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Flooding Prediction in Wadi Zarqa Ma'in Basin, Jordan: A Study in Applied Geomorphology

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Abstract

The study focused on different methods to analyze the hydrological and Morphometric properties of the Zarqa Ma'in Basin and bind them with a specific number of natural variables for predicting the possibility of floods in the basin by using different scenarios. At the end of the stage, the study aims to find the best-applied aspects of the basin in terms of geomorphology in light of the results of the study. The methodology was applied by using Geographic Information Systems (GIS), Analytical Hierarchy Process (AHP), different satellite images, Digital Elevation Model (DEM) and different data sources that were needed to produce flood maps. The study showed that the basin is vulnerable to floods of varying levels during the seasons of the year based on the natural characteristics, especially regarding climate changes, which include rain precipitation and its intensity. The result showed that 34% of the basin is vulnerable to floods during the Autumn season due to heavy rains and the absence of vegetation cover. It also observed that the probability of the basin might be exposed to flood during the winter season with the same intensity and reached 19% in the steepness area which is characterized by low infiltration and penetration of rainfall. The study recommended using field surveys supported by a Global Positioning System (GPS) device to study the natural and human causes that could be introduced into estimating the possibility of flooding or not.

Keywords: Analytical hierarchy process, geographic information systems, applied geomorphology, rainfall, floods.

توقع حدوث الفيضانات في حوض وادي زرقاء ماعين: دراسة في الجيومورفولوجيا التطبيقية

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ملخّص

ركزت الدراسة على الطرق المختلفة لتحليل الخواص الهيدرولوجية والمورفومترية لحوض وادي زرقاء ماعين، وربطها بعدد محدد من المتغيرات الطبيعية والبشرية للتنبؤ باحتمال حدوث الفيضانات في الحوض ضمن سيناريوهات مختلفة، وتهدف الدراسة كذلك -في ضوء النتائج- إلى وصول أفضل الجوانب التطبيقية في الحوض من ناحية جيومورفولوجية. وطبقت منهجية الدراسة باستخدام نظم المعلومات الجغرافية (GIS) ونموذج التحليل الهرمي (AHP)، بتوظيف صور الأقمار الصناعية اللازمة والمناسبة، ونموذج الارتفاعات الرقمية والبيانات المختلفة المستقاة من مصادرها المختلفة، في إنتاج خرائط احتمالات الفيضانات. وأظهرت الدراسة أن حوض وادي زرقاء ماعين عرضة للفيضانات بمستويات متفاوتة خلال مواسم السنة المختلفة تبعًا لخصائص المنطقة الطبيعية وبخاصة عنصر الهطول المطري وغزارته؛ إذ تبين أن 34% من مساحة الحوض عرضة للفيضانات خلال موسم الخريف في حال هطول مطر غزير؛ وذلك نظرا لغياب الغطاء النباتي وغياب تأثيره، في حين أن النسبة لاحتمالية تعرض المنطقة للفيضانات خلال موسم الشتاء مع نفس مقدار غزارة المطر تصل إلى 19% وذلك في المناطق المنحدرة وقليلة النفاذية للماء. وأوصت الدراسة بجملة من الأمور تمثل أبرزها باستخدام المسوحات الميدانية المدعومة بنظام تحديد المواقع العالمي (GPS) لدراسة الأسباب الطبيعية والبشرية التي تدخل في تقدير احتمالية الفيضانات من عدمها.

الكلمات الدالة: عملية التسلسل الهرمي التحليلي، نظم المعلومات الجغرافية، الجيومورفولوجيا التطبيقية، هطول الأمطار، الفيضانات.

Introduction

The number of deaths in Jordan, because of floods, during the second half of the twentieth century is estimated at 324 deaths, and the number of injuries is estimated at 680 (General Directorate of Civil Defense, 2018). Floods occur mostly because of heavy rains and their continuity without interruption. Floods have many types that occur from time to time in arid and semi-arid regions in Jordan, especially when these areas are under the influence of atmospheric instability that occurs in Jordan, which accounts for 67% of the total air disturbances (Alnawaisa, 2017) Jordan was exposed to a state of air instability on the evening of October 25, 2018, which brought a large amount of rain to separate areas of the Kingdom, including the Zarqa Ma'in Basin, which resulted in severe flooding, and this incident was accompanied by the presence of a number of hikers in the area where the stream of the valley ends ; What led to the death of a group of children.

Study objectives

The study of water hazards is an important matter that is not clear in its importance and neglecting it - in the early years - may lead to many dangers, especially with the natural variability of the climate in its systems and cycles. Many factors require conducting these studies in Jordan, including: the decrease in the capacity of the dams to hold water, and the stability of many people in the valleys and torrents in separate parts. The importance of this research lies in the awareness of the importance of studying climatic hazards in supplementing geomorphological, climatic, and geographical studies in Jordan. Therefore, this research aims to:

1- Accessing the most prominent natural and human characteristics that are included in the assessment of floods in the Zarqa Ma'in Basin and building a database for them.

2- Finding the most suitable applied aspects in the basin from a geomorphological perspective.

3- Producing maps of expected scenarios for the possibility of floods in Wadi Zarqa Ma'in Basin, based on the natural and human characteristics of the basin.

Study area

The Wadi Zarqa Ma'in basin, in its elongated shape, is one of the drainage basins of the Dead Sea, which is located on the eastern side of it, between longitudes 35°35'19" - 35°51'25" east, and latitude of 31°49'51" - 31°32'51" north, fig (1). The area of the basin is about 266 km². The region administratively belongs to the governorate of Madaba and includes the Kasbah of Madaba and some of its various districts, such as: Ma'in district, and parts of the Grainah district. It should be noted that some parts of the northern basin are located within the administrative boundaries of the Amman Governorate, where the Hesban and Umm Al-Basatin areas are. Figure 1 shows a map of the study area.

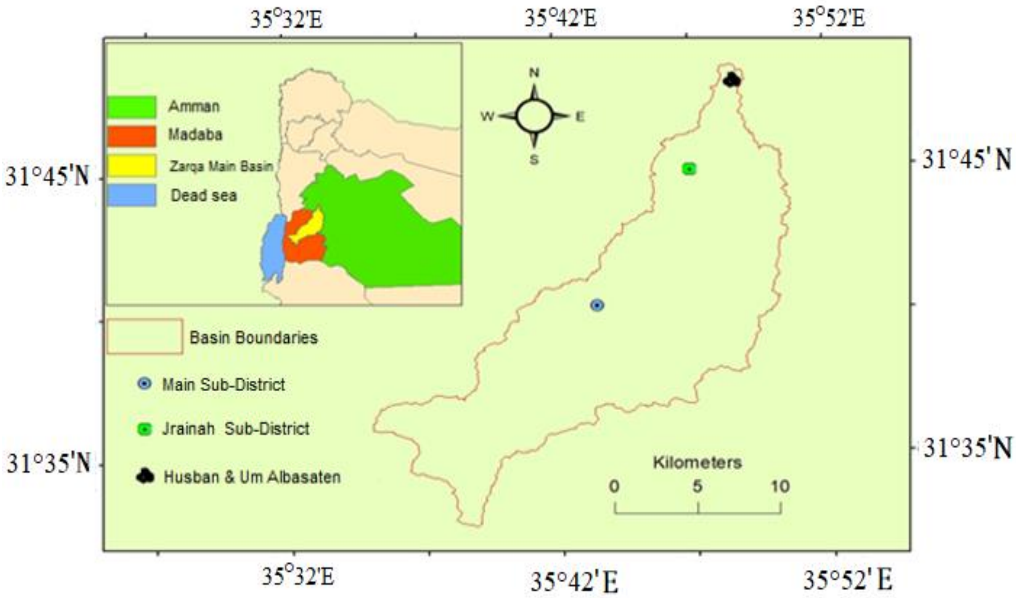

Figure 1. Map of the study area (Source: Researcher's preparation based on DEM)

Geology and Topography

It can be said that the basin of Zarqa Ma'in is a museum of the formative diversity of rocks in terms of age and type. As the modernity of the rocks increases towards the source, perhaps due to the erosion activity in that region, and in general the Cambrian sandstone dominates the downstream region significantly while the Triassic sandstone, which dates to the Middle Life period, extends in the lower basin of the region (Al Aqrabawi, 2007). The most prominent geological formations in the study area are: (Ghoneim, 1987) the Cambrian Formations, Triassic Formations, Lower Cretaceous Formations, and Upper Cretaceous Formations, And finally volcanic rocks. The following figure (No. 3) shows a detail of the different rock formations (geological compositions) that spread in the study area. The elevations begin to be light and gentle in the north and center of the basin and tend to straighten in parts of that range, while it increases until it reaches the extreme crest at the downstream area, and the heights in the basin range from 923 m above sea level to -230 m below sea level.

