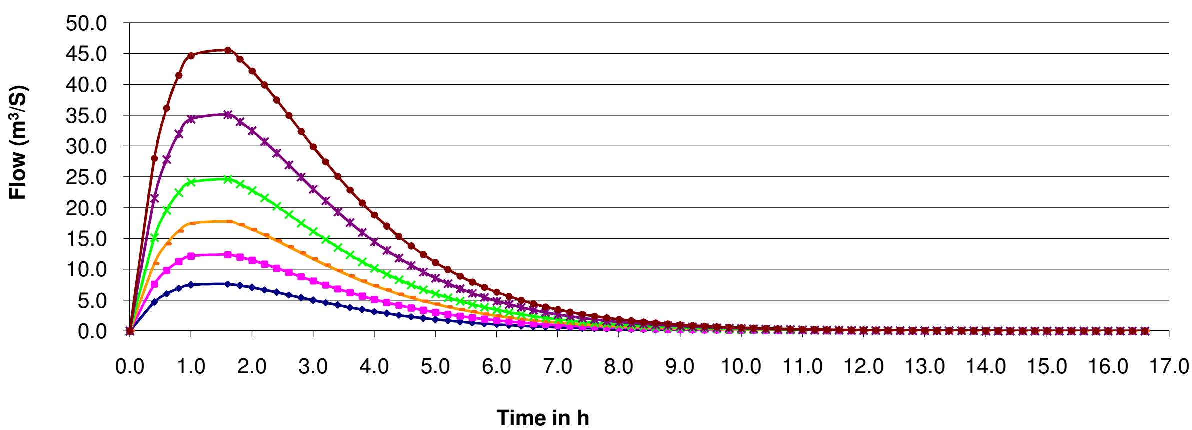

Figure-7
Rounded hydrograph flood (*sub-basin* 3)

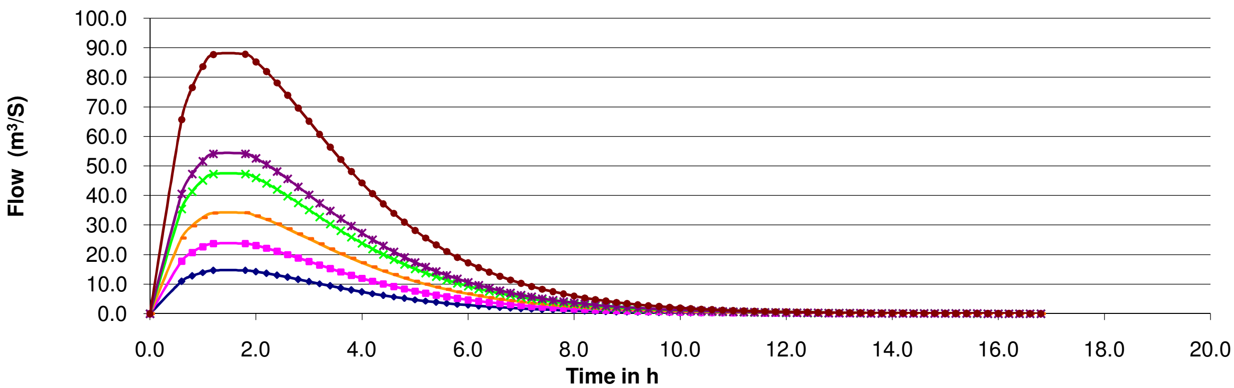

Figure-8
Rounded hydrograph flood (*sub-basin* 4)

