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Flood Hazard Mapping Using remote sensing and GIS Tools: A case study of Souss Watershed

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Abstract

The Souss watershed is one of the most important drainage basins in Morocco, this basin had been exposed to frequent flood hazards which were responsible for many damages in several areas of the basin, the present work introduces a flood hazard assessment methodology, using multi-criteria analysis in a GIS environment. In order for the most prone flooding areas to be identified, seven factor maps were combined in a GIS environment, these factor maps are, the rainfall intensity, the altitude, the slope ,the land use, the flow accumulation, the soil erodibility, and the distance from drainage networks, the relative importance of each parameter for the occurrence and severity of the flood has been connected to weight values, according to their weight values, information of the different parameters is superimposed, resulting in flood hazard mapping, the flood hazard for each one of these factors is classified into five categories: very low, low, moderate, high, and very high . The study area was separated into five regions characterized by different degrees of flood hazard ranging from very low to very high. The reliability of the final flood risk map is verified using historical flooded data from Souss Massa Draa Hydraulic Basin Agency (ABHSMD), the proposed methodology can be applied as a judgment making tool for flood risk mitigation to any river basin.

1. Introduction

Floods are the most common natural disasters that affect societies around the world, estimated that more than one third of the world's land area is flood prone affecting some 82 percent of the world's population. About 196 million people in more than 90 countries are exposed to catastrophic flooding [1][1], in Morocco, floods caused more than 1,165 deaths, more than 232,896 affected population, and more than US$ 295 million in damage from 1995 to 2005[2], Floods are a natural part of the hydrological cycle. However, they have the potential to cause fatalities, displacement of people, and damage to the environment which may also severely endanger the economic development.

Morocco experienced major floods at the beginning of the 21st century that caused significant human and material damage in several parts of the country. The catastrophic floods of the Ourika Valley in 1995, the plain of Martil in 2000, the region of Mohammadia, Berrechid and Settat in 2002, the Tanger region in 2008, the Gharb plain in 2009, the Taza region in 2010 and the Khénifra region in 2011[3], Souss watershed is vulnerable to floods, whose intensity is becoming increasingly alarming and this area does not escape to the effects of this extreme event, Indeed, the susceptibility of this region to this type of hazard is accentuated by its rapid evolution in terms of demography, uncontrolled land use, anthropogenic actions and physical behaviour of the environment (higher slope, impermeable rocks)[4].

The flood hazard is the probability that a flood incident of a certain degree will occur in a given area within a given period of time, Flood hazard mapping is a vital factor for appropriate land use planning in flood-prone areas. It creates easily read, rapidly accessible charts and maps which facilitates the administrators and planners to identify areas of risk and prioritize their mitigation efforts [5], according to Meyer et al. (2001)[6], remote sensing and GIS are particularly powerful tools for the study of natural hazards, Earth observation data are a powerful tool for monitoring flood phenomena because they allow identify the affected areas, but also can help in the implementation of risk prevention plans; thus several works have used radar and optical satellite images to assess the risk of flooding, and remote sensing space and GIS play a role leading role in this quest for knowledge.

2. Material and Methods

2.1. Study area

The Souss River Basin is located in the middle western Morocco, occupying a total surface of 17186km2, which is approximately between 9.6 and 7.47 degrees west longitude and between 29.70 and 31.11 degrees north latitude, the Anti-Atlas mountains in the south, the High Atlas mountains in the north, the Siroua massif in the east, and the Atlantic Ocean in the west are the natural limits of the Souss river basin (Figure 1). The study area has a very important value economic due principally to its high-value agricultural production, tourism industry, and fishery development , The variation of rainfall in Souss Basin is very important in time and space which are favourable factor to the genesis of floods.

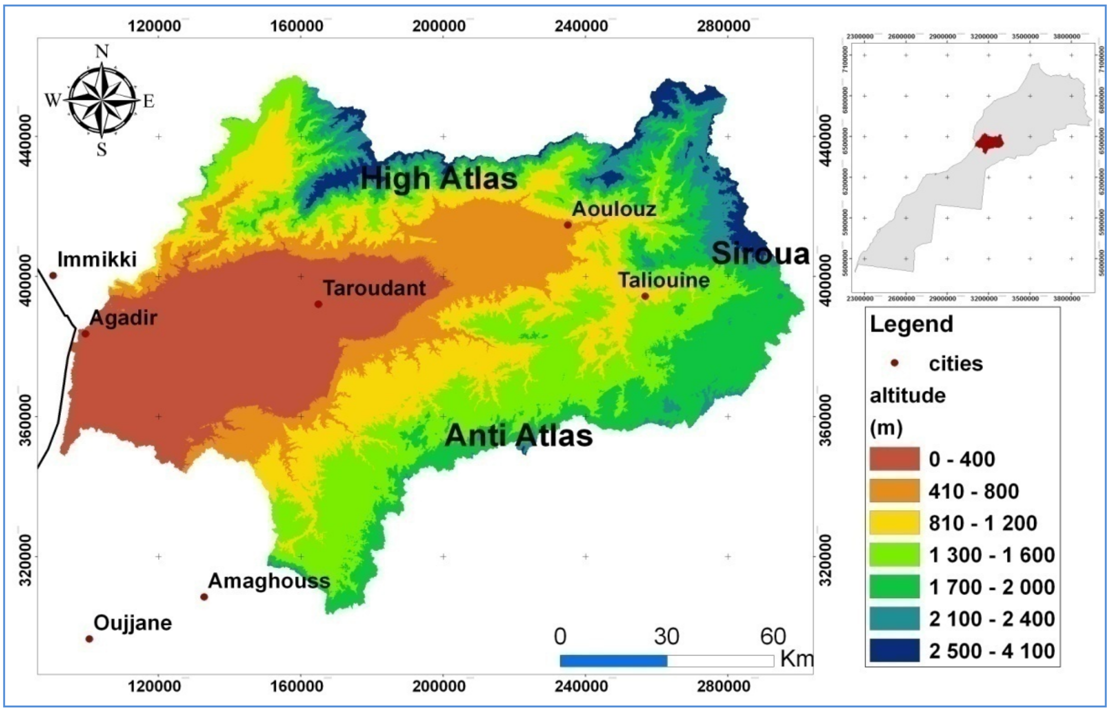

Figure 1: Geographical situation of Souss river basin.