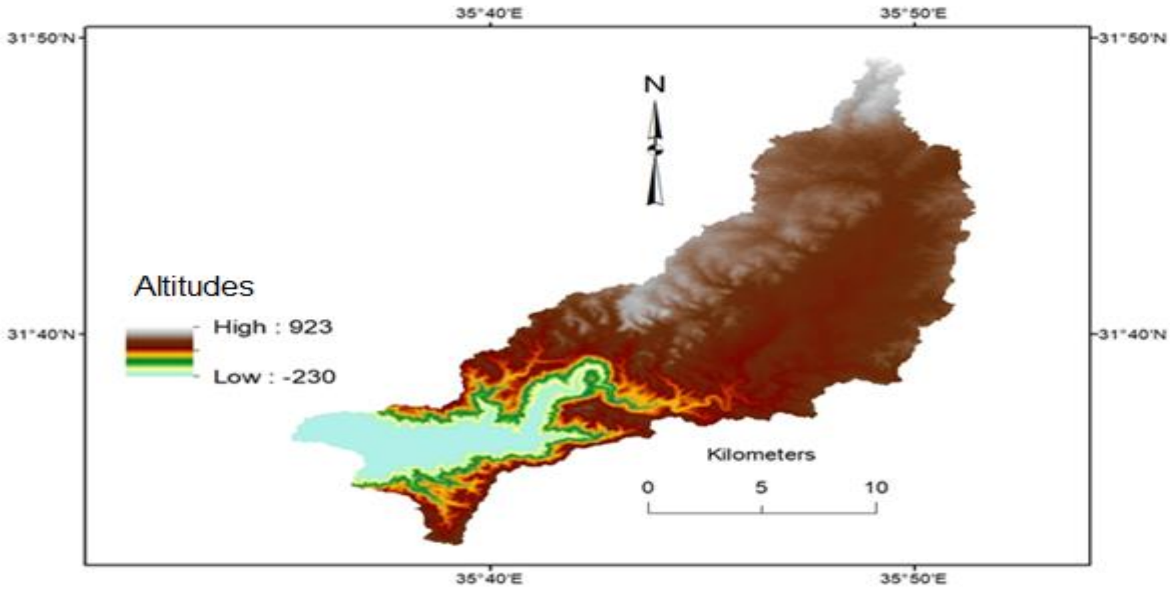

Figure 2. Classification of the study area according to altitudes (Source: the researcher's preparation based on DEM)

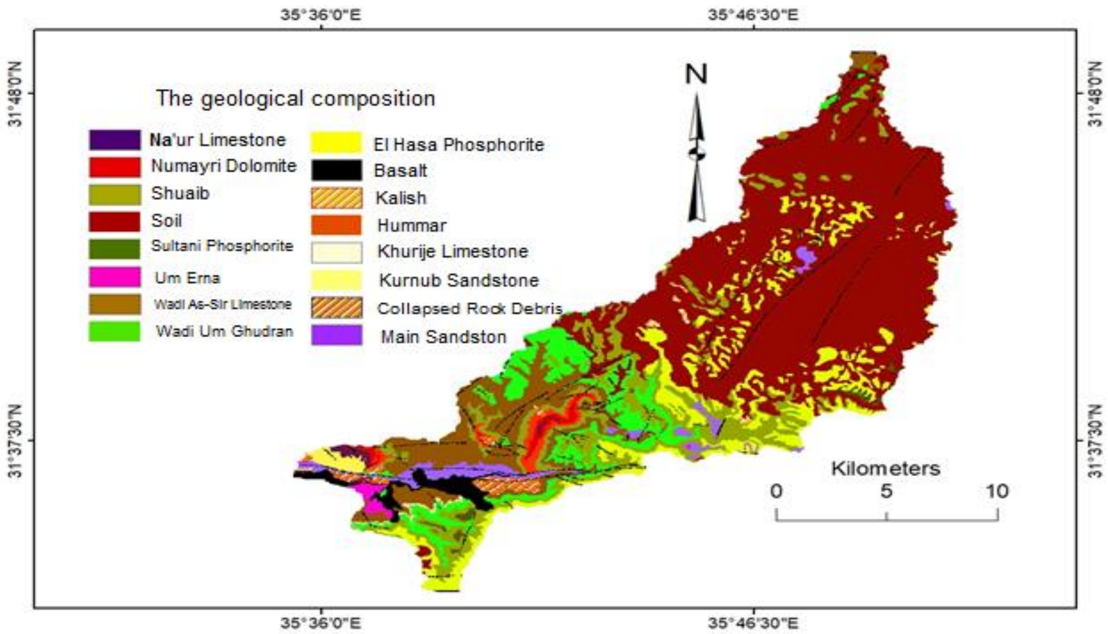

Figure 3. The geological composition of the study area

(Source: the researcher's preparation based on data from the Ministry of Energy and Mineral Resources, 2019)

Climate

The study area is located, according to the Köppen classification, within two main climatic regions: the arid region, which is spread over all parts of the basin except for the northern parts that are dominated by the semi-arid climate region, which is the second region in the basin. In addition, the climatic characteristics of the basin differ remarkably, as are the climate characteristics of the rest of the Kingdom's regions. This is due to many reasons, such as the variation in elevations (Sloping area). In addition, the different climatic data show a remarkable variation in the average annual temperature, and the same is true for the annual rainfall.

Hydrology

The basin is one of the basins whose water discharges increase in just four months, as is the case for the Jordan Basins, except for the Mujib and Wadi Al-Hasa basins. The average annual rainfall in the basin is about 82.1 mm 3 and varies significantly from year to year (Salameh, 1985), while the surface runoff in the basin fluctuates between winter and summer, and the average annual drainage from the basin to the Dead Sea is 23 million cubic meters annually (Al Zahir, 2005). As for the water flow of the basin, its quantities fluctuate according to the rainy months of the year and from year to year according to the depth of the depressions. As the winter increases because of increased rainfall, and the amount of discharge has effects on a number of matters, such as sedimentary output, for example (Ghoneim, 1987).

Population

It can be said that the population grouping in the basin is concentrated in certain areas and not others, in addition to dispersed localities in its various parts. The population of the basin is estimated at about 300,000 people (Department of Statistics, 2019), and the largest distribution of the population was in the northern basin regions at 48 '35 ° east longitude, and the latitude 43' 31 ° north, which is the city of Madaba, the center of the governorate of Madaba, followed by Ma'in. Where longitude is 43 '35 ° east, and latitude 41' 31 ° north, while the southern basin is almost devoid of any population centers.

Previous studies

As for the most important previous studies that dealt with the study variables, they are numerous; (Rincon, et al., 2017) realized the importance of accurate assessment of flood risks in mitigating their severity in urban areas and aimed to develop accurate simulations and maps of flood risk in the Don River Basin in Toronto, Canada, by relying on geographic information systems and analyzing multiple criteria based on the Analytical Hierarchy Process. The researchers ‘produced four flood risk maps representing four scenarios and their impacts on the socio-economic status of the region.

Al-Maghari (Al-Maghari, 2016) identified and carved out the river drainage network of Wadi Al-Hasa basin in Jordan, as well as building a database for this basin, in addition to creating a morphometric map using geographic information systems. The researchers were able to access the morphometric characteristics of the Wadi Al-Hasa basin, build a database of those characteristics, and create a digital map for the basin based on the characteristics.

Ozkan and Tarhan (2015) focused in their study on determining the effect of the basin characteristics on the occurrence of floods, and the researchers reached to identify places exposed to potential floods in the study area, which was the city of Izmir, in western Anatolia, Turkey. By producing maps that are quantitatively representative of the criteria that they have defined for the likelihood of flooding.

The aim of both researchers Al-Husban and Zureikat (Al-Husban and Zureikat, 2015) was to analyze the Zarqa River basin in Jordan, morphometry, including their analysis, to study the river levels, their number, the river bifurcation, as well as the river drainage density. The two researchers ‘found a variation in the areas of the sub-water basins within the borders of the Zarqa River, as well as the high drainage density of the river despite the desert characteristic of it.

Al-Fitouri (Al-Fitouri, 2015) studied the importance of highlighting the role of geographic information systems as an important means in measuring the different characteristics and elements of terrestrial shapes and comparing them with traditional methods and means, and he aimed to calculate the morphometric characteristics of river drainage networks and then to extract the hydrological characteristics of the Wadi Qattara basin in Libya.