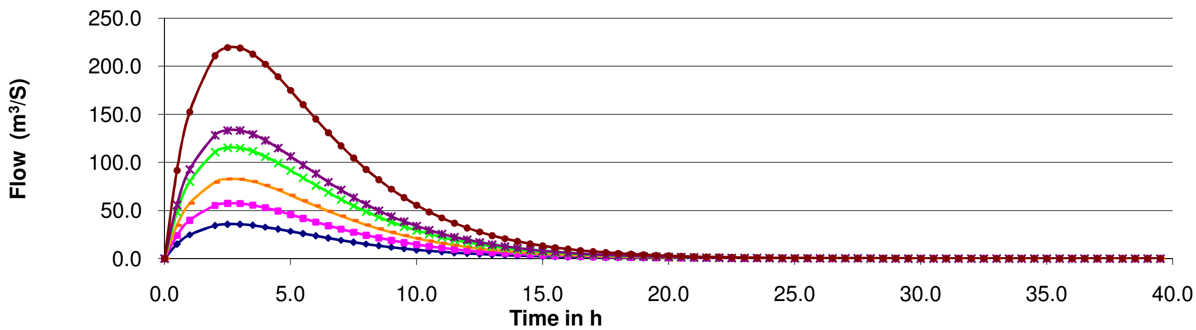

Figure-9
Rounded hydrograph flood (*sub-basin* 5)

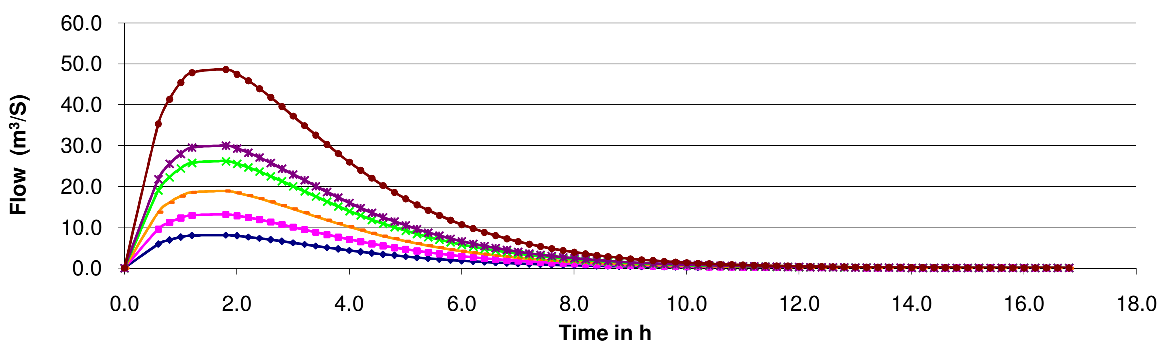

Figure-10
Rounded hydrograph flood (*sub-basin* 6)

Volumes of floods The volume of flooding was determined from simulated hydrographs. The table-3 shows the volumes of a flood of different frequencies for each sub basin.

The statistical analysis of the monthly maximum observed rainfall series for the station Cherfech CRGR, gave a maximum monthly observed of 227.3 mm for a return period of 26 years. We can thus calculate the volumes corresponding to this value for the various sub-watersheds, to finally compare with the results of the model of Sokolovsky.

From the table-4, it was found that the estimated volumes due to the statistical analysis of the data are underestimated compared to the results given by the application of the Sokolovsky model.

Thus, given the importance of volumes of flood which are used for the design and sizing of hydraulic equipments, the application of Sokolovsky model takes a greater importance to perform a better estimation.

Study of solid transport: The table-5 shows that the specific erosion at the level of all the sub watersheds is the same in the order of 2669, 5 tonnes/km²/year.

On the other hand, given the average annual contribution of each sub-basin, and erosion of its specific, its strong transportation annual average was determined, which allows estimating the average concentration of the materials extracted and transported by the waters of floods which is approximately 21 g/l at the scale of all the sub watersheds. This same value for all sub-watersheds expressed the homogeneity in the flow regime and the hydrometric characteristics in the region of study.

Study of the status of erosion and preparation of the management plan: Preparation of the map of erosion risk: Due to the superposition of the two layers (land use and classes of slopes), it has been able to achieve the map of potential erosion.

The map of risk of erosion has been developed by the interaction between the erosion potential and the friability of materials.