2.2. Methodology

In order to estimate the flood-hazard areas the Souss river basin area was divided into five regions characterized by different degrees of flood hazard (very high, high, moderate, low and very low), this classification is performed by considering the factors that form and influence a flood and by assigning relative weights to them, this process is performed in a Geographic Information System (GIS) environment and thematic maps are produced for each parameter, the linear combination of the thematic maps and the selection of the weights yield the final map of flood hazardous areas [7].

For the estimation of the flood-hazard areas in the study area, seven thematic-layer factors were created using a GIS ArcMap environment: flow accumulation, slope, elevation, rainfall intensity, land use, geology and distance from the drainage network, the factors used in this study were selected due to their general relevance to the flood hazards and according to literature surveys [7-8], all of these variables were georeferenced to the Merchich Coordinate System.

Thematic maps of elevation, slope and flow accumulation are products of the digital elevation model (DEM), geological information offers insight on the geological units, while land use information is related to the normalized difference vegetation index (NDVI), distance from the drainage network can be calculated by imposing buffer zones around the drainage network. Finally, rainfall intensity is estimated from rainfall measurements, using a modified Fournier index.

The flood hazard areas cannot be estimated by considering the effect of each factor separately, the integration of all factors is necessary in order to obtain the overall map of flood-hazard areas, since all factors do not have the same degree of influence on the hazardous areas, a weighting approach, in which a different weight is assigned to each factor, was applied, the factor weights were determined by employing the methodology presented by Kourgialas and Karatzas 2016 [7], which considers the effect of each factor on all other factors (Table 1).

Table 1: Interaction between factors that influence the flood risk

Factor Changing	Major Effect	Minor Effect	Factor Rate (FR)
Flow accumulation (F)	(L)	(S)	1.5 pts (1major + 1minor)
Slope (S)	(L), (F),		2.0 pts (2major + 0minor)
Land use (L)	(F), (R)	(G), (S)	3.0 pts (2major + 2minor)
Rainfall intensity (R)	(F)	(L)	1.5 pts (1major + 1minor)
Geology (G)	(L), (F), (S)		3.0 pts (3major + 0minor)
Elevation (E)	(L), (F), (R), (G)	(S)	4.5 pts (4major + 1minor)

Kazakis et al. 2015[8] suppose that distance from drainage networks and elevation are assigned an equal importance since flooded areas are often located in low elevation and near the drainage network, the summation of all the factor weights yields the grand total weight (Table 1), the contribution of each factor to the flood hazard areas, expressed as a percentage, is shown in the last column of Table 1, the percentage of each factor was computed as the ratio of the total factor weight to the grand total.

The resulting map of hazardous areas includes the combination of the above seven variables which are related directly to any flood event that occurs in the area of study, specifically, the seven maps that were developed after the classification method were combined using a weighted linear combination approach in a GIS environment, according to this technique, each factor is multiplied by its percentage weight and the summation of all factors yields the final map of hazardous areas[9]:

$$S=\sum W_i X_i$$

Where S is the final map of flood hazard areas, Wi is the weight of factors i and Xi are the rate of factor i.

2.3. Rainfall intensity

In order to determine the rainfall intensity, the meteorological data of the 20 meteorological stations in and out of the Souss River Basin, recorded in the period 1988–2014 were used, The Rainfall intensity map (Figure 1) was created by using the Modified Fournier Index methodology [7]:

$$\text{MFI} = \sum_{1}^{12} p^2/P$$

Where:
MFI: the Modified Fournier Index,
p: the average monthly rainfall
P: the average annual rainfall

The MFI indicator expresses the sum of the average monthly rainfall intensity at a station. The MFI rate of each station was interpolated at the GIS environment using the deterministic technique of spline method. This method was selected based on various studies which indicate that the spline method is the best method for representing smoothly varying surfaces of phenomena such as rainfall [7]. MFI ranges from 12 to 160 (Table 2), with the higher values located in the north part of the study area.

Table 2: calibration and weight evaluation of the factors affecting flood risk areas

Factor	**Domain of effect**	**Descriptive level (flood hazard)**	**Proposed weight of effect (a)**	**Rate (b)**	**Weighted rating (a × b)**	**Total weight**	**Percentage (%)**
Rainfall intensity (Units MFI)	130-160	Very high	10	1.5	15	39	7.98
	88-130	High	8		12		
	68-88	Moderate	5		7.5		
	48-88	Low	2		3		
	12-48	Very low	1		1.5		
Elevation (m)	0-250	Very high	10	4.5	45	117	23.95
	250-500	High	8		36		
	500-1000	Moderate	5		22.5		
	1000-1500	Low	2		9		
	1500-4141	Very low	1		4.5		
Slope (degree)	0-7	Very high	10	2	20	52	10.65
	7-14	High	8		16		
	14-23	Moderate	5		10		
	23-33	Low	2		4		
	33-72	Very low	1		2		
Land use	-1.053	Very high	10	3	30	78	15.97
	0.063-0.1	High	8		24		
	0.1-0.15	Moderate	5		15		
	0.15-0.25	Low	2		6		
	0.25-0.58	Very low	1		3		
Flow accumulation (pixels)	1613000-2310000	Very high	10	1.5	15	39	7.98
	887800-1613000	High	8		12		
	380500-887800	Moderate	5		7.5		
	81530-380500	Low	2		3		
	0-81530	Very low	1		1.5		
Geology	Impermeable formations	Very high	9	3	27	46.5	9.52
	semipermeable formations	Moderate	5		15		
	Permeable formations	Low	1.5		4.5		
Drainage distance	<200	Very high	10	4.5	45	117	23.95
	200-500	High	8		36		
	500-1000	Moderate	5		22.5		
	1000-2000	Low	2		9		
	>2000	Very low	1		4.5		
SUM						488.5	%100