Kia and others concluded that there are no differences in morphometric properties between the two means, except for the number of tributaries of the first order. It increased its number using geographic information systems (Kia et al, 2012) aimed to develop a model for predicting flood probability to identify areas of water tyranny in the drainage network in the Johor River Basin in Malaysia, depending on the various factors that are among the main causes of floods, including: rain, slopes, Surface runoff, soil, land use and geological characteristics. The researchers concluded that the estimates of the probability of flooding in the Johor Basin in Malaysia agree with the hydrological records of the region.

In here stud Al-Aqrabawi (Al-Aqrabawi, 2007), deals with the study of morphometric properties of various water basins in Jordan in comparison to the basin of Zarqa Ma'in Valley, so that they can be used in studies related to geomorphology and water studies. The study reached a set of results, the most prominent of which was: the variation in morphometric characteristics between the water basins according to several factors, including climatic, rocky, and structural factors. The proportion of the circularity of the Zarqa Ma'in basin was 0.41, which indicates that the basin is still in its youth stage. The aim of Odeh and Salameh in their study (Odeh and Salameh, 2005) was to study the geomorphology of the Zarqa Ma'in Valley, a valley that is considered one of the most important valleys of the Dead Sea drainage, while many researchers 'attributed this development in the valley to the effect of the tectonic fault. The researchers' used geographic information systems to analyze spatial data collected from its various sources, such as: topographic maps, aerial photos, and ground control points (GPS) in addition to the use of field work in the necessary analysis, the study concluded that the development in the basin is due to many geomorphological processes practiced by the streams in the valley. Odeh and Salameh (2003) dealt with different methodologies for creating a database in geographic information systems in order to apply them to the Lower Wadi of Zarqa Ma'in in Jordan for the purpose of research and geomorphological evaluation, the previous database includes spatial data that includes many things, in addition to the features of these spatial data, the study resulted in the development of a database for the study area that allows creating many maps covering the study area.

Research Methodology

The researchers followed the analytical approach based on the analysis of digital elevation model data and satellite images using geographic information systems. In order to achieve the research objectives; As the researchers accessed the most prominent natural characteristics of the study area (such as permeability, soil depth, slopes ... etc.) as well as human characteristics such as land uses, and he benefited from previous measurements in determining the chances of flooding in parts of the basin based on geographic information systems and the Analytical Hierarchy Process.

To achieve the research objectives, the researchers collected various data (fig 4) from its sources as follows:

Secondary sources of data: represented by books, theses, research papers, pamphlets, and periodicals, which were collected and used to describe the study area in terms of physical characteristics, location, area, etc. A map of the main soils in Jordan is added to the above, from which the map of soil depth and fragility in the study area was derived.

The primary sources of data, which are: the digital elevation model (DEM for the study area with a discrimination capacity of 30 m from the United States Geological Survey (USGS) .Space visuals for the study area (Sentinel-2) with a discrimination capacity of 20 m, for the 10 months of 2018, and the 2 month of The year 2019 was obtained by the United States Geological Survey (USGS), in addition to a geological map representing the geological composition of the area surrounding the study area, which obtained by the researchers depending on the Ministry of Energy and Mineral Resources data (Ministry of Energy and Mineral Resources data, 2019).

Factors affecting floods that are included in the Analytical Hierarchy Process before going into the results of the flood assessment, it is necessary to review the criteria and characteristics that are included in the process of estimating the probability of flooding that the researchers determined after reviewing the literature related to this field. Perhaps the most prominent of these characteristics are the following:

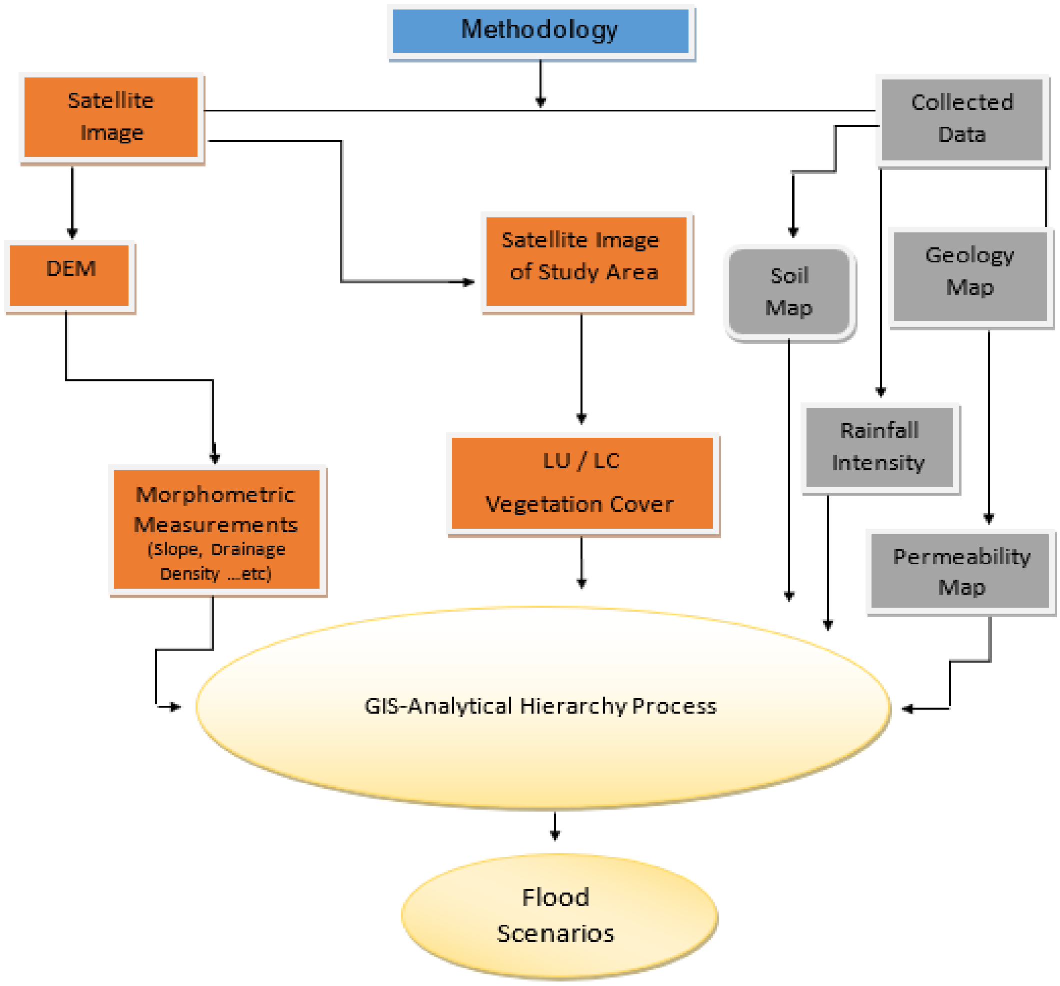

Figure 4. Study methodology

Permeability:

The researchers identified the parts of permeability in the basin (which is the factor affecting the movement of water from the surface of the earth to the lower regions and is a characteristic of rocks and soil and is an evidence of the ability of liquids and gases to penetrate, pass and flow through the rocks). Permeability is of great importance in studying floods and assessing their risks. - which is what the researchers will resort to in this study - because areas or parts with less penetration pave the way for a faster flow of water. Accordingly, the aforementioned areas are more vulnerable to flooding, provided that other data are not neglected, chief among them the abundance of rain and slope. In this study, the permeability ratios for parts of the Zarqa Ma'in basin were estimated based on the geological composition of the area, obtained from the Ministry of Energy and Mineral Resources, (Ministry of Energy and Mineral Resources, 2019), and also on the classifications of the rock cover contained in the various references and studies. Regarding the geological structure of the Zarqa Ma'in Basin, and that during the years 2018-2019; The northern region of the basin, as well as the northeastern region of it, are dominated by sandy soils with high permeability, and these soils are interspersed with many types of geological structures, such as the formation of Umm Al-Hasa phosphate with medium permeability (Zhang, et al., 2016) Which ranges in thickness between (60-70 m), where it starts over two prominent layers of gray flint and is dominated by the Sultani phosphorite class, which consists of Marley limestone with successive layers of phosphates .. as well as the relatively impermeable Umm Ghadran formation (Wernick, 1999), which was formed by the action depositional processes resulting from the tyranny of the sea at a time, where white chalky rocks were formed and deposited (Al-Draba'a, 2003) as well as the formation of relatively impermeable Shoaib, consisting of successive layers of green, gray and flesh colored marl, whose permeability characteristics are like the Ma'in sandstone. It appears abundantly in the east of the basin over a layer of Kornob Sandstone

