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GIS Approach for Flood Risk Assessment in the Large Irrigation Area of the Western Mitidja Plain (Algeria)

Hind Raked[1]*, Nour El Islam Bachari[1], Mohamed Saïd Guettouche[1], Mohammed Tayeb Touahri[4]

1. University of Sciences and Technology Houari Boumedien (USTHB) Bo.32 El Alia, Bab Ezzouar, 16111, Algiers, Algeria. nbachari@usthb.dz; mguettouche@usthb.dz

2. Higher Normal school of Laghouat , Laboratory applied geography of Higher Normal school of Bouzareah, Algiers, Algeria. m.touahri@ens-lagh.dz

* Corresponding author: h.raked@ens-lagh.dz

ABSTRACT

The large irrigation Areas of the Mitidja plain are areas that are frequently prone to flooding, resulting in significant losses for farmers and the agency managing the hydraulic infrastructures. The objective of this study is to develop a model for identifying, evaluating and mapping the flood-prone areas of these LIAs, in order to allow optimal management of hydraulic infrastructures and natural resources. To this end, we have used GIS tools and remote sensing to create a geodatabase of flood-control factors such as lithology, morphopedology, slope, altitude, natural drainage, artificial drainage and land use.

This modelling is based on a multi-criteria combination of the geographical data related to the above factors. A combination of the factors considered was carried out using the spatial analysis tools provided by ArcGis software to produce a flood risk assessment map. The result is a map showing the spatial distribution of flood risk areas in the large irrigation Area of the Western Mitidja, classified into four classes (low, medium, high, very high) risk. This result was verified by field surveys. It was also confirmed by comparing with the Halloula Lake controlled area.

Keywords: Large Irrigation Area; Mitidja plain; Flood Risk; GIS; spatial analysis.

Evaluación del riesgo de inundación a través del Sistema de Información Geográfica en una área de gran irrigación al oeste de la llanura de Mitidja, Algeria

RESUMEN

Las grandes áreas irrigadas de la llanura de Mitidja son zonas propensas a las inundaciones, lo que deriva en perdidas significativas tanto para agricultores como para las entidades de manejo de las infraestructuras hidráulicas. El objetivo de este estudio es desarrollar un modelo para identificar, evaluar y mapear estas grandes áreas irrigadas con el fin de permitir una administración óptima de las infraestructuras hidráulicas y de los recursos naturales. Con este fin los autores utilizaron herramientas del Sistema de Información Geográfica y de detección remota para crear una base de datos geológica con los factores que controlan las inundaciones, como la litología, la morfopedología, la inclinación, la altitud, el drenaje natural, el drenaje artificial y el uso del suelo. Este modelamiento se base en una combinación de múltiples criterios de información geográfica relacionada con los factores antes mencionados. Una combinación de estos factores se llevó a cabo a través de herramientas de análisis espacial producidas con el software ArcGis para realizar un mapeo evaluatorio de los riesgos de inundación. El resultado es un mapa que muestra la distribución espacial de las zonas propensas a las inundaciones en las grandes áreas irrigadas del oeste de la llanura de Mitidja, clasificadas en cuatro clases de riesgo: bajo, medio, alto y muy alto. Este resultado se verificó con estudios de campo. También se confirmó a través del área controlada del lago Halloula.

Palabras clave: grandes áreas irrigadas; llanura de Mitidja; riesgo de inundación; Sistema de Información Geográfica; análisis espacial.

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1. Introduction

Hydrometeorological disasters, such as floods, storms, cyclones, etc., are devastating natural phenomena (Gabriel P et al., 2024). Due to the significant socio-economic and environmental damages they cause, these events have become a global concern in this century (Mirza et al., 2002). These disasters have intensified in recent years as a result of climate change affecting the planet (Tomasz et al., 2024). According to a report by the United Nations under the International Strategy for Disaster Reduction, floods are the most widespread disasters, frequently occurring across multiple regions worldwide (UNO., 2024). Moreover, numerous authors have also predicted a significant increase in the frequency of floods in the coming years (Kundzewicz et al., 2013; Mirza et al., 2002; Van Aalast, 2006; IPCC, 2007; Hirabayashi et al., 2008; Whitfield, 2012; Giardino, 2012). In Algeria, flood risk is among the ten most significant major risks (Law n°04–20 of December 25, 2004). Given the extent of the material and human damage it causes, whether in the northern Tellian strip or the southern desert (Roukh et al., 2018), this phenomenon is ranked second after seismic risk (Ziadi et al., 2024). In fact, floods have occurred with unusual frequency over recent decades (Khouas et al., 2021). The annual regional distribution of flood frequency has shown that the highest number of floods was recorded in the country's central region, followed by the east, indicating that these areas are more vulnerable to floods (Hafnaoui et al., 2023). This phenomenon affects both urban and rural areas. Although the consequences are catastrophic in both urban centers and rural suburbs (Dhungana et al., 2024; Jamshid et al., 2024), studies on rural flooding are less common than those on urban areas, where loss of human lives is higher during floods (Jamshid et al., 2024). However, several authors have shown that rural floods can also have positive effects, contributing to the ecological balance of plains (Mirza et al., 2002) by fertilizing soils, filtering excess or pollutant elements, recharging groundwater, and slowing the salt wedge phenomenon (the intrusion of brackish seawater into groundwater). Nevertheless, the impacts are undeniably fatal, with devastating effects on agriculture and rural life in general, as the majority of food-insecure people after disasters live in rural areas (Jamshid et al., 2024). Therefore, equitable flood risk management must be promoted across different geographic contexts (Dhungana et al., 2024). Our study area, specifically the large irrigated perimeters (LIA) of Mitidja West, faces significant flooding issues during heavy rains. Despite this, the area was neither included in the national flood management strategy developed (MRE., 2015), which identified and classified 689 flood-prone sites across the national territory nor considered in the Master Plans for Planning and Urbanism (PDAU.,2009) of the concerned municipalities. For instance, the PDAU of the municipality of Sidi Rached, which partially encompasses our study area, stated that the municipality does not face any major risks. The lack of attention to this phenomenon poses a serious problem for managers and users of this LIAs. Thus, the fundamental issue of this work is: How can we design a tool to identify and classify flood risk areas? As a result, the objective of this research is to develop a geospatial model to identify and classify flood risk areas within the Mitidja West LIA using a Geographic Information System (GIS). To assess flood risks, we used both factors that exacerbate and those that mitigate this type of risk. The selected criteria are heterogeneous, encompassing multi-source and multi-scale factors. The aim is to synthesize these into cartographic document that reflect the reality of flood risk levels in the large irrigated Area (LIA) of the Western Mitidja plain. To achieve this objective, we used surface parameters such as topography (slope and elevation), high-resolution land use data (photo interpretation), and subsurface parameters such as morpho-pedological and geological factors (lithology). This type of model, known as integrated surface and subsurface hydrological models, has demonstrated higher effectiveness by providing a more complex representation of hydrological systems affected by natural and anthropogenic factors (Maxwell et al., 2014; Le et al., 2015; Khatami et al., 2019). The significance of this work lies not only in providing managers and users of these LIAs with a decision-support tool but also in offering a scientific model that can be applied to other irrigation perimeters.