Table-3
Volumes of floods (m^3)

Return period (Years)	2	5	10	20	50	100
Sub-basin 1	104430	170019,1	244195,76	338212,1	394819,3	624209
Sub-basin 2	39724	64769,69	93016,174	128510,2	150877,8	235208
Sub-basin 3	185095	300811	432317,11	599559,6	686242,2	1112791
Sub-basin 4	87745,1	142749,8	205166,27	284159,7	404802,2	525445
Sub-basin 5	888838	1437760	2070920,6	2886220	3342251	5497772
Sub-basin 6	106411	172955,3	248759,69	344943	395131,3	641254

Table-4
Volumes of floods (m^3) of return period 26 years

Volume	Sub-basin 1	Sub-basin 2	Sub-basin 3	Sub-basin 4	Sub-basin 5	Sub-basin 6
Statistics	330057	121378	573082	226377	1941073	310205
Sokolovsky	349533	132983	616896	308288	2977426	354980

Table-5
Estimation of solid transport in annual function of annual volumes

	Sub-basin 1	Sub-basin 2	Sub-basin 3	Sub-basin 4	Sub-basin 5	Sub-basin 6
V (m3/year)	658622	271272	1185926	574929	4171315	666623
S(sq km)	5.186	2.136	9.338	4.527	32.845	5.249
T(tons/sq km/year)	2669,5	2669,5	2669,5	2669,5	2669,5	2669,5
PT(tons/year)	13844,03	5702,05	24927,79	12084,83	87679,73	14012,21