(Al-Aqrabawi, 2007). The ranges of these soils extend almost to the middle of the basin, as the geological diversity begins to extend its influence over the basin to the downstream area. As the Umm Ghadran formations reappear in abundance, in addition to the formation of Umm Al-Hasa phosphate, which forms a long-range passing through the southeast of the basin, then the Ma'in sandstone appears at other times in simple parts (Al-Taj, 2008), which consists of thin layers of limestone and sugar-grained dolomino, as well as thin layers of dark gray flint. In the lower part of the formation there are layers of gypsum. Likewise, in the southern region of the basin there is the Nimeiri dolomite stone, the Wadi Sir al-Jiri formation (Darab'a, 2003) and the al-Hommar formation, which closely resembles the formation of Shoaib (Al-Aqrabawi 2007) The caliche stone, which forms a cohesive layer of calcium carbonate granules, but begins with a shallow, fragile layer of soil, which makes it somewhat impermeable (medium permeability) (Hennessy, et al., 1983) as well as showing the formation of graduated lime whose thickness ranges from 16 to 29 m and it consists of yellow marl, Celtic limestone and dolomitic Marley with shells, jellyfish and bivalves, which is deposited in a shallow marine environment (Ministry of Energy and Mineral Resources, 2019), while Basalt spreads in the far south of the basin and is filled with cracks, which makes it move from partial failure to implement Relatively outlet, and in the far southwest of the basin, where the downstream area, many different formations appear, such as the medium permeable red formation, basalt rock, kornob sandstone, and the sandstone of Ma'in (Al-Darab'a, 2003). The Na'our al-Jiri formation, which consists of three prominent mass layers, which includes the light brown Dolomitic limestone (Al-Haddadin, 1996), and is considered a low-permeable formations (The British Dam Society, 1996) and the 67 m thick Umm Arna formation extending along the Dead Sea and forming It has two classes: the first one is lower, forming fine sand, and the other is upper, containing several layers of clay and shale, which makes it an almost impermeable formation, especially in the presence of mudstone (Al-Darab'a, 2003). Figure 5 shows the permeability levels in the Zarqa River Basin, Ma'in, and it is followed by Table 1 for the percentages of the area of different permeability levels from the total area of the basin.

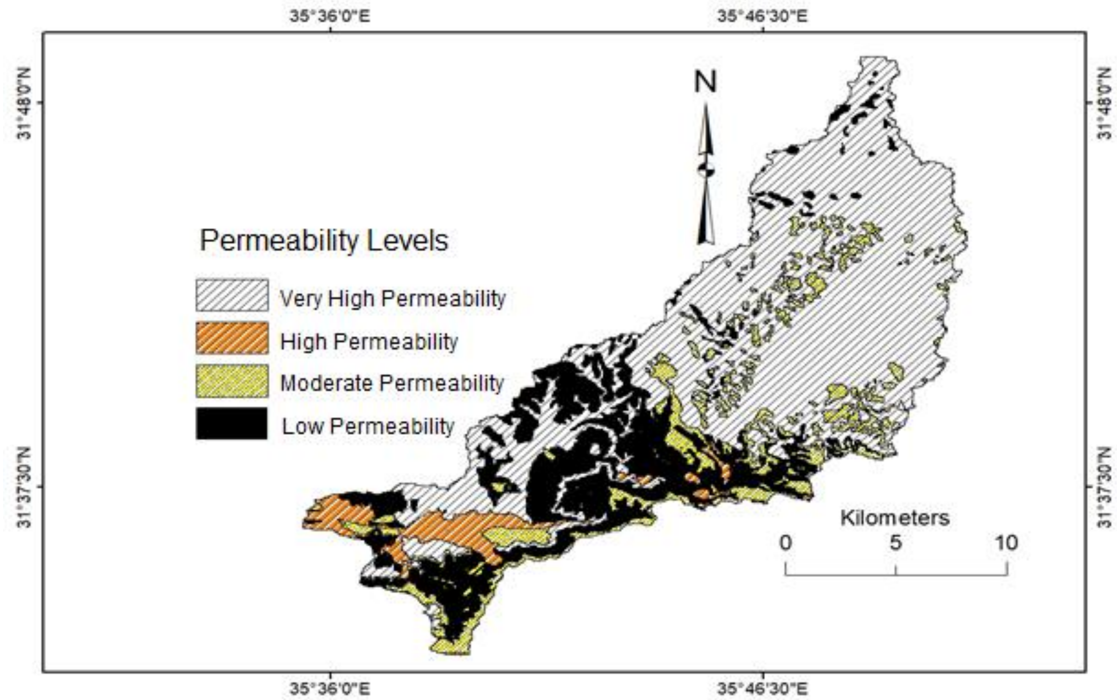

Figure 5. Permeability levels in the study area

(Source: the researcher's preparation based on data from the Ministry of Energy and Mineral Resources)

It was found that most of the basin area is dominated by high permeability, with an area of approximately 170 km², or 64% of the basin area, and this means that large parts of the basin area are not exposed to flood dangers regarding the permeability of their rocks, but other criteria cannot be neglected. The other, while the share of the second level or large permeability was 8 km², which constitutes 3% of the basin area. Then followed that the medium permeability level with an area amounting to approximately 30 km², occupying 11.27% of the basin area, while the low permeability was what its amount 58 km², which is formed by the basin's area of 21.73%. This last part is the part of the basin most vulnerable to flooding in case there are other data.

Table 1. The percentages of the area of different permeability levels from the total basin area (Source: researcher's preparation)

Permeability Levels	Area (km2)	The percentage of the Basin area
Very High Permeability	170	64%
High Permeability	8	3%
Moderate Permeability	30	11,27%
Low Permeability	58	21,73%

Slopes:

The researchers brought out the categories of slope in the basin, and slope means the deviation or inclination of the earth from the horizontal plane, and the greater this deviation, the steepest the slope. The slopes were classified into seven categories by Young, for the reader to become clear about the detail of the slopes in the basin. As for the slopes according to Young's classification, they were as follows: (Alaji, 2010). The gradient which is almost flat to very gentle (0-2 degrees). Gentle slope: (2-5 degrees). Average slope: (5-10 degrees). Above Average Slope: (10-18 degrees). Steep slope: (18-30 degrees). Very steep slope: (30-45 degrees). Cliff slopes: (the slope is greater than 45 degrees). About the study area, the basin of Zarqa Valley Ma'in is, based on the previous classification, a basin in which the shapes of the different slopes, light and strong, vary in very close proportions, while the lowest percentage was the semi-flat gradient (more than 2-5 degrees) with a rate of 11.7% and its area was 31.5 km². And between this and that, the average gradient (more than 5-10 degrees) acquired an area of 39.8 km² at a rate of 15.3%, and the area of the higher-than-average gradient category represented by grades confined between (more than 10-18) was about 39.5 km² a rate of 15%. The area of the steep slope represented by degrees reached between (more than 18-30 degrees) 38 km² by 41.5%, and the very steep gradient (more than 30-45 degrees) took an area estimated at 36 km² at a rate of 13.8%. Finally, the area of the category represented by the cliff gradient (More than 45 degrees (34.7 km²), a ratio of 13.3% to the study area. Figure (6) shows the slope levels in the Zarqa Ma'in basin, classified into seven levels according to Young's classification, While Table No. (2) shows the slope classifications in the Zarqa Ma'in basin, in addition to the areas occupied by all gradients in the region and their percentages to the total area of the basin.