2. Data and methods

Study area

The Mitidja plain is located in the north-central part of Algeria and extends in an ENE-WSW direction over a length of 100km. It corresponds to a large depression of alluvium and colluviums between Wadis Nador and Wadis Boudouaou. It is bordered by the low hills of the Sahel to the north and the foothills of the Blidean Atlas to the South. The plain has geographical characteristics that increase the impact of flood phenomena (fig.1). The Large Irrigation area (LIA), the object of our study, is located in the Western part of Mitidja plain.

It should be noted that the site of Lake Halloula, located near the LIA West Mitidja, was included in the study as a control area. Statistically, it was integrated into the second range of this LIA.

The climate of the region is Mediterranean: characterized by cool, wet winters and hot, dry summers, wich is classified in a subhumid bioclimatic level according to the climatogram of L. Emberger (Seltrez., 1938). A rainfall study including 13 stations which are dispersed on the whole of the plain showed that the rainfall average is 742mm for the whole of the stations with 82 days of rain. The lowest value is that posted at the level of Ameur El Ain with an annual average of 546 mm and with less days of rainfall which is of 61 days of rain (Seltrez., 1938), this value is the closest to our zone of study. But we note in the station of Mouzaîa Lake located on the summits of the Blidean Atlas at 1270m of altitude, a rainfall value of 933 mm with 88 days of rain (Seltrez., 1938), which explains the torrential character of the Wadis worsens the flooding of the submerged agricultural lands in the plain. We observe an increase in precipitation going eastwards with altitude. For the study of rainfall in Hydro-agricultural development study of the Mitidja plain (Macdonald et al., 1992), it was found that the maximum number of consecutive rainy days was only 5 days for a 2 years period and 7 days for a 10 years return period. The average value for a one day rainfall per return period in the Mitidja plain was 56mm of rainfall for a 2 years return period, 96mm for a 10 years return period and it can reach 148mm for one day for a 100 years return period. This study also showed that rainfall increases from east to west and in the foothills to the south.

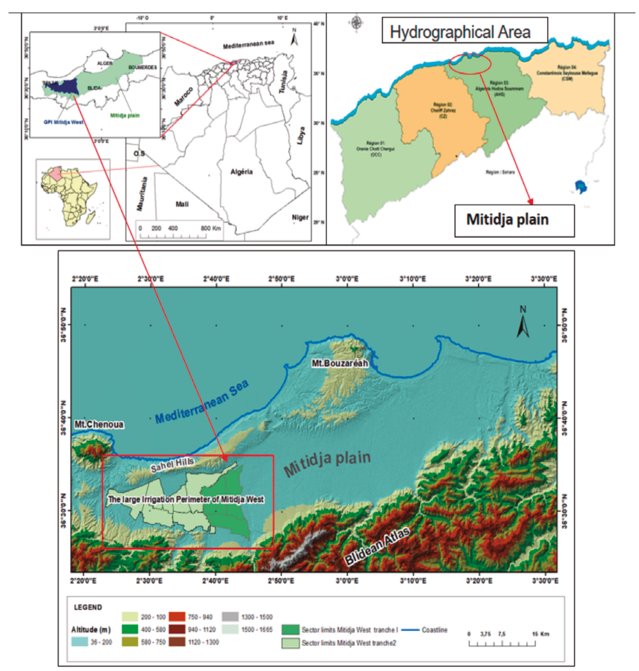

Figure 1. Study area, the Large Irrigated Area of Western Mitidja plain (SRTM)

The LIA Mitidja West (LIA.MO) is located in Algérois Hodna Soummam watershed (fig.1). It straddles between two provinces: Blida and Tipaza. It is equipped on a surface of 24 200 hectares, launched in two sections: the first section was put into service in 1988 on an equipped surface of 8 600 ha, of which 86% is located in the Province of Blida and the second section was put into service in 2005 on an equipped surface of 15 600 ha and 92% of its surface is in the Province of Tipaza (fig.2), the two sections are exploited by two different exploitation units (Mouzaïa for the first and El Affroun for the second).

The water resources mobilized for irrigation come from both the Boukerdane dam and the El Moustakbal system (Bouroumi dam and its three transfers from Wadis Djer, Wadis Harbil and Wadis Chiffa).

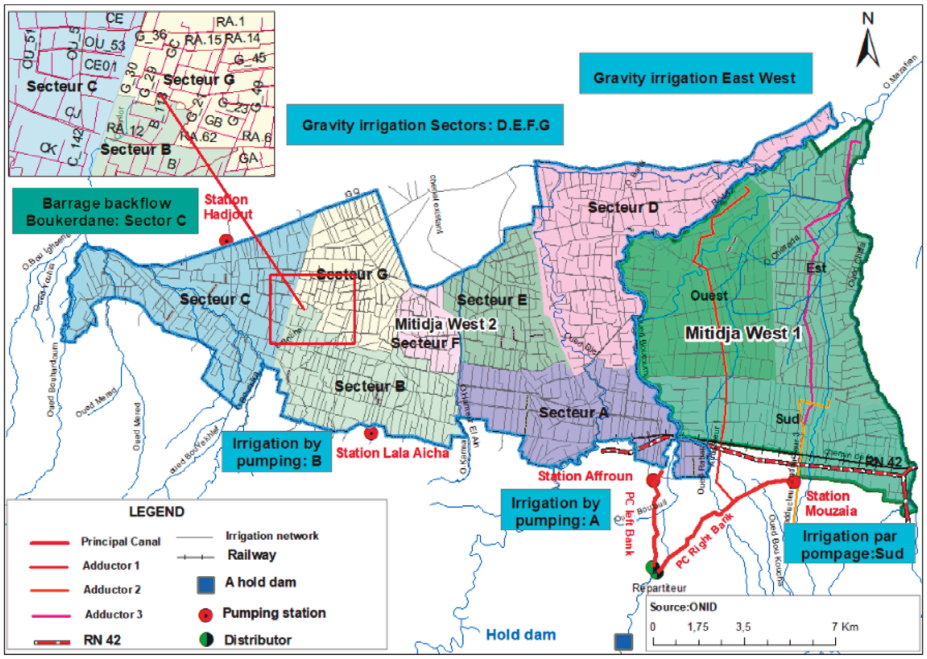

Figure 2. Irrigation networks in the large irrigated area of Western Mitidja plain (AGID.,1992)

The north facings slopes of the Blidean Altlas are crossed by several Wadis that arrive with important flows, arriving on the plain of low slope, their lengths are short and their external drainage to the sea, is reduced because of the topographic obstacles caused by the hills of the Sahel, which is the origin of frequent floods.

Actually, the irrigated area illustrated in (Fig.2), is reduced, as it represents only 22.2% of the irrigable area initially (fig.3), which confirms that water resources in that area are poorly managed. However, lack of irrigation water was recorded during the drought periods, and flooding were reported during the periods of heavy rainfall. This lack of irrigation is also explained by its location in the Algérois Soummam Hodna area, which is in water stress, this has led to a decrease in water for irrigation in order to favor drinking water supply in this region (Remini et al., 2010). Flooding still continues to cause damage in the Mitidja plain despite the scarcity of water during other periods of crop water stress.