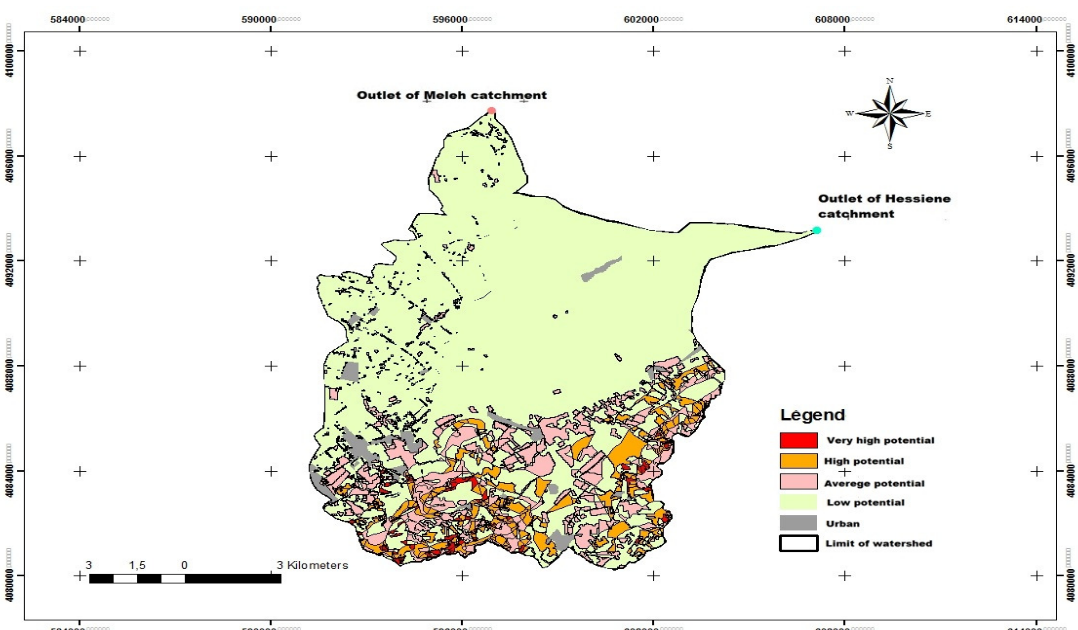

Figure-11
Map of potential erosion

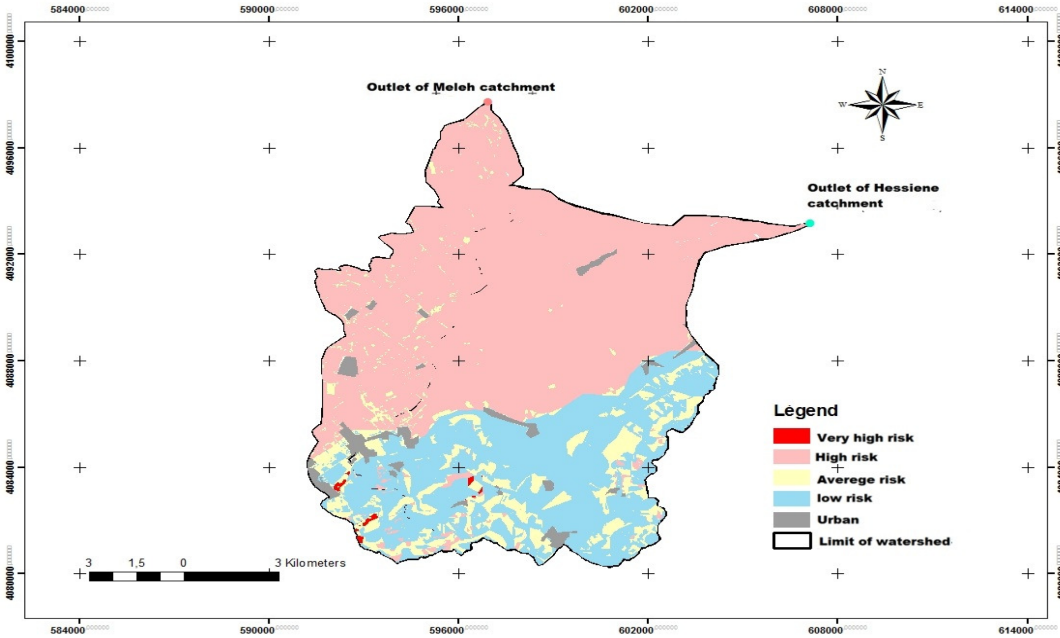

Figure-12
Map of risk of erosion

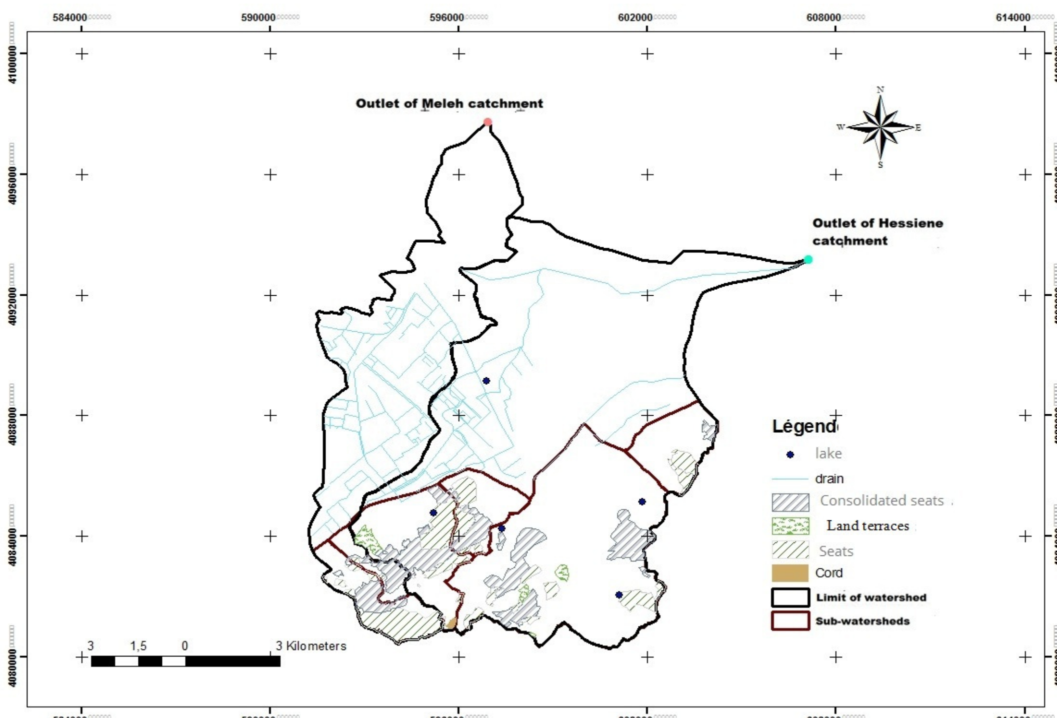

Figure-13
Map of existing equipments

Maintaining of the existing equipments: The examination of the current state of equipments showed that the parties appointed in non-consolidated benches as well as appointed in dry stone cords pose a significant depreciation.