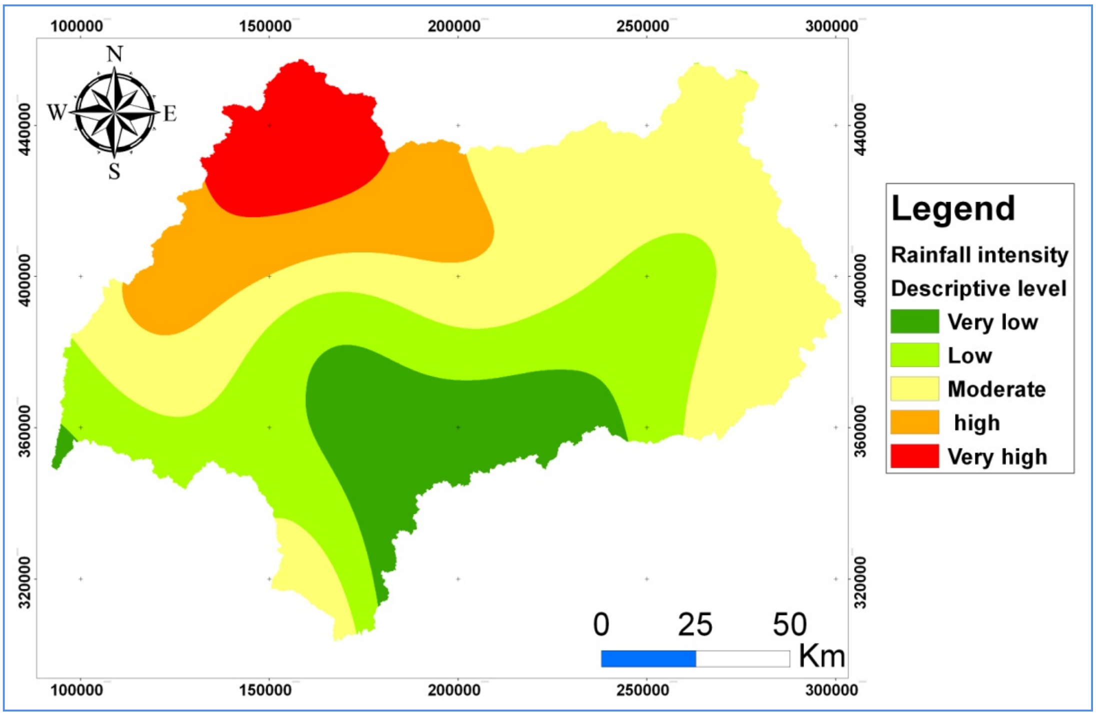

Figure 2: Rainfall intensity map

2.4. Elevation and slope

Topography plays an important role in flood brutality and for the determination of a flood-prone area, topographic factors have a direct effect on flow size and runoff velocity[10]. Water flows from higher to lower elevations and therefore slope influences the amount of surface runoff and infiltration, flat areas of low elevation may flood quicker than areas of higher elevation with a steeper slope [8]. Elevation and slopes were derived from a DEM extracted from the SRTM data for the study area, the SRTM DEM of 1 Arcsec resolution (30 m) was obtained from the USGS DEM global data explorer archive, In the studied area high-elevation appears in the southern and northern part, where the slope is also steeper.