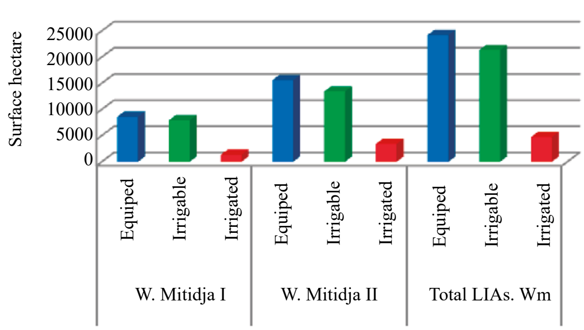

Figure 3. Irrigated surface in the Large irrigated Areas of West Mitidja (ONID, 2022)

3. Methodology

The data used are heterogeneous, multi-source, and at different scales depending on their availability. As show (fig.4), they consist of three types of data :

Remote sensing data: Very high-resolution satellite images acquired via Universal Maps Download, Sentinel-2 images, and Shuttle Radar Topography Mission (SRTM) data downloaded from the USGS website (USGS, 2024).

Basic maps: Irrigation network maps, drainage and sewerage network maps obtained from the National Office of Irrigation and Drainage (ONID), Morpho-Pedological and hydrogeological maps from the National Agency for Hydrological Resources Studies (ANRH).

***In-situ* data** : Collected from the Directorate of Hydraulics, Agriculture, and the two operating units of this large irrigation perimeter (GPI).

Using ArcGIS 10.8 software, we created a geodatabase structured into two types of parameters based on their influence on the flooding phenomenon:

Natural parameters (topography, morpho-pedology, lithology).

Anthropogenic parameters (land use and various networks).

Subsequently, we spatialized these parameters by creating thematic maps (raster or vector) related to the aforementioned parameters.

A rasterization of vector data was performed to enable manipulation using the raster calculator. The rasterization operation consists of switching from vector mode to raster mode using spatial analysis tools: the pixels obtained were resized to (10mx10m) and their values were reclassified according to the weights assigned to each parameter, using a grid detailed in the tables below, all parameters were reclassified by weighted scales from 0 to 5 based on their impact on the flooding phenomenon. Next, using the raster calculator, we performed arithmetic operations, namely:

- ***Addition*** of the weights of lithology, morpho-pedology, altitude, and drainage factors to obtain an LSSAD map.
- ***Multiplication*** of elimination parameters to obtain an LU.S map.

The multiplication of the two maps resulted in a flood risk assessment map.

The choice of criteria and the assigned weights are explained one by one as follows:

Modeling of natural criteria

The aim of the first stage is to draw up flood risk assessment maps based on natural criteria: lithology, morpho-pedology, slope and altitude.

Lithological criteria

Permeability is defined as the capacity of porous geological formations to transmit a reference fluid, such as water, under the effect of a pressure gradient.

High permeability reduces the risk of stagnation of surface runoff. However, impermeability prevents infiltration of surface water into the ground; it reduces the recharge rate of the groundwater and promotes stagnation of water (Bennia et al., 2017). Moreover, impermeability increases the probability of flooding risk. For this reason, the highest weight (5) is assigned to lithological formations with low permeability, the lowest weight (1) is given to lithological formations with high permeability, and the weight (2) is assigned to formations with moderate permeability.

The hydro-geological map was used to develop the lithological map (Fig.5.1).

The selected classes and the assigned weights are presented in **Table 1**.

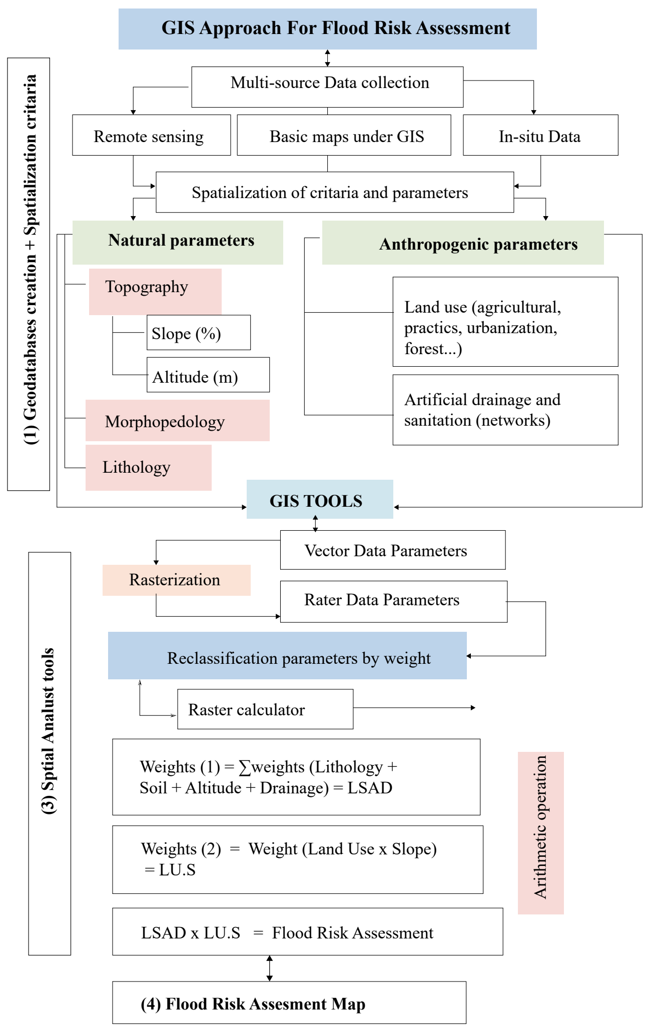

Figure 4. Methodology for assessing the risk of flooding in the Large Irrigated Areas LIA of Mitidja West plain

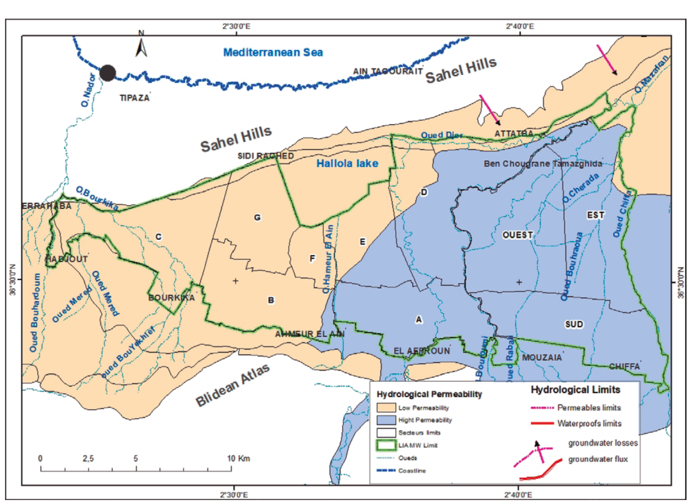

Figure 5.1. Hydrogeology of Western Mitidja Plain (DEMRH., 1973)

Table 1. Weights assigned according to permeability

Permeability type	Weight	Risk type
Strong permeability	1	weak effect
Average permeability	2	medium effect
Very low permeability	5	very high effect