It is therefore mandatory to perform maintenance work and backup in these areas, it must be also the consolidated, to improve their capacity of water retention and therefore increase their impact on the reduction of runoff.

The actual position of these installations is as follows: i. The benches consolidated by plantations of olive-tree are in good condition and ensures their features well. ii. The unconsolidated benches present a filling by solid contributions and themselves are almost on the same topographic level that the rest of the ground original. It is thus essential to maintain them. iii. The dry stone cords are practically filled and do not ensure any more their roles, from where the need for engaging a program for their maintenance and consolidation.

Development Proposal for the priority areas: The areas that require an intervention are localized due to the superposition of the map of erosion and that of existing equipments, by delineating the areas to erosion high and very high, and which are not affected by the development.

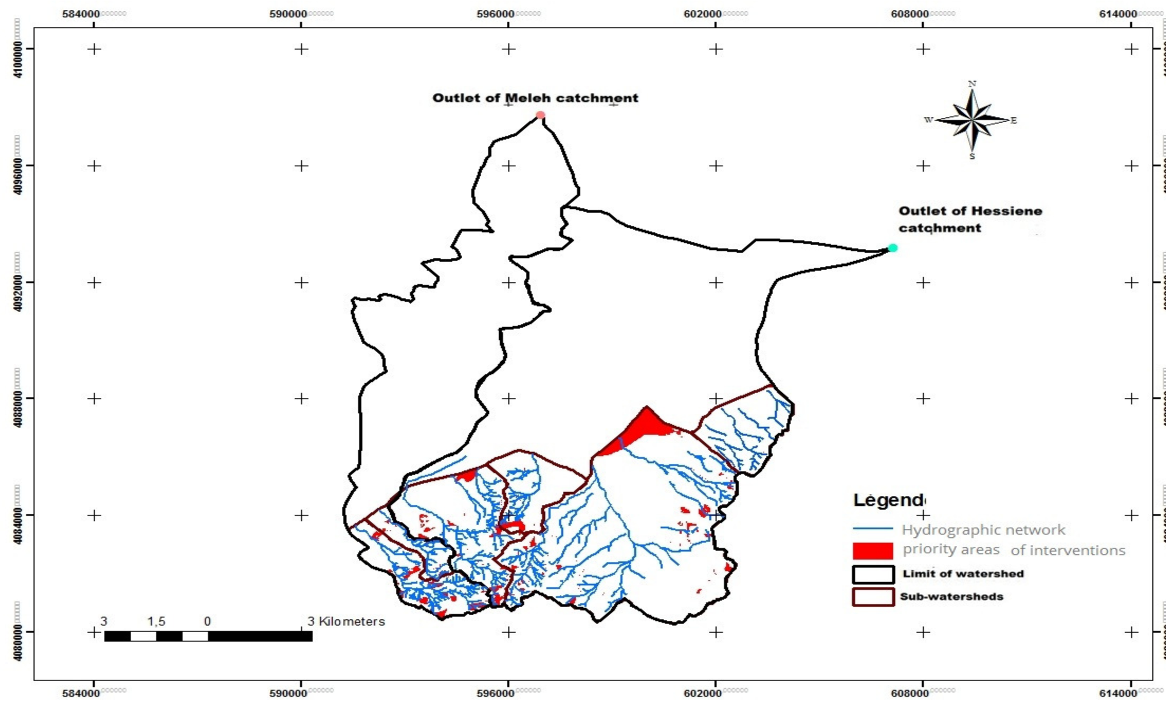

Figure-14
Map of priority areas of intervention

Table-6
Area of intervention and proposed development

Under basin	Area (ha)	Proposed Développent		
		Planning	**Unit**	**Quantity**
Sub-basin 1	7.7429	Consolidated Bench	HA	7.74
		Spillway Threshold	Unit	1
Sub-basin 2	6.0676	Consolidated benches	HA	3.19
		land terraces	HA	2.87