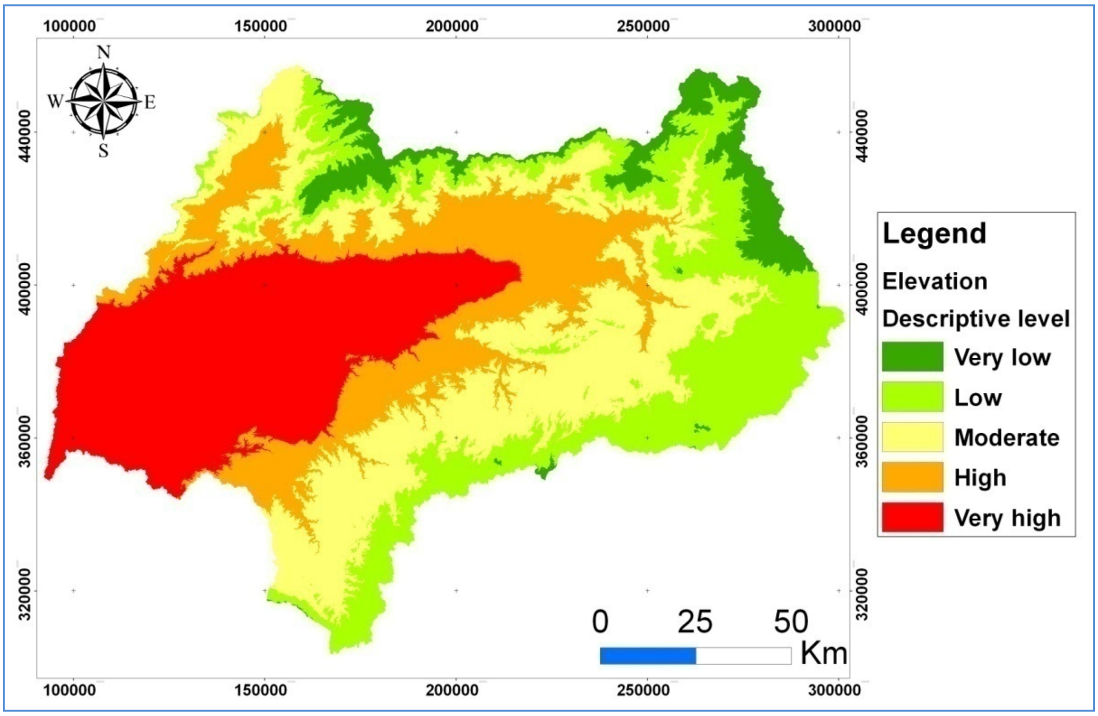

Figure 3: Elevation map

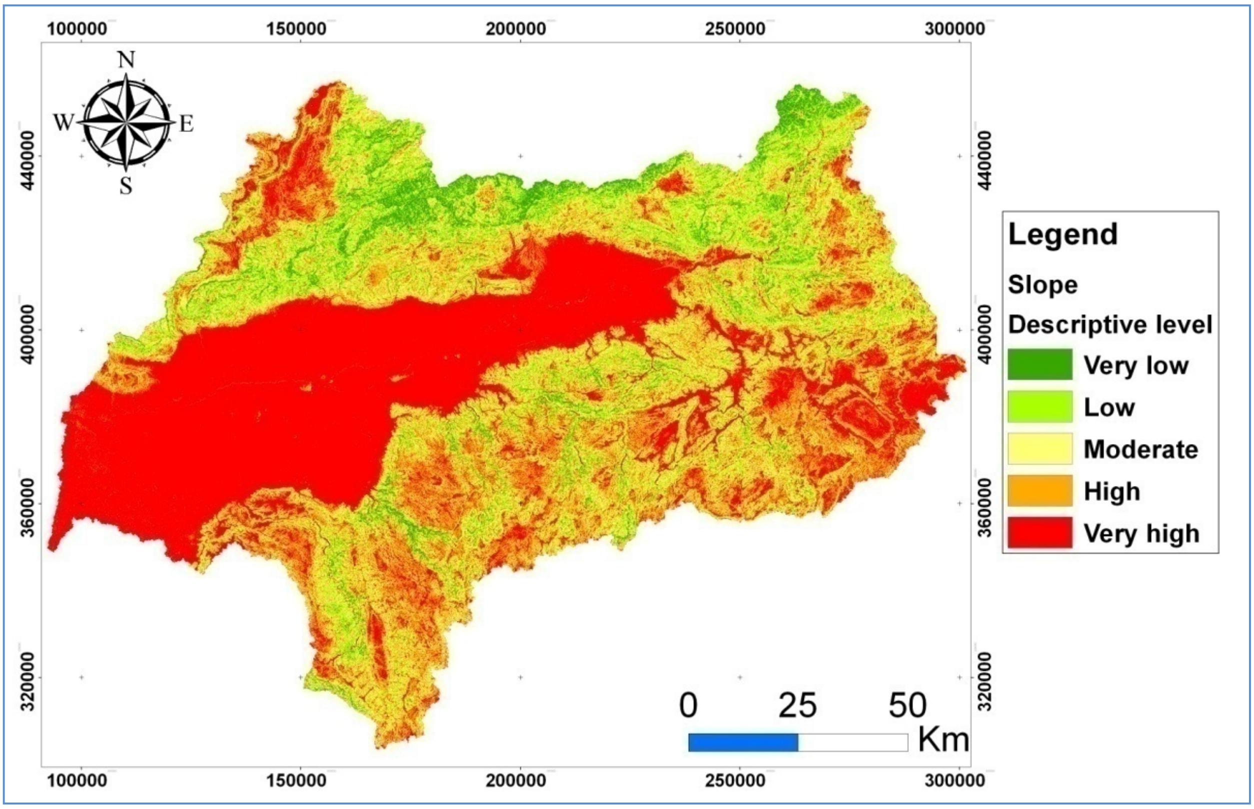

Figure 4: slope map

2.5. Land use

Land use and nature of land cover are also key factors responsible for flood incidence, Land use is the surface cover of the earth in a specific location (e.g., vegetation type, an artificial structure…). It can be derived directly from remote sensing data and it needs to be verified by survey [11]. Land use influences infiltration rates, the interrelationship between surface and groundwater as well as debris flow, thus, while forest and lush vegetation favour infiltration, urban and pasture areas support the overland flow of water [8].

According to Ait Brahim et al[12], the land use map of Souss Basin, made by using the global land cover data from the Food and Agriculture Organization (FAO), shows the existence of eight soil classes, the most abundant soil classes correspond to sparse vegetation, bare soil, and cropland. 75.26% of the area is equally divided between the sparse vegetation and bare soil. This high proportion demonstrates aridity and forest degradation of the Souss region, 16.84% of the area is mainly cultivated with cereals (35%), citrus fruits (21%), and vegetable crops (14%).

To define this factor, land use was estimated based on plant canopy (Pc) in percent using the following equation[13]:

$$\text{Land use} = 20 - 0.2 * \text{P}_\text{c}$$

To determine Pc, a relation between canopy and NDVI was developed for this area[13].

The equation is as follows: $\text{P}_\text{c} = 64.1 * \text{NDVI} + 15.9$

The final map of the land use is shown in Figure 5.

2.6. Flow accumulation

Flow accumulation is an indirect way of measuring drainage areas and increases constantly from the drainage divides to the outlet and river channels[9], Is important parameter in defining flood hazard, accumulated flow sums the water flowing downslope into cells of the output raster, high values of accumulated flow indicate areas of concentrated flow and consequently higher flood hazard [8].