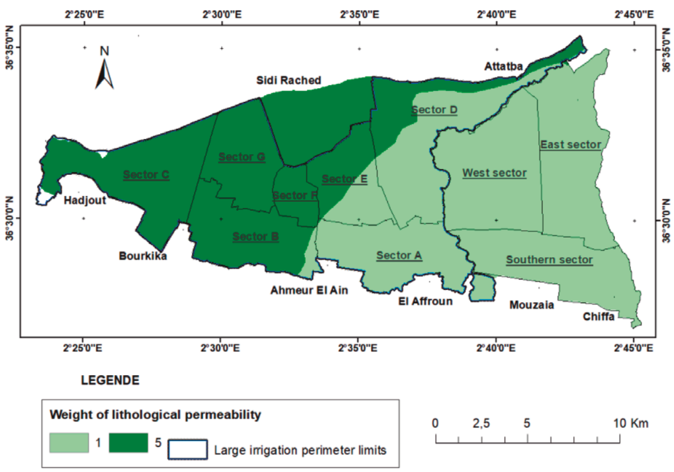

Figure 5.2. Weight of lithological permeability LIA.MW

Morphological and soils criteria

Morpho-pedology is an important parameter in our GIS approach to flood risk assessment, as the physical and hydrological characteristics of soil directly influence how water infiltrates, flows, or accumulates. it is used to better identify areas prone to stagnation and hydromorphy (characterised by the presence of gleys and pseudo-gleys). The soil classification map used is that of the CPCS (Classification of the Commission for Pedology and Soil Mapping). Although it is the only one available for the Mitidja plain (DEMRH., 1970) and although it is relatively old, its validity is confirmed with an accuracy of 1/50000, as shown in (Fig. 5.3).

The morpho-pedological maps resulting from the first stage in vector mode were modified in raster mode on pixels of size (10mx10m) and reclassified according to the weights assigned (Tab2). The weights chosen were justified by consulting a soil scientist from the Ministry of Hydraulics, who helped assign weights for each sub-criterion and soil type according to the four main classes (classes, sub-classes, groups and sub-groups) as explained in Table 2.

A very high weight (5) is given to a soil sub-criterion that is very conducive to water stagnation (very high risk), the sum of the four weights given to each gives a value that varies between (1- 20), the maximum value (20) is given to soil types that allow a very high risk of flooding and the minimum weight (1) is given to very permeable textured soils. The weight assigned to the morpho-pedological criterion is the sum of weights of classes, subclasses, groups and subgroups (Tab.2).

This reclassification allowed establishing the map shown in (Fig.5.4).

The highest values, close to (20), concern first Lake Halloula and then its surroundings. These are sectors (E, F and G) in the second tranche, followed by the eastern sector in the first tranche of this Large Irrigated Area.

Other criteria were added to further refine the model. The next step was to include the topography of the terrain.

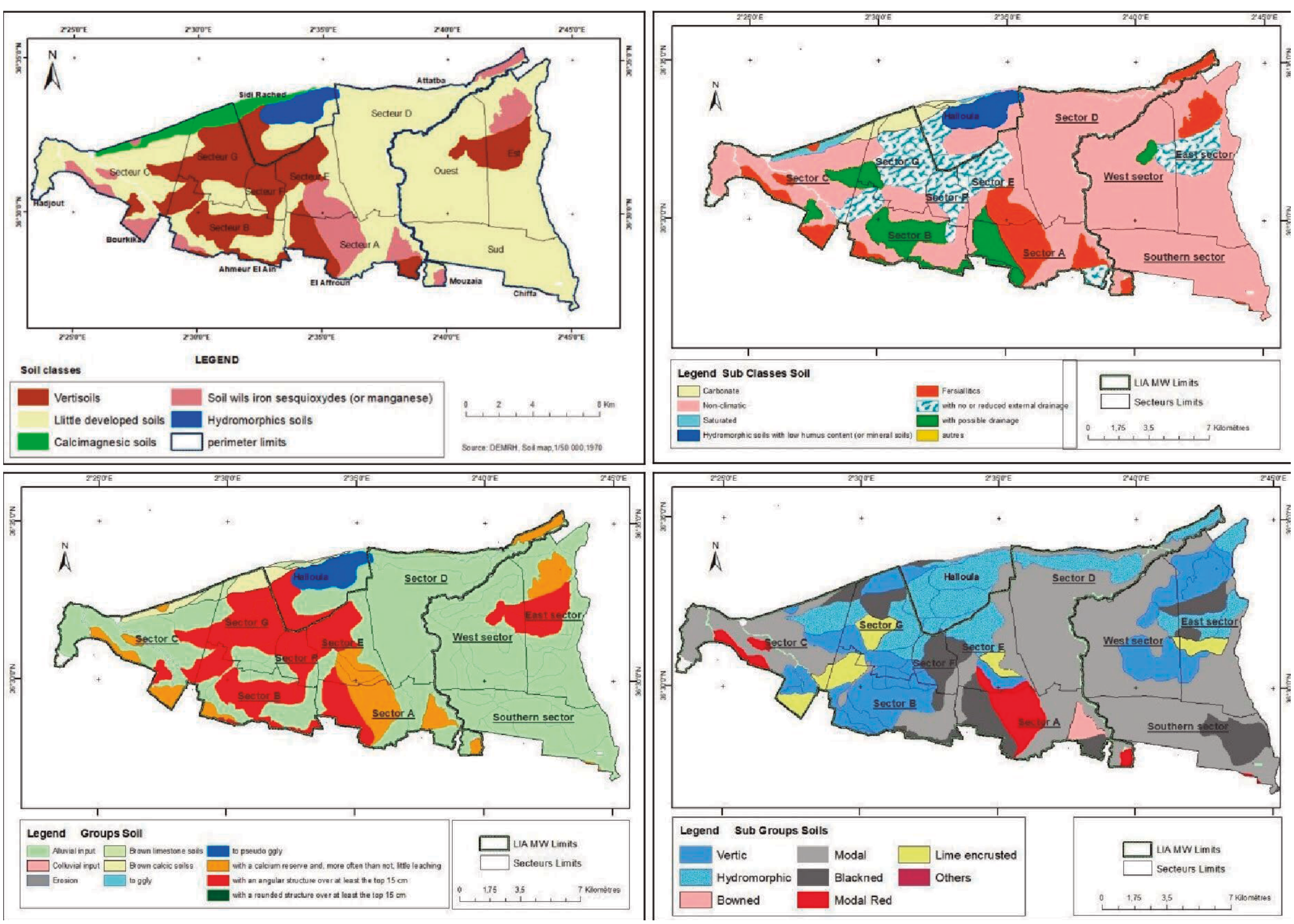

Figure 5.3. Morpho-pedological maps (Classes, Sub-Classes, Groups, Sub-Groups) of the LIA Western Mitidja plain of the AIL (DEMRH., 1970)

Table 2. Reclassification of soil categories

Criteria	Category	Typical Weight	Type	Risk classes
Classes	Raw mineral soil	1	permeable	low
	Poorly developed soil	1	permeable	low
	vertisol	4	Low permeability	high
	Calcimagnesic soil	1	permeable	low
	Iron sesquioxyde soil	1	permeable	low
	Hydromorphic soil	5	impermeable	very high
Sub classes	low-moisture (or mineral) hydromorphic soils	5	impermeable	very high
	saturated	5	impermeable	very high
	Vertisol with reduced or no external drainage	4	Low permeability	high
	vertisol with possible drainage	2	Medium permeability	medium
	Other	1	permeable	Low
Groups	with gley	5	impermeable	very high
	with pseudogley	5	impermeable	very high
	little leached	4	Low permeability	high
	Other	1	permeable	low
Sub groups	Hydromorphic	5	impermeable	very high
	Modal	3	Low permeability	high
	Vertic	4	Low permeability	high
	Blackened	3	Low permeability	high
	with limestone brown facies	1	permeable	low
	lime encrusted	2	Medium permeability	medium
	Red Modal	2	Medium permeability	medium
	Browned	1	permeable	low
	Browned modal	3	Low permeability	high
	Shallow gley (<80cm)	5	impermeable	very high
	deep gley (>80cm)	5	impermeable	very high
	Surface pseudogley	5	impermeable	very high
	Leached pseudogley	5	impermeable	very high

Terrain topography

The data obtained from the shuttle radar topography mission (SRTM) were utilized to extract the site topography data, namely the altitudes, in order to determine the basins which promote the stagnation of runoff, and the maps showing the angles of inclination of slopes. The shuttle radar topography mission data, with a resolution of one arc second (30m) (Farr et al., 2007).