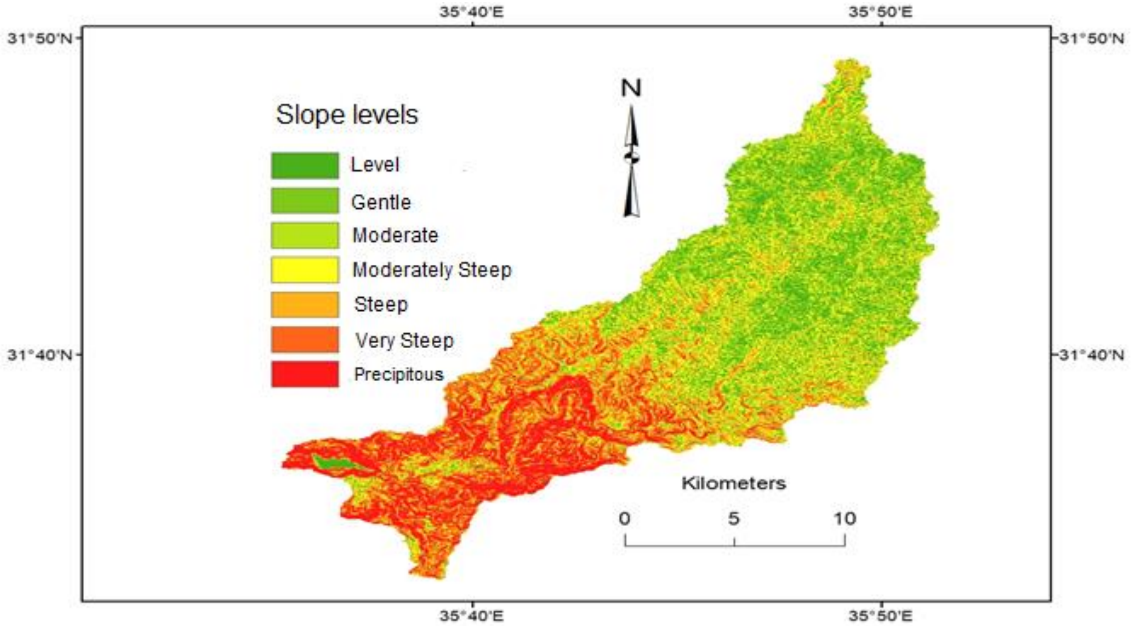

Figure 6. Slope levels in the study area according to Young's classification
(Source: researcher's preparation based on DEM)

Table 2. The slope levels of the Zarqa Ma'in basin and its areas and percentages of the basin area
(Source: researcher's preparation based on DEM)

Slope Levels	Slope Degree	Area (km2)	The percentage of Basin area
Level	0-2	31,5	11,7%
Gentle	2-5	43,5	16,4%
Moderate	5-10	39,8	15,3%
Moderately Steep	10-18	39,5	15%
Steep	18-30	38	14,5%
Very Steep	30-45	36	13,8%
Cliffs	>45	34,7	13,3%

Drainage density:

The researchers determined the drainage density in the basin, which is one of the important and influential streams characteristics in many riverine operations and is one of the most important measures of the water drainage network, and it is calculated by dividing the total length of the streams by the area of the drainage basin (Al-Husban and Zureikat, 2015). The total length of the streams in Zarqa Ma'in basin was 226.13 km, and the area of the drainage basin was equal to 266.02 km², which means that the drainage density is equal to = 0.85 km / km², which means that the drainage density of the basin is weak, but it is not weak in absolute terms but in most cases. That is, some areas are dominated by a higher drainage density than others, which are the areas that surround the mainstream of the basin in the middle of it almost to the downstream area. Drainage density classes were extracted through the Focal Statistics tool in GIS based on the sum of the lengths of the Stream order. Table 3 shows the average drainage density of stream order.

Table 3. The rates of drainage density for each order of the river

(Source: researcher's preparation)

Stream order	Drainage Density (km/km2)
1	0,61
2	1,22
3	1,18
4	1

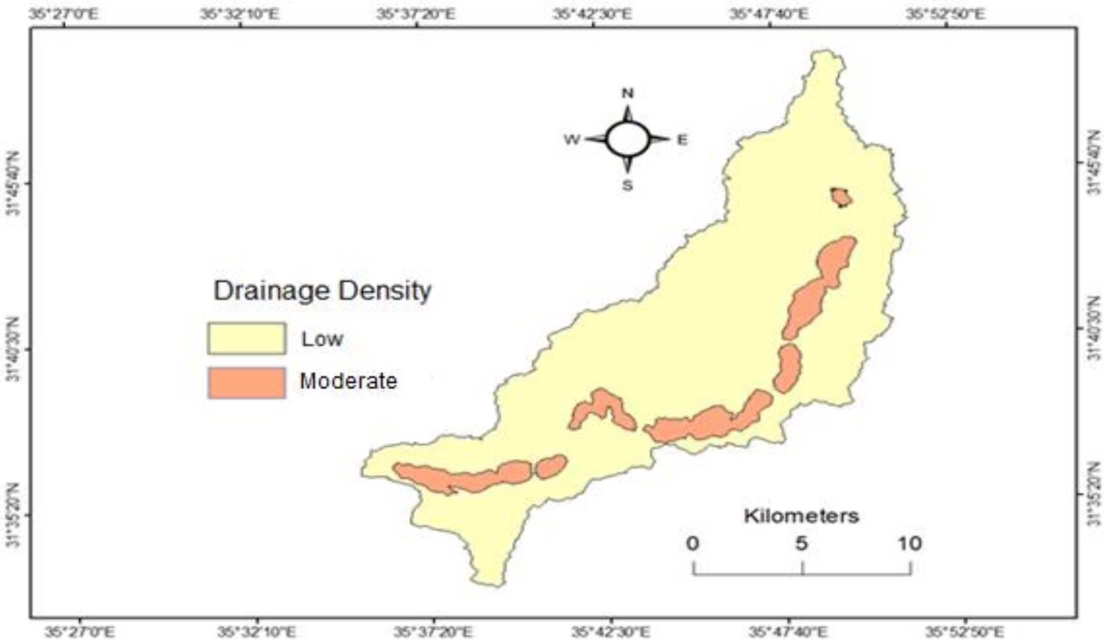

Figure 7. Basin drainage density (Source: researcher's preparation)

Land uses and land cover LC / LU:

It refers to those natural characteristics such as forests, trees, rocks, soil, and water, as well as human-made activities that cover the surface of the earth. It should be noted that these uses change over time and with the change of the various human needs of the earth (Hamid, 2016). About the Zarqa Ma'in basin, the classification of the different land uses is as shown in the following, and that was during the year of 2019:

First: The human cover, which includes everything created by human action, and is divided into multiple uses, including:

Residential use: It includes residential areas of all categories, and the area of this use is approximately 22.52 km², and therefore the percentage of this use from the area of the basin is approximately 8.46%.

Agricultural use: It includes the cultivated areas in the basin regardless of the type of agriculture. In general, the area occupied by agricultural use from the basin was estimated at 6.18 km², which constitutes 2.32% of the basin area.

Industrial use: It is concentrated in the north of the basin only and was limited to that, and it refers to factories, quarries, and industrial areas such as the Madaba Industrial Zone, which is located at a longitude 43'17 "° 31 ° east and a circle of latitude 43'17" ° 35 north. **Services use**: It includes places of worship such as mosques and churches that are distributed near residential communities, as well as includes markets, major commercial stores, stadiums, and government departments located in the study area.

Finally, the main paved transport roads, and the parts that they occupy are very impermeable to water, which increases the flow, and the total length of the main roads paved in Zarqa Ma'in Basin estimated of 126.92 km².

Second: Natural Cover, which is divided into:

Natural vegetation: It includes grasslands and small shrubs and is limited to that as there is no presence of forests in the area, and this category is very important for its great role in intercepting water and withdrawing much of it, as the absence of vegetation cover leads to not absorbing part large amounts of water and increase the chances of soil erosion. Most of it was concentrated in the middle and north of the basin, in addition to small parts of it in the south of the basin, and part of it will be singled out later to remove the vegetation cover in the basin for the different seasons of the year separately from the uses of the land; so that vegetation cover is constantly changing. The total area occupied by shrubs was approximately 9 km², which means that they occupy an estimated 3.38% of the basin area. Whereas the area occupied by weeds was 3 km², or 1.12% of the basin area, then bare and rocky lands: it includes all open and unexploited lands in the area, and perhaps the preferred area of the basin for the occurrence of floods, given that there is no objection to the movement of water, and with the availability of rain heavy downpours, slope and more, the water will flow unimpeded. This use had the largest share of the basin area, amounting to 225.02 km², or 82.78%. The different land uses and land cover in the basin are shown in detail in Figure 8, and their areas relative to the basin area in Table 4, respectively.