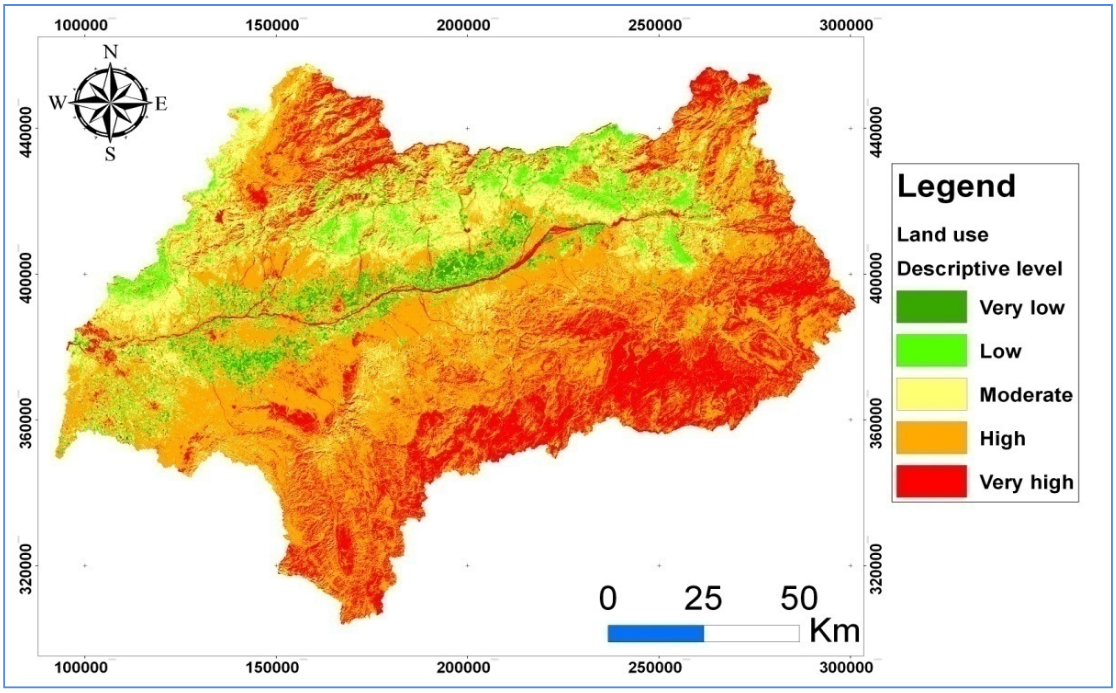

Figure 5: Land use map

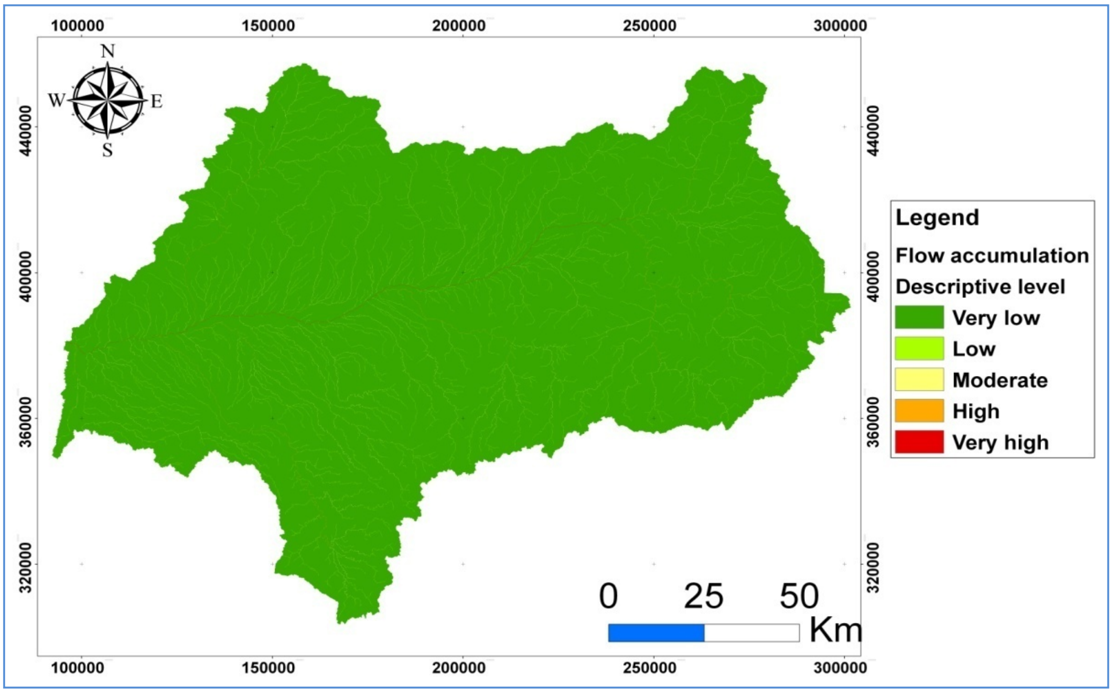

Figure 6: Flow accumulation map

2.7. Geology

The geology of flood hazard areas is an important condition, because it may increase/extenuate the degree of flood events, permeable formations support water infiltration, through flow and groundwater flow, On the contrary impermeable rocks, such as crystalline rock, favour surface runoff [8], According to Hssaisoune et al[12] the age of the geological formations of study area ranges from Paleozoic to Quaternary, the plain is composed of Plioquaternary sediments (sands, gravels, and lacustrine limestone), which covers a Cretaceous syncline in the north of the basin and a Paleozoic schistose basement in the south, the High Atlas shows an alternation of permeable and impermeable Mesozoic formations ,The geology map of the study area was generated from the geology map of the Souss river basin from El Morjani thesis 2002[14].