Low-elevation areas lead to water stagnation (in the lowest points), while gentle slopes result in poor water circulation. These last two topographical criteria will be addressed in the next step.

The slope criterion

The slope criterion is used because, on gentle slopes, water stagnation is very frequent; conversely, steep slopes favor drainage and runoff. According to the map presented (Fig. 5.5), five slope classes have been defined based on the reclassification table assigning weights to the slopes (Tab. 3).

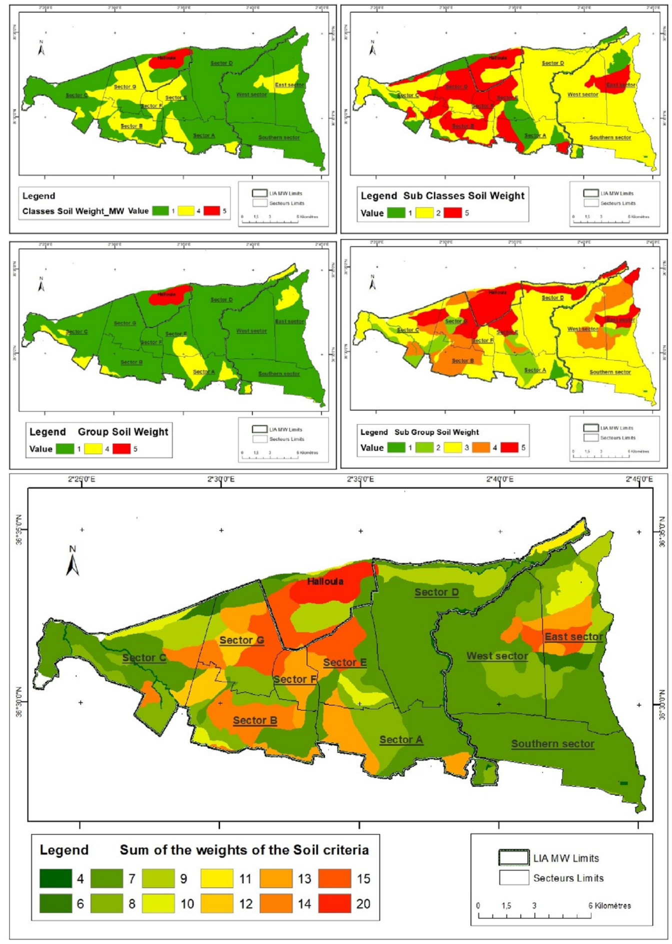

Figure 5.4. Sum of the weight assigned to the morpho-pedological criteria

Table 3. Reclassification of the weights according to the slope

Slope classes %	Weight	features	Risk class
Classe 1	5	0-2 %	Very high
Classe 2	3	2-3 %	High
Classe 3	2	3-4%.	Medium
Classe 4	1	4-5 %.	Low
Classe 5	0	>5%	Eliminating criterion

It should be noted that classes with slopes of less than 3% present a high to very high risk of flooding, according to the standards used in the construction of drainage networks in Algeria. The class characterized by slopes greater than 5% presents a zero risk; this class is therefore eliminated as it poses no flooding risk. Consequently, the results obtained show that classes 1 and 2 predominate, which means that the Mitidja plain presents a high risk of flooding (Fig.5.6).

The altitude

The altitude criterion was used because the flow of water converges towards the lowest areas, making them the most favorable zones for flooding. Altitudes were extracted from the data of the Shuttle Radar Topography Mission (SRTM) (USGS, 2024). An altitude map was created after verifying the values against topographic maps of the region (Fig. 5.7).

A reclassification based on altitudes was performed according to the five classes presented in Table 4. To calculate the weights for this parameter, a reclassification was carried out according to the five classes (Tab.4). For altitudes below 20 m, the risk of flooding is very high, with the highest weight assigned (5). The risk is also high when the altitude ranges between 20 m and 40 m, medium to low between 40 m and 80 m, and zero above 80 m.

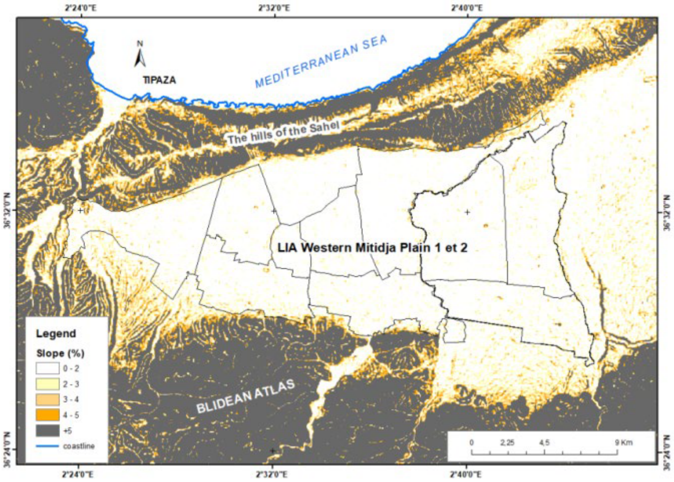

Figure 5.5. Slopes map (USGS, SRTM., 2024)