		Spillway Threshold	Unit	2
Sub-basin 3	38.3331	Consolidated benches	HA	28.38
		land terraces	HA	5.06
		Cord dry-stone	HA	4.90
		Spillway Threshold	Unit	2
Sub-basin 4	2.8562	Consolidated benches	HA	2.86
		Spillway Threshold	Unit	0
Sub-basin 5	182.2431	Consolidated benches	HA	23.01
		Cord dry-stone	HA	5.21
		Tree plantation	HA	129.24
		Spillway Threshold	Unit	2
Sub-basin 6	1.9471	Tree plantation	HA	1.95

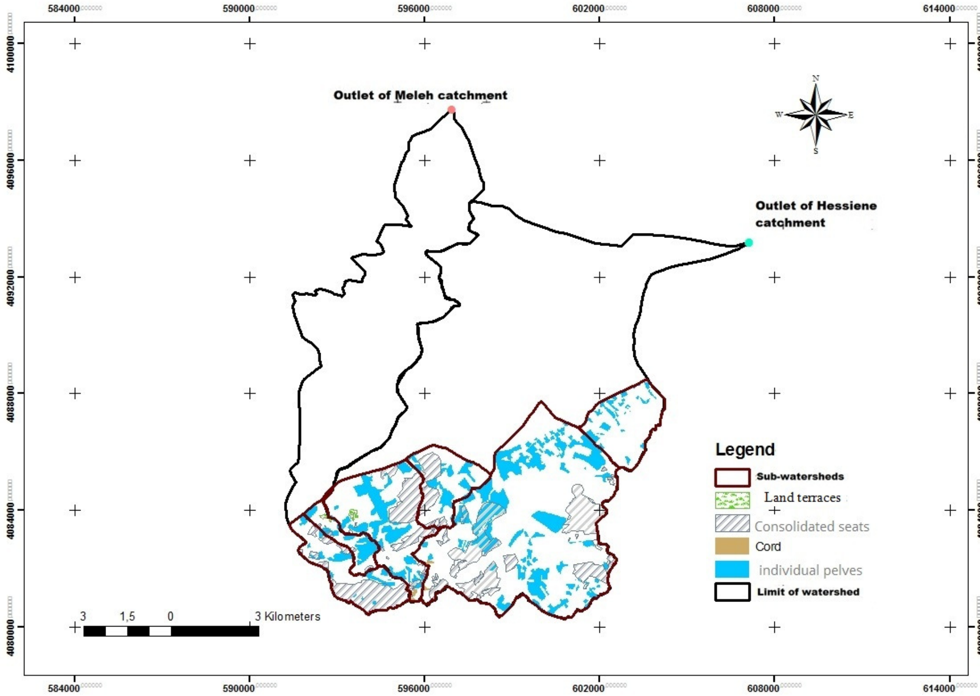

Figure-15
Map of proposed developments

Conclusion

The development of the sensitivity map to the runoff has helped us to determine the annual liquid volumes, in addition that it was carried out a study of flooding by application of the Sokolovsky model which ensures a better estimation of it.

The development of map of erosion's risk presents a great importance in the development of the proposed development these, the map that is derived shows four areas of vulnerability to water erosion: low, medium, high and very high. The areas at high and very high risk of erosion correspond to the priority areas of intervention.

The analysis of different available data has allowed us to obtain the map of reliable and practically executable equipments that has for goal to plan for the installation of the techniques that will ensure the maintenance and improvement of soil fertility, instead of the stabilization and rehabilitation of eroded areas.

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