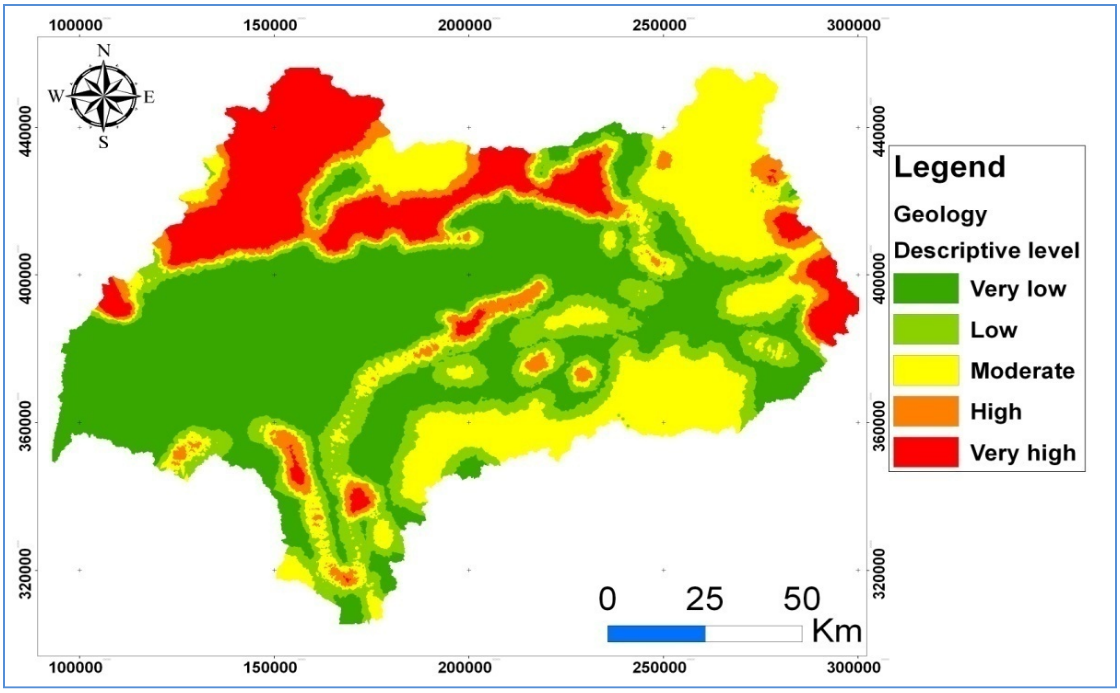

Figure 7: geology map

2.8. Distance from drainage network

separately from areas of concentrated surface water, river overflows are critical for the initiation of a flood incident, frequently the inundation emanates from riverbeds and expands in the surroundings, The role of riverbed decreases as the distance increases, That explains why "distance from the drainage network" has been assigned a high weight in the methodology[8].

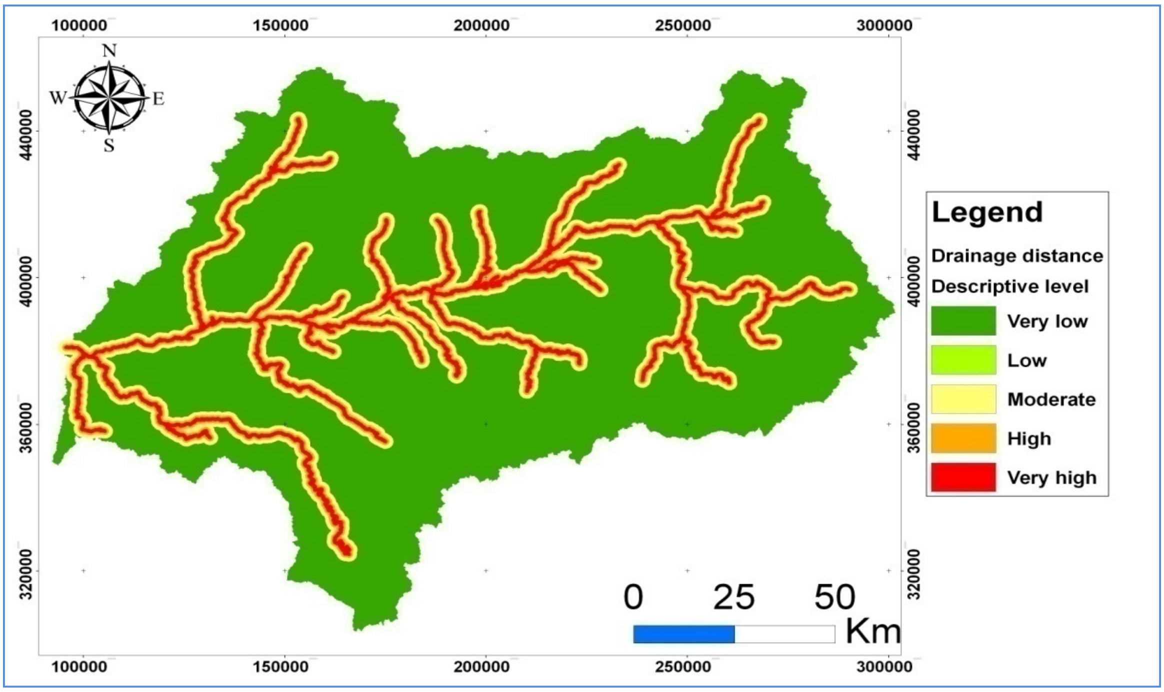

Figure 8: drainage network map

3. Results and discussion

3.1. Maps' interpolation

After the determination of the weights of the factors, a multi-criteria evaluation is used by utilizing the specific weights for each factor, for created the flood hazard map after superimposing the thematic maps with different weights in a GIS environment, the result is a flood hazard map showing the most vulnerable areas to flooding within the Souss watershed, the results of this stage of analysis are shown in figure 9. The results show that a 11.29% of the total study area was prone to "high" and "very high" flood hazards, these areas are flat areas located close to main channels, close to the rivers and generally laying at low elevations, 53.80% of the study area was prone to "low" to "very low" flood hazards, 34.91% to "moderate" level of flood hazards, most of these areas tended to be on the higher grounds and further away from the high drainage density areas, table 3 shows the summary statistics computed for each hazard class.