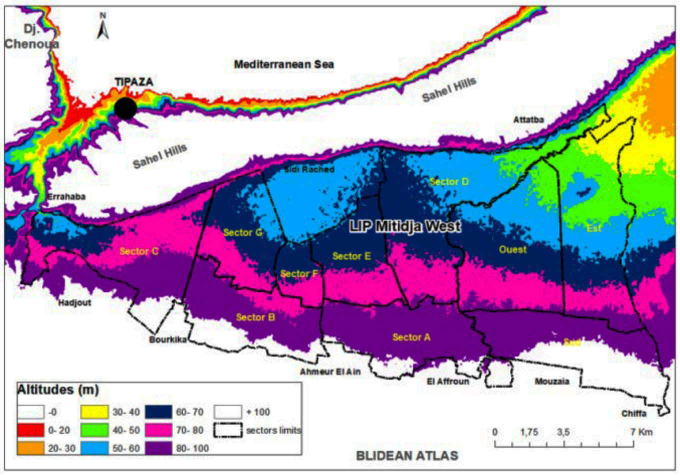

Figure 5.7. Altitudes in LIA Western Mitidja

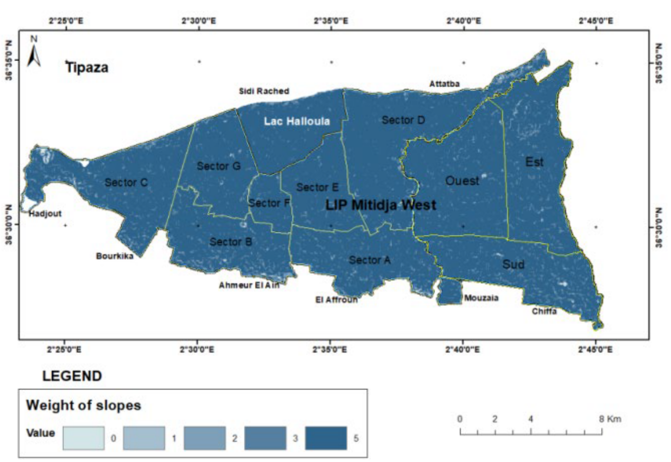

Figure 5.6. Weights slope

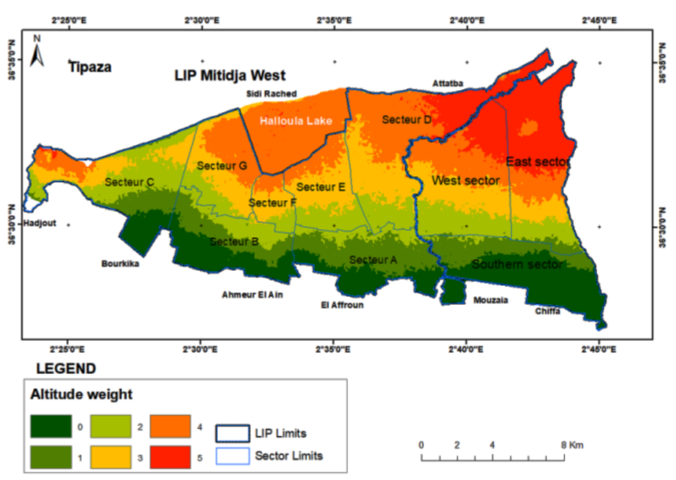

Figure 5.8. Altitudes weights

Table 4. Reclassification of altitudes weights

Altitudes	Weight	Characteristics	Risk class
Classe 1	5	0m-20m	very high effect
Classe 2	3	20m-40m	High effect
Classe 3	2	entre 40 m et 60 m	medium effect
Classe 4	1	entre 60 m et 80 m	Low effect
Classe 5	0	>80m	very low effect

Despite the presence of a depression at Lake Halloula, the lowest points were found in the northeastern part of the large irrigated area (LIA) of the Mitidja plain, which explains the flow of Wadi Bouroumi and Wadi Chiffa in the direction of Wadi Mazafran. It should be noted that these two zones present the greatest risk of flooding (Fig.5.8).

Humans, through their activities, practices and modes of intervention in space, acts directly or indirectly to accentuate or mitigate the risk of flooding. Two criteria were taken into account to assess human action: drainage and land use.

Anthropogenic Critaria

Drainage and natural sanitation

The artificial drainage networks of excess water and the natural sanitation system were identified from previously geo-treated plans, in collaboration with the GIS unit of the National Office for Irrigation and Drainage (ONID). For the first section, sixteen detailed pre-project plans of Detailed Preliminary Project of irrigated areas and networks were used (AGID., 1992). In addition, irrigation, drainage and natural sanitation plans were realized for the large irrigated areas (LIAs) of West Mitidja. For the second section, twenty-two plans of the adaptation network were exploited at the level of the irrigation plot, with a scale of 1/5000.

A buffer zone was determined based on the distance to existing artificial or natural drains (Fig. 6.1). To identify poorly drained areas, values were established from field observations and surveys, regardless of soil quality and permeability (Hafnaoui et al., 2022). An area located within 350 m of artificial or natural drainage networks (Wadis) is considered to have good drainage and is reclassified with a weight of 1. Areas located more than 350 m away are classified as poor drainage and sanitation areas; they are reclassified with a weight of 5, as shown in (Fig. 6.2). These zones require the construction of artificial drains, either open or buried.

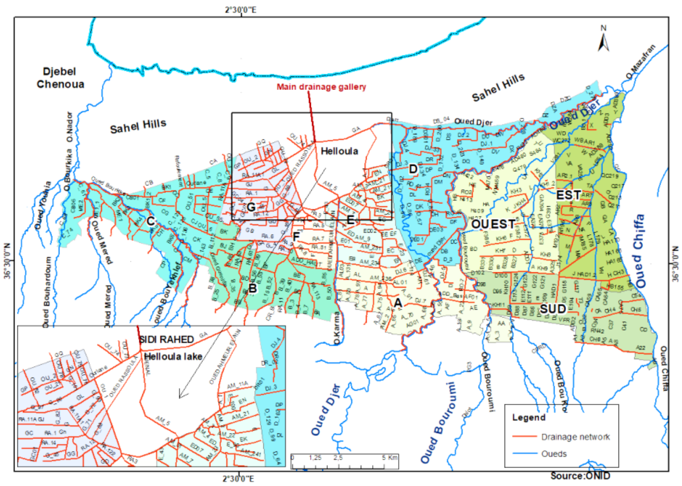

Figure 6.1. Sanitation and drainage networks in LIA Western Mitidja (ONID.,2023)

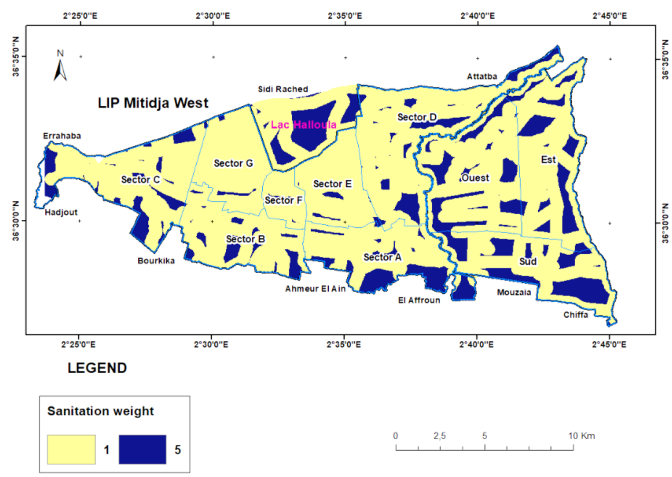

Figure 6.2. Sanitation and drainage weights

Land use

This parameter was used not only to exclude the urbanized areas from the irrigable area (declassified areas which have consequently lost their initial agricultural vocation), but also to classify certain lands uses which promote the risk of flooding and others that hamper that risk. Progress has been transformative, and the information obtained from remote sensing of floods is becoming mature enough to not only be integrated with computer simulations of flooding to allow better prediction, but also to assist flood response agencies in their operations (Schumann et al., 2018). Very high resolution images by Universal Maps Download; a photo-interpretation was also established in combination with data provided by Landsat 8 Operational Land Imager (*OLI*). The recorded data were at the L1T level, which means that the images were radiometrically and geometrically corrected (Saadoud et al., 2018).