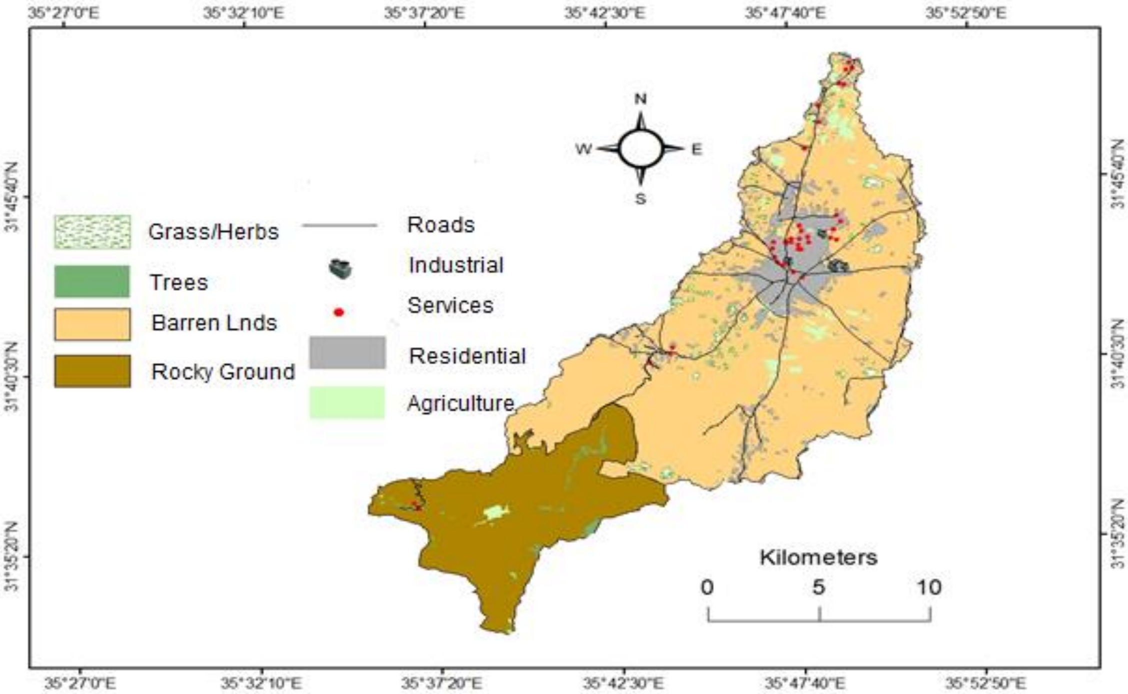

Figure 8. Land use in the study area.

(Source: The researcher's preparation based on the satellite visual Sentinel-2)

Table 4. The areas of the various land use and its percentages of basin area

(Source: researcher's preparation)

Land Use	Area (km2)	The percentage of Basin area
Agriculture	6,18	2,32%
Residential	22,52	8,46%
Trees	9	3,3%
Grass/Herbs	3	1,12%
Barren & Rocky Lands	220,02	82,78%

Vegetation cover:

Vegetation cover with its various varieties, trees, shrubs and grasses, is one of the ecosystems that make up the surface of the earth, and the vegetation cover has great importance in affecting this surface; As it affects the weather conditions by increasing humidity, reflecting solar rays, reducing wind speed, stabilizing the soil and reducing the chances of its erosion, and the vegetation cover in any region generally depends on several factors, which are the type of soil in the region, the nature of its climate, its geographical location, the customs and traditions of the inhabitants of the same region in addition to the nature of its construction (Al-Mashhadani, 2009).

In view of the difference in vegetation cover and its different extension between the seasons of the year and thus its effect on the occurrence of floods; The vegetation cover coefficient (NDVI) was calculated in the study area for two seasons representing two periods, the first: autumn (November) which represents the dry period, and the second: winter (February), which represents the wet period, and the researchers relied on that on the Sentinel-2 satellite visuals for each season separately. The vegetation cover was in the study area for the seasons as in Figures 9 and 10 which show the vegetation cover in the basin and the Zarqa Valley Ma'in during the autumn and winter seasons, respectively.

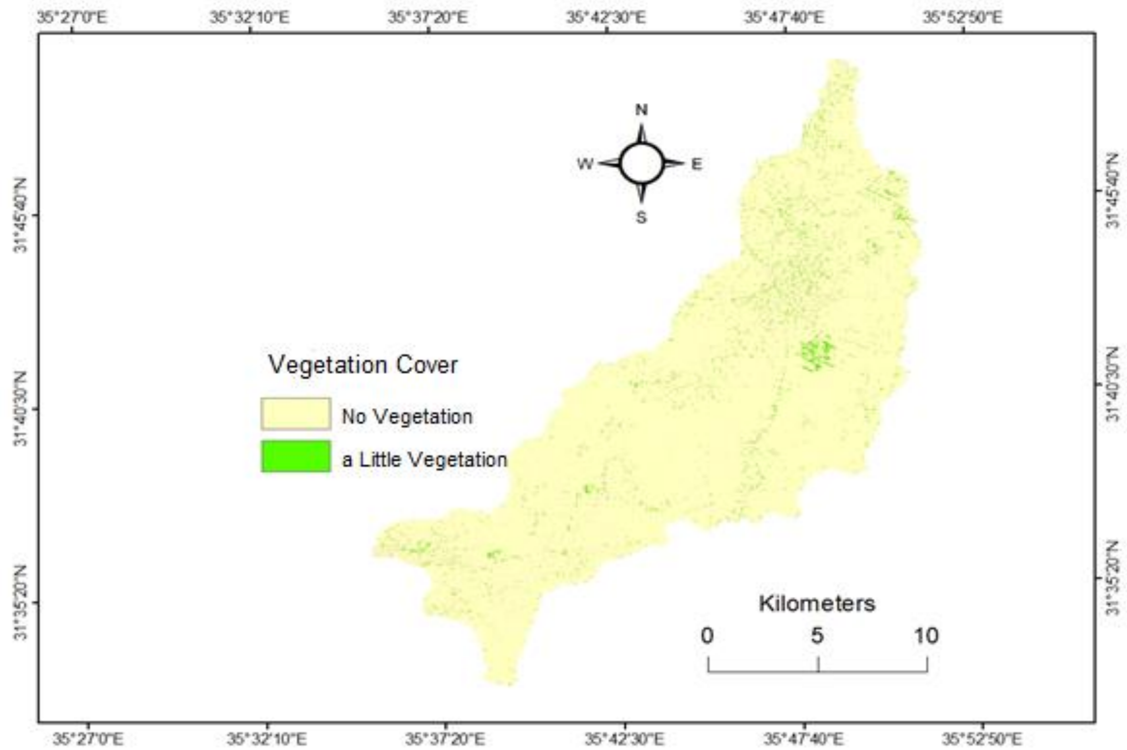

Figure 9. Vegetation cover in Zarqa Ma'in basin during autumn

(Source: The researcher's preparation based on the satellite visual Sentinel-2)

It is evident that the region lacks a great lack of vegetation cover during the period that can be called the dry period, and the presence of vegetation cover is limited to all agricultural areas surrounding the outskirts of cities, in addition to - as well as - the natural shrubs and grasses that spread in some parts of the basin. It can be said that the absence of vegetation covers the area an important component in resisting surface water runoff. This can greatly affect the occurrence of torrents and floods, during times of heavy rain in steep areas, and the areas covered by the actual presence of vegetation reached an amount of 5.18 km², while vegetation cover was absent from the rest of the basin.

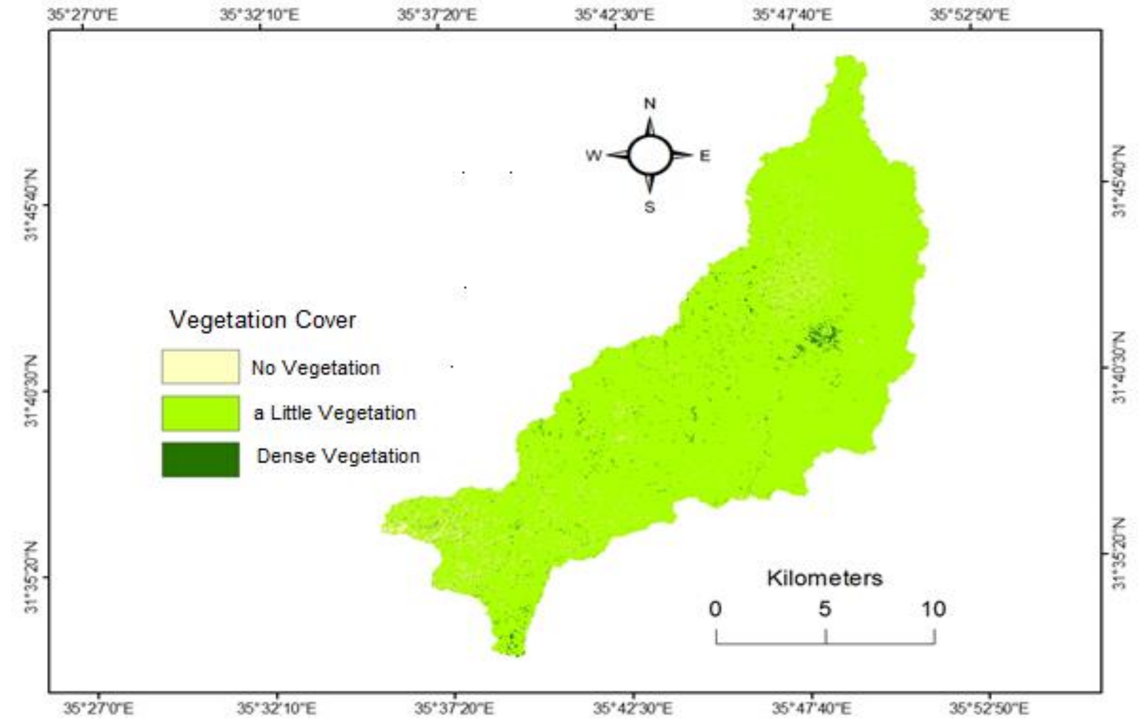

Figure 10. Vegetation cover in Zarqa Ma'in basin during the winter season

(Source: The researcher's preparation based on the satellite visual Sentinel-2)

There is a big difference in the vegetarian presence between November and February. As the basin is almost not devoid of areas covered by vegetation in its various parts even if this vegetation cover is limited to just small weeds, and it has been found that the area covered by dense vegetation during this season is about 1.65 km², and the areas covered with little vegetation covered a large area It is 258.39 km², while the remaining parts of the basin, amounting to an area of about 5 km², are completely empty of vegetation.

Rainfall Intensity:

the intensity of rain means the amount of rainfall during a short period of time that may not exceed a few hours, and the heavy rain results in massive and destructive floods and not a few geomorphological changes, and the heavy rain stimulates erosion in its various forms; Its tinplate and grooves play a large role in the development of an intense network of streams and grooves (Al-Husban, 2010). The heavy rain had a great impact in the occurrence of the last flood in Zarqa Ma'in basin on October 25, 2018, which killed a group of children. Madaba stations recorded heavy rainfall estimated at about 40 mm within one hour only, and this large amount drained from the area between the Zarqa Dam and Ma'in Baths through the valleys of the region towards the Dead Sea, which led to a massive flood in the mainstream of Wadi Zara Ma'in (Ministry of Water and Irrigation, 2019). The researchers were not able to prepare a map of the rain intensity in the study area due to the lack of data from its sources. And for this, the value of the rain intensity will be relied upon in determining the probability of flooding in the parts of the basin, combined with all the variables that go into estimating this probability, through several scenarios, in case the rainfall was the same value (40 mm / hr.) and if it was greater than that and if it were less; In order to determine the role of excess rainfall in the likelihood of flooding in the basin.

Soil depth:

The depth of the topsoil plays a very important role in limiting soil degradation caused by water erosion, as well as in reducing the chances of flooding due to the ability of non-shallow soil to hold water and prevent its run-off in contrast to shallow soil. Significant impact on vegetation cover, area hydrology, and soil surface protection, and clay texture, soil moisture content and the amount of organic matter in it, in addition to being related to clay particles - affect the depth of the soil; All these components hold water and bind its molecules. However, the components will be of negligible importance if they are located on steep terrain. (Abu Ras and Issa, 2017). In the basin of the Zarqa Ma'in Valley, like most dry and semi-arid steppe regions in Jordan, there are two main types of soils, and they are: A branch of Entisols, which is Torriorthent: it is a very weak soil without horizons, shallow and shallow, containing stones and gravel. And a branch of the inceptisols, which is Xerochrept: it is a deep, moderate to medium growth, red color, rich in primary and secondary calcium carbonate and with a high capacity for ion exchange, and it also has a high content of clay in its layers, which makes it suitable for runoff after saturation (Lucke, et al. 2013). Figure 11 shows two main types of soils in the basin.

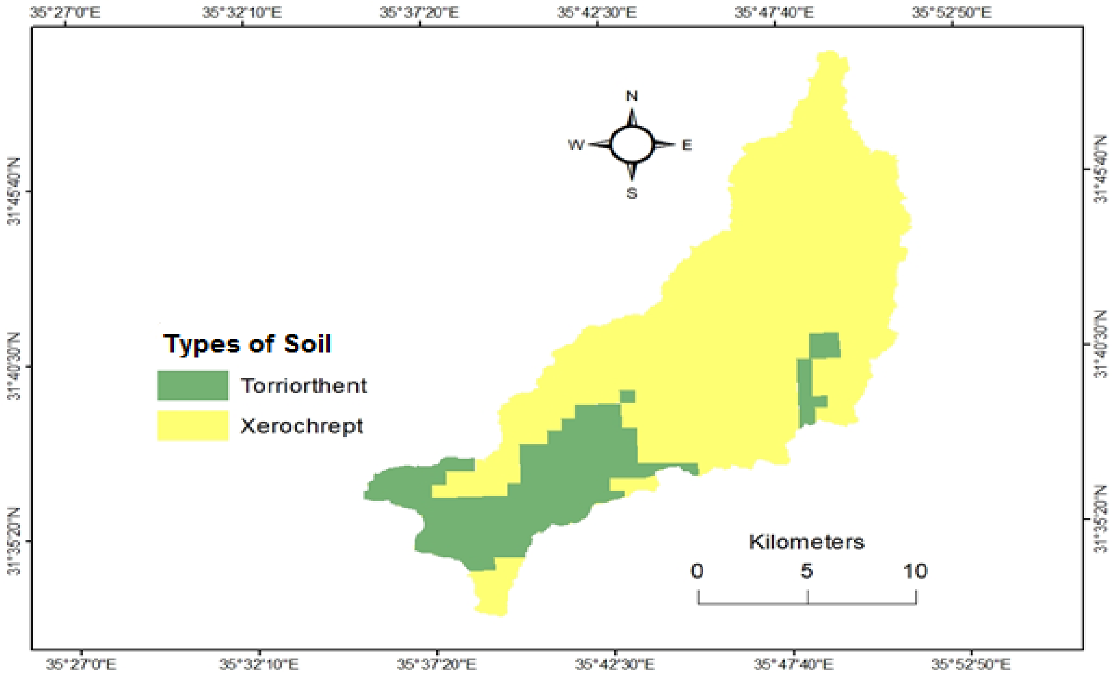

Figure 11. The main soil types in Zarqa Ma'in Basin

(Source: Prepared by the researcher's based on the map of soil types in Jordan from Lucke, et al, 2013)

Analysis and Discussion:

To reduce the risks arising from floods, reduce the chances of their occurrence or avoid them as much as possible; There is no indication of its study and estimation after studying and estimating the characteristics affecting them. Floods are measured, identified, and predicted through what is known as flood estimation methods, and these methods aim to model the relationship between falling rain and what happens after that of surface runoff, and the methods used in estimating floods differ. There are many great multiplicities, such as empirical equations based on a small number of information, or as the number curve (CN) method, which is the most famous and most widespread method, and some of them are detailed and more complex, as it studies all the factors affecting the transformation of precipitation into surface runoff (Dawood et al., 2012). In this study, the researchers followed one of the detailed methods to reach accurate results, which is the Hierarchical Analysis method based on giving weights for all the elements or criteria that enter the assessment process and affect it according to priority, and then it is then based on multiplying these different weights together to come up with a final map. The grading results are represented by multiple categories. In the following figure No. 12, the weights of the categories of flood estimation criteria are shown in the Analytical Hierarchy Process.