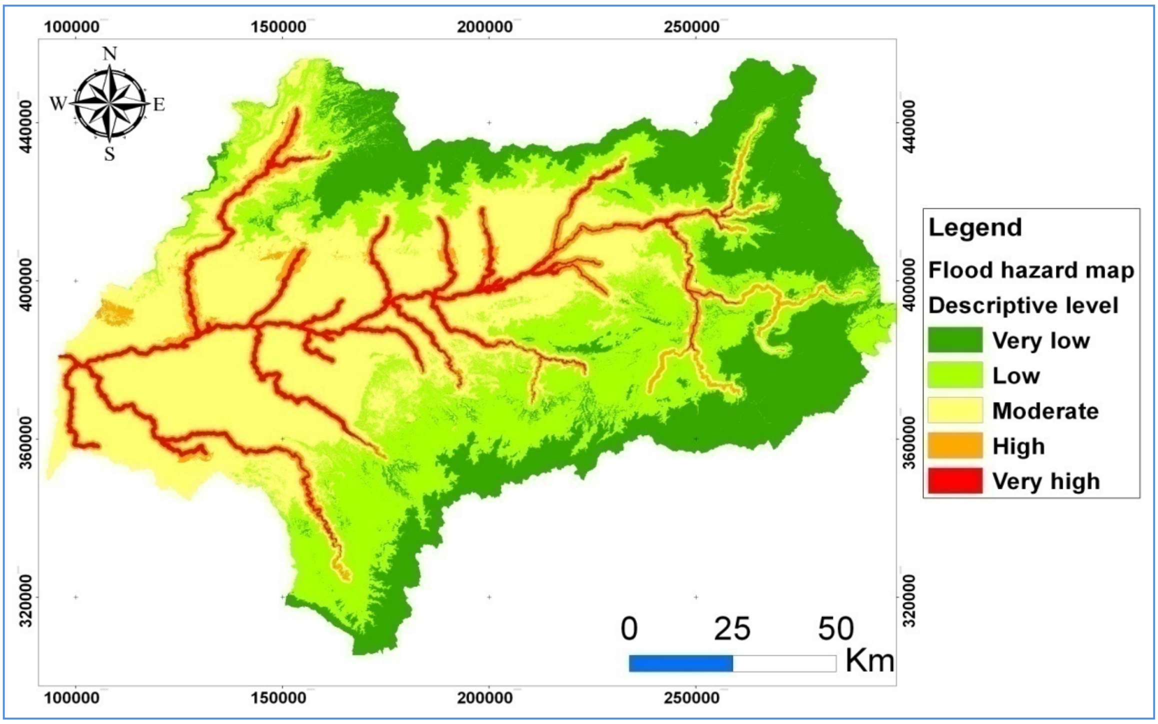

Figure 9: Flood Hazard Map

The result indicates that about 4.62% of the land area is demarcated as very high, 6.67% as high, 34.91% as moderate, 27.73% as low, and 26.07% as very low flood-vulnerable zones (Table 3). High to very highly vulnerable zones are mostly located along the central part of the study area (Fig. 9). These high to very high flood vulnerability zone areas are characterized by the lower slope gradient, lower elevation, braided flood plain and closer to the main river, which are the important conditioning factors for flood susceptibility mapping.

Table 3: Flood vulnerability zones and their areal coverage

Flood vulnerability zones	Flood vulnerability index	Area	
		km2	%
Very high	23.38-30.86	785.22	4.62
High	18.99-23.38	1132.34	6.67
Moderate	14.60-18.99	5929.81	34.91
Low	10.41-14.60	4711.36	27.73
Very low	5.43-10.41	4428.35	26.07

3.2. Validation of the Flood Hazard Map

To perform the validation of the flood hazard maps results, the locations of the historical flood events were generated based on field inspection information coming from the Souss Massa Draa Hydraulic Basin Agency (ABHSMD)[2], providing relevant information concerning 90 flooding sites (Fig. 10). These historical flood points were overlaid on the modelled output. Table 4 shows examples of these historical flood points[15] (15 events at 10 locations), their x-y coordinates as well as the location of the respective modelled flood vulnerability zones. All historical flood points in table 4 are located on the high and very high flood vulnerability zones, according to the modelled output which indicates the reliability of the flood vulnerability model used in this study.

Table 4: Historical flood points and their position on the modelled flood vulnerability zones

Flooding Site	X coordinate	Y coordinate	Rural Commune	Valleys	Province	Location at modelled flood vulnerability zones
Ait ougarda	218,300	408,200	Sidi Ouaâziz	Lemdad	Taroudant	High
Takarzna	216,000	407,000				Very high
Loulija	207,700	401,200	Lmhara	Boussriouil		Very high
Chbika	207,500	400,000				High
Tagadirt N'ait Ali Ouhsseien	190,200	403,700	Ait Igas	Nokhail		Very high
Agadir Abbou	192,700	401,900	O. Aissa			High
Agadir Azdou	186,200	397,000				Very high
Ait Natough	189,300	397,900				Very high
Tamaloukt	170,100	406,000	Tamaloukt	El Ouaâr		High
Sidi dahmane	169,100	391,100	Sidi dahmane			High
Ait Bouaicha	175,300	392,700	Freija	Sdass		High
Oulad Aâjal	174,300	393,000				Very high
Agafay	127,500	395,700	Amskroud	Amskroud	Agadir Ida Outanane	Very high
Tallat Izzeur Lotissement Tilila	108,000	382,000	Drarga	Ighzer larbaa		High
Poste ONE et RN 1 et RN 10	107,675	380,000	Aît Melloul	Aît Melloul	Inezgane Ait Melloul	High