Traditional ground-based monitoring systems are sparse and in decline. The value remote sensing can offer is growing rapidly, and the challenge now lies in ensuring sustainable and interoperable use as well as optimized distribution of remote sensing products and services for science as well as operational assistance (Schumann et al., 2018). The land use parameter was considered in (Fig.6.3). A more significant weight was assigned to water system, and annual crops. Land use was then classified as indicated in (Tab.5), the results of this reclassification are presented in (Fig.6.4).

Table 5: Reclassification of land use

Classes	Weight	Type	Risk class
Seasonal and annual crops	3	low permeability	High
Perennial tree crops	1	Permeable	low
Forests, reforestation, wasteland	1	permeable	low
Hydrographic network	4	-	Strong
Urbanization	0	Elimination criterion	-

The presence of trees is a sign of good soil drainage, as tree roots cannot tolerate excessive irrigation or poor soil drainage, so the presence of trees can in no way be associated with a risk of flooding. Despite the high profitability per hectare of arboriculture in this plain, farmers turn to annual crops when the soil is poorly drained, so the absence of trees means there is a high risk of flooding.

Urbanization is considered as an elimination criterion. These lands considered are excluded from the agricultural.

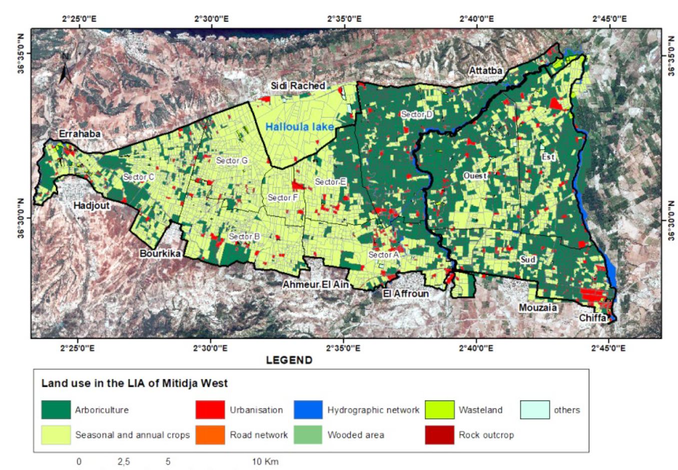

Figure 6.3. Land use map

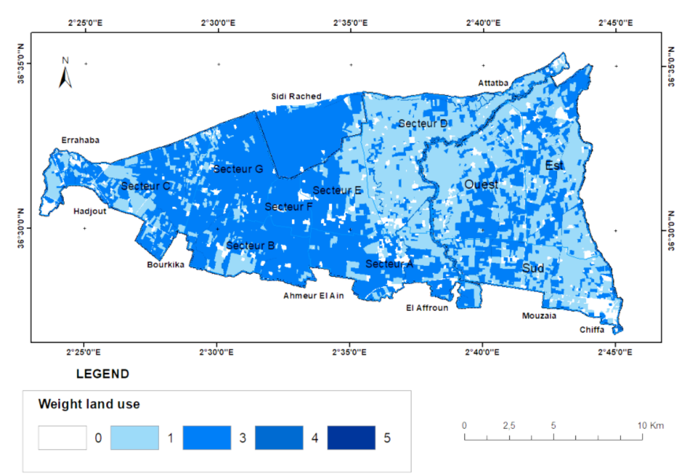

Figure 6.4 .The weight assigned to land use

4. Results

The results of the arithmetic operation, which consists of adding the weights of the lithology, morpho-pedology (soil), altitude and drainage criteria (Fig.7.a), showing the addition operation carried out in ArcGis using Raster Calculator. The results obtained are shown on the map (Fig.7.b), with weights ranging from 6 to 32. The second section of the LIA, sectors E, F and G, shows the most significant weight values.

The results of the multiplication of weights assigned to land use criteria and slope are illustrated in (Fig.8).

The two results obtained from the arithmetic operations were multiplied (LSAD x LU.S) to create a flood risk assessment map. A classification was carried out using the equal interval method in ArcGIS across four classes, each with a range of 150. The result is illustrated in Fig.9.

The results of this model are also summarized in (Tab.6) and (fig.10), the area exposed to high to very high flood risk represents nearly 5% of the total surface area. However, the medium flood risk areas cover a significant portion (35%) of the total area under study. They are predominantly located in the western part of study area (section 2).

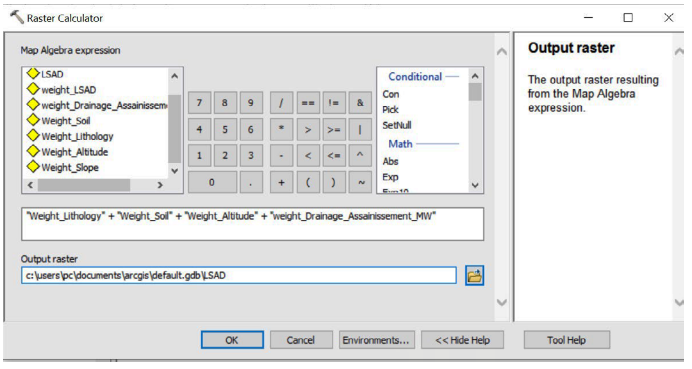

Figure 7.a. Raster Calculator's addition operation

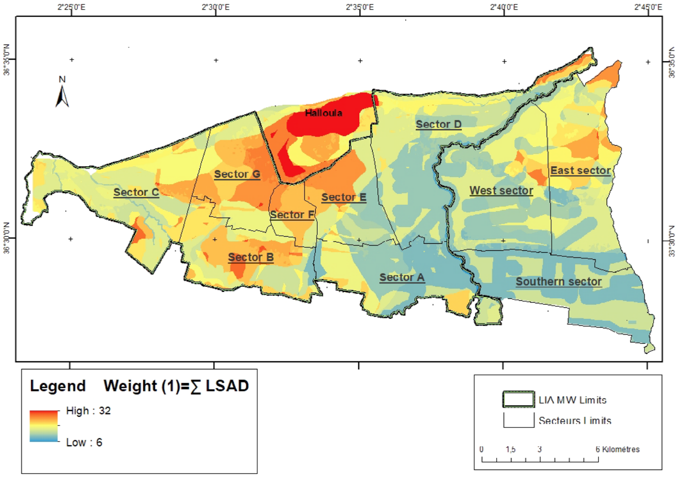

Figure 7.b The sum of the weights assigned to the criteria of lithology, Morpho-Pedology, altitude and drainage (LSDA).

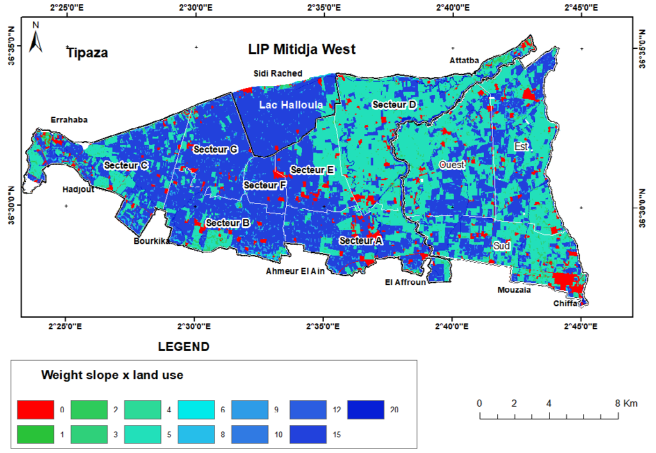

Figure 8. The weights of the Land use x slope (LU.S).