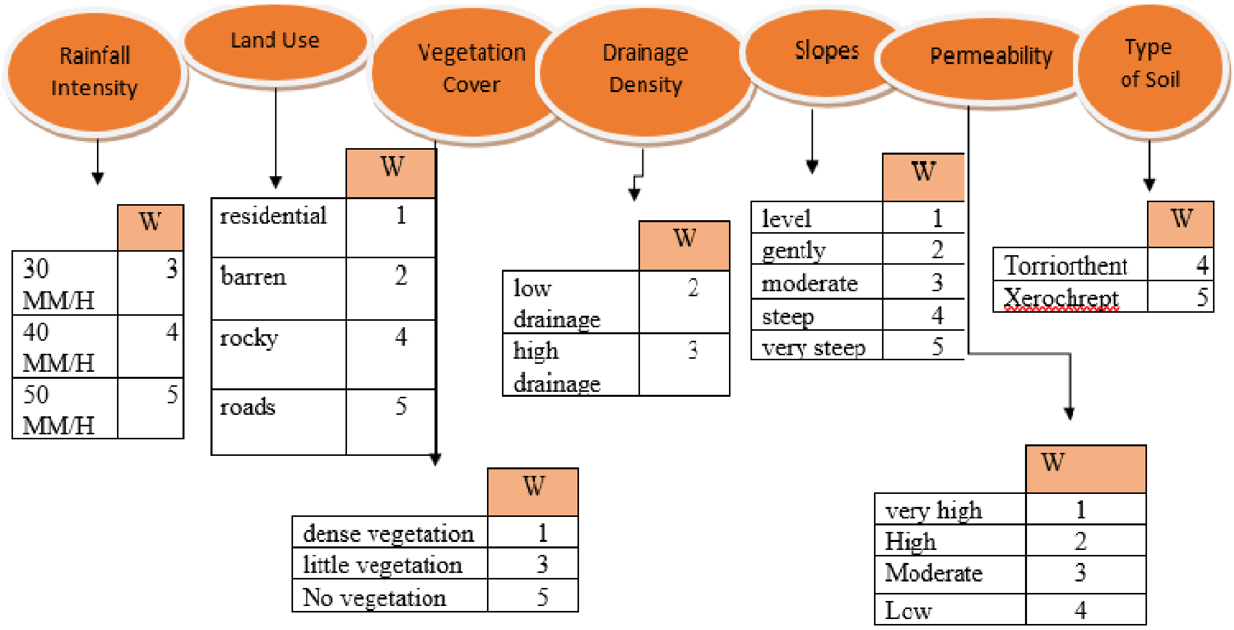

Figure 12. Weights of criteria classes in Analytical Hierarchy Process

Flood Scenarios in Wadi Zarqa Ma'in basin:

1- The first scenario: the dry period (generally little vegetation cover during the autumn season), rain abundance = 30 mm / hr., with the remaining parameters constant. Figure.13 shows a variation in the chances of flooding in parts of the Zarqa Ma'in basin of in the event that a rainfall of 30 mm / hr., was recorded during the summer and autumn seasons, and this variation was between areas not at risk of 27% of the basin area, and vulnerable areas with a weak degree of 54% and another highly exposed by 19% of the basin area, the areas north of the basin to the middle of the basin intersect in which the first and second levels overlap, and they are the same areas dominated by rocks and soils with high permeability, flat areas and gentle slopes, and they are also the areas of distribution Architecturally, it contributes to making the land acquire something that can be called a water barrier in some parts, which reduces the chances of flood In the middle of the basin, at the intersection of a latitude 45'0 "° 35 north with a longitude 38'0" ° 31 ° east, there are chances of real flooding in the area despite the existence of an urban sprawl, and the reason for this is due to a number of factors, most notably the dominance of rocks, the low permeability in those areas with the high amount of water drainage compared to the parts of the basin, in addition to the presence of very steep slopes in those areas up to the southeastern end of the basin, with the exception of some areas as the previous figure shows, causes of flooding in it.

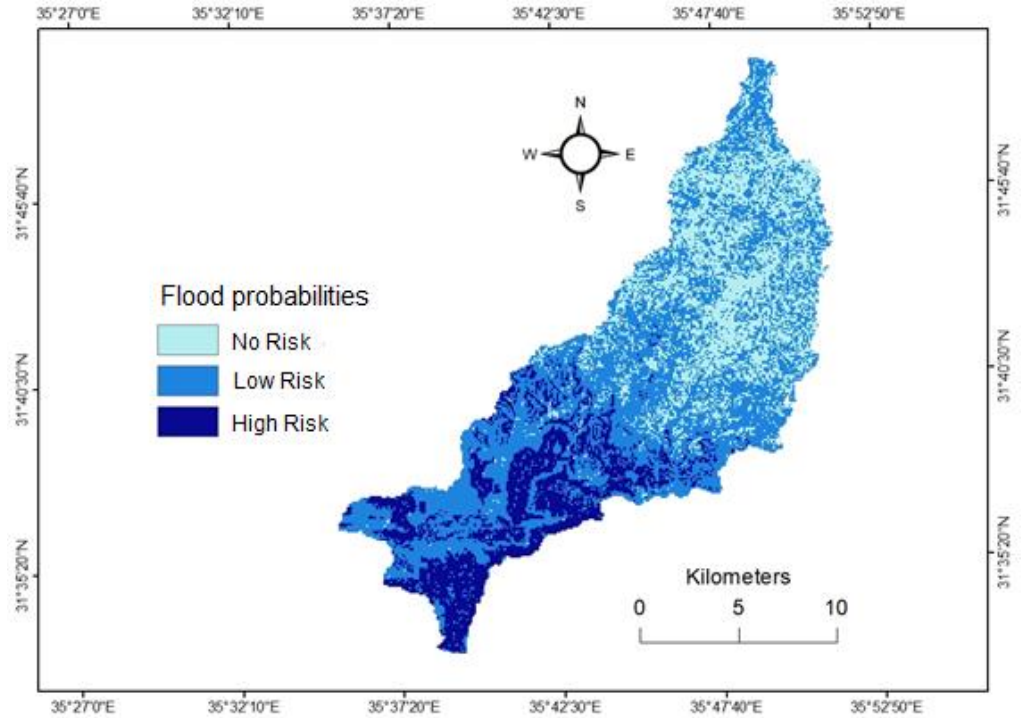

Figure 13. Flood probabilities in Wadi Zarqa Ma'in basin during the dry period with a rainfall of 30 mm / hr.
(Source: researcher's preparation)

2- The second scenario: the dry period (generally little vegetation cover during the autumn season), rain abundance = 40 mm / hr., with the rest of the parameters fixed.

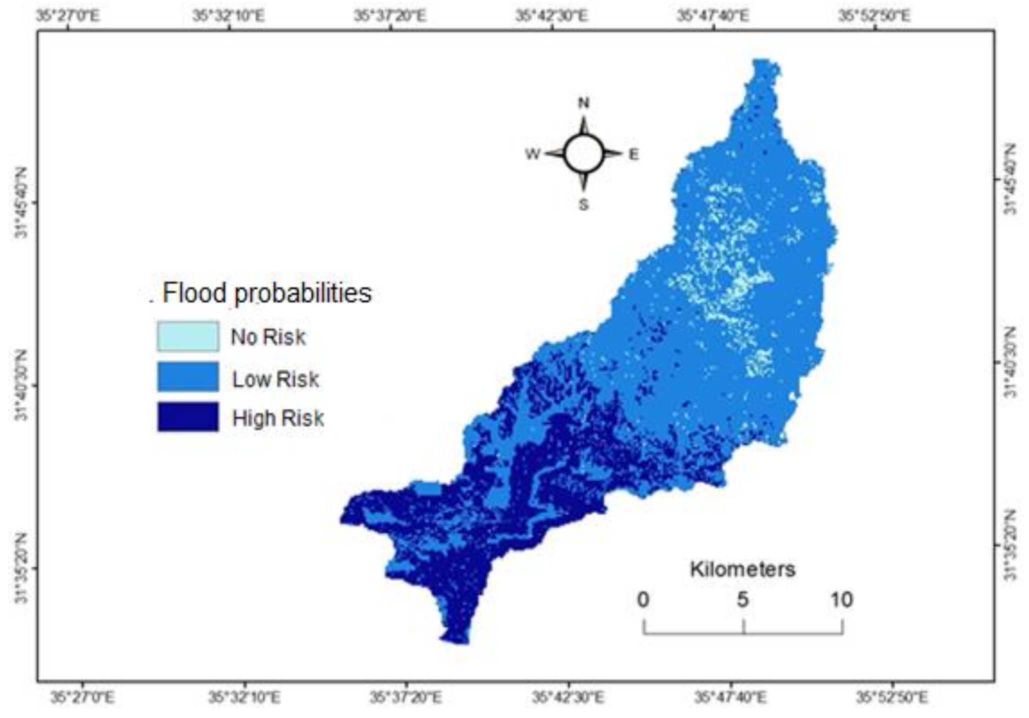

Figure 14. Flood probabilities in Wadi Zarqa Ma'in basin during the dry period

With a rainfall of 40 mm / hr. (Source: researcher's preparation)

Most of the areas not exposed to the risk of flooding in the basin - except for urban areas and areas that witness the presence of vegetation cover with permeability to water - moved to areas exposed to a weak degree with an increase in the expected rainfall to 40 mm / h, with the exception of urban distribution areas in the north and middle of the basin. It was within the low probability level to the high probability level in the rest of the basin, as shown in Figure 14, and since the amount of rain intensity during the last flood was approximately equal to 40 mm / hr., this means that the rainfall was the first cause of the flooding regardless on the opening of the dam or not, taking into account the natural characteristics of the basin, the aforementioned areas are steep rocky areas and often have little water permeability.

3- The third scenario: the dry period (generally little vegetation cover during the autumn season), rain abundance = 50 mm / hr., with the rest of the parameters fixed.