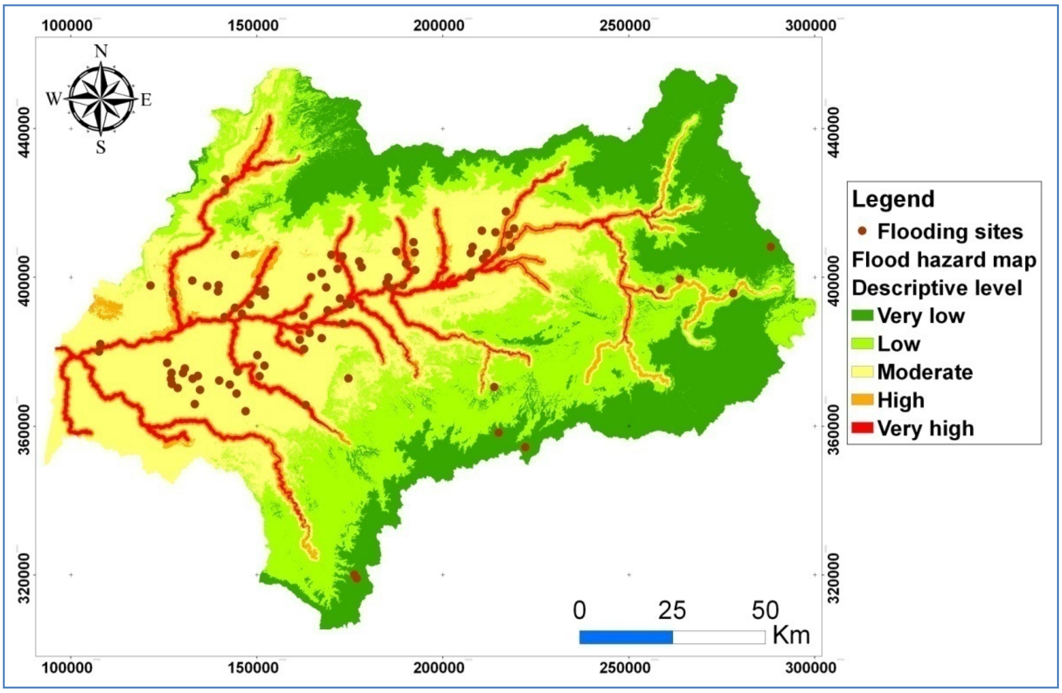

Figure 10: ABHSMD flooding sites distribution map for the Souss River Basin

The final flood hazard map with its respective vulnerability zones was converted into a vector shape file , These vulnerability zones were then used to clip out the village points, population and roads using the 2004 census data. After the clipping process, statistics were generated to estimate the number of villages, population and length of roads which are found under different flood vulnerability zones (Fig. 11). The results showed that the high number of villages as well as the populations and length of the road were found in the high and very high vulnerability zones (Table 5), which means that 12% of the population within the high to very high vulnerability zones, 71.52% of the population inside moderate vulnerability zones .

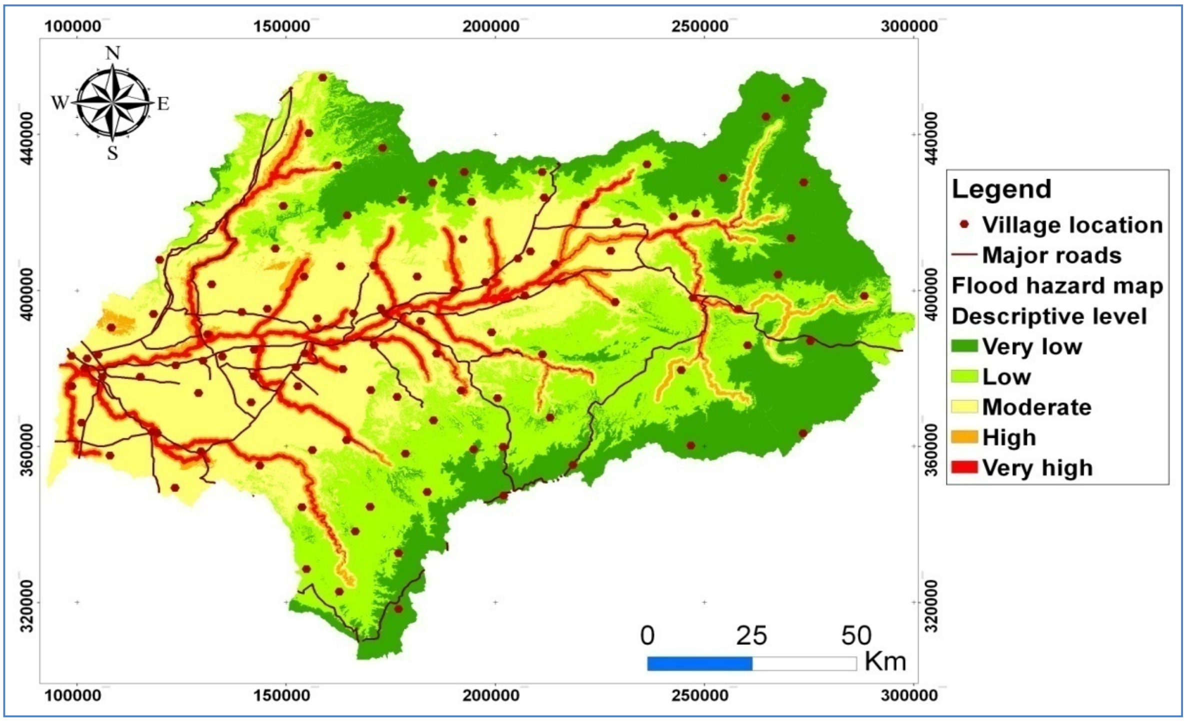

Figure 11: overlay of villages and roads on food vulnerability zones

Table 5: Flood vulnerability zones and possible impact on the local population

Flood vulnerability zones	No of villages (count)	Population		Total length of the road (km)
		(count)	%	
Very Low	16	101260	6.58	95.13
Low	28	152574	9.92	146.33
Moderate	56	1100045	71.52	632.82
High	13	137332	8.93	140.43
Very High	2	46940	3.05	140.98

Conclusion

The estimation of the flood hazard areas is a fundamental component of a flood management strategy, the proposed approach was applied to the Souss River Basin in order to determine the areas in danger of flooding, Multi-criteria evaluation methods have been applied in many studies and have proved to be a very successful tool in aiding decision-making processes, seven different input maps were prepared, which are rainfall intensity, elevation ,slope, land use, flow accumulation, geology and distance from the drainage network, Finally, the modelled output maps like floods Hazard map, validation map, the obtained results were validated against ABHSMD data from historical floods in the basin. It was confirmed that remote sensing and GIS techniques can be very useful in identifying flood vulnerability zones and to prepare flood susceptibility map. It has also proved that the multi-criteria analysis approach can help provide useful and important information for better management of floods.

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