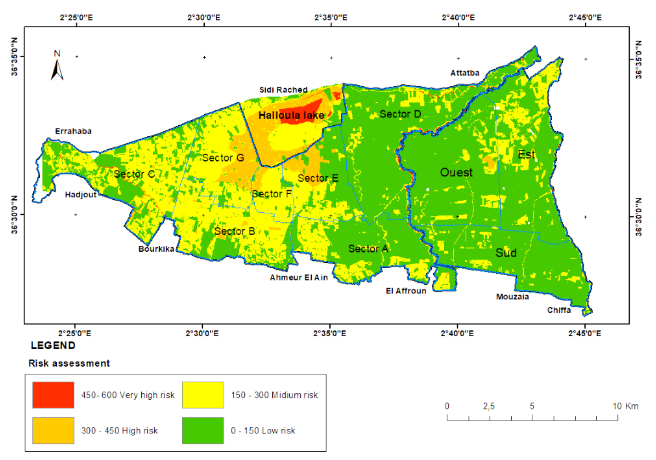

Figure 9. Flood risk map in the large irrigated area (LIA) of West Mitidja plain

Table 6. Flood risk assessment by class in the LIA.M.W by section

Class values	Type of risk	Section 1	Section2	Total study area	%
150-0	**Low Risk**	7 353	7 565	14 918	59,91
300-150	**Medium Risk**	1 812	6 898	8 710	34,98
450-300	**High Risk**	59	1 116	1 175	4,72
600-450	**Very high Risk**	13	84	97	0,39
Total		**9 237**	**15 663**	**24 900**	**100**

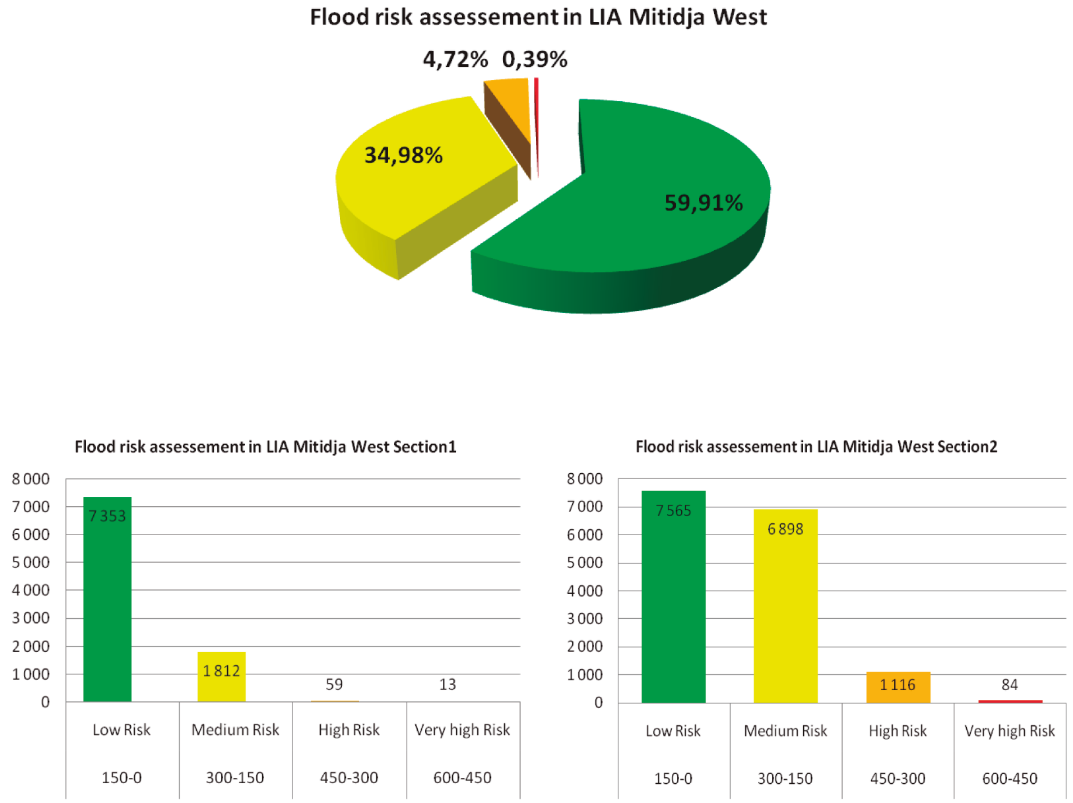

Figure 10. Flood risk map in the large irrigated area (LIA) of West Mitidja plain

Discussion

The very high risk areas represent 0.39% of the total surface area of the study zone, or 97 ha (Table 6), of which 84 ha are located near the Halloula lake, a depression where the drainage and sewerage networks converge (then discharged to the sea via an underground gallery with a reduced cross-section), and an area of only 13 ha in Tranche 1, along the Oued Bouroumi.

The high-risk zones cover an area of 1,175 ha, or 4.72% of the study area. Of these areas, 1116 ha are located in Tranche 2, a large part of which is on the Lac Halloula site, and 59 ha in Tranche 1 of this GPI. The distribution of very high and high risk flood zones demonstrates the effectiveness of this assessment model.

According to agricultural services, between April 13 and 14, 2018 (Fig.11), thousands of hectares of agricultural land were damaged, and numerous material damages were recorded. The Large Irrigation Area Mitidja West Section 2 completely flooded after the third day of the 2018 rains.

This issue also occurred again in 2012 and 2017. It is worth noting that the most exposed sector is sector G, followed by sectors E and F. Therefore, the large irrigated area of West Mitidja, in the second section, was the most affected by these frequent floods.

The area with medium flood risk covers 8710 ha, or 34.98% of the study area, with 6,898 ha in tranche 2 and 1812 ha in tranche 1. The area with low flood risk represents the majority, at 59,91% of the study area. It is almost evenly distributed across the two sections of the GPI. The low-risk area is mainly located in the eastern part of the study area, which explains the strong presence of tree cultivation in this region, while annual crops (cereal and forage production) are found in the western part, which presents medium, high, and very high flood risks.

Figure 11. Flood in the Large Irrigation Area of Mitidja West (Sector G) (SAW, 2018)

Conclusions

In this study, we developed a model for assessing flood risk using a geographic information system (GIS). This model combines various natural and anthropogenic soil and subsoil criteria, including lithology, morpho-pedology, altitude, drainage systems, slope and land use. Using the spatial analysis tools available in ArcGIS, we integrated these criteria to produce a classification map of the study area based on flood risk.

The resulting flood risk map enabled us to identify and classify areas into four categories: very high risk, high risk, medium risk, and low risk. Notably, Halloula Lake and its surroundings were classified as very high-risk and high-risk zones, respectively. Field surveys confirmed these findings, highlighting «black spots» recognized by local farmers, which attests to the effectiveness of the developed model.

This flood risk assessment map can serve as a decision-support tool for managers and users of the LIAs, offering a proactive perspective for managing this risk and anticipating necessary actions to mitigate damages.

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Conflict of Interest

The authors declare no conflict of interest.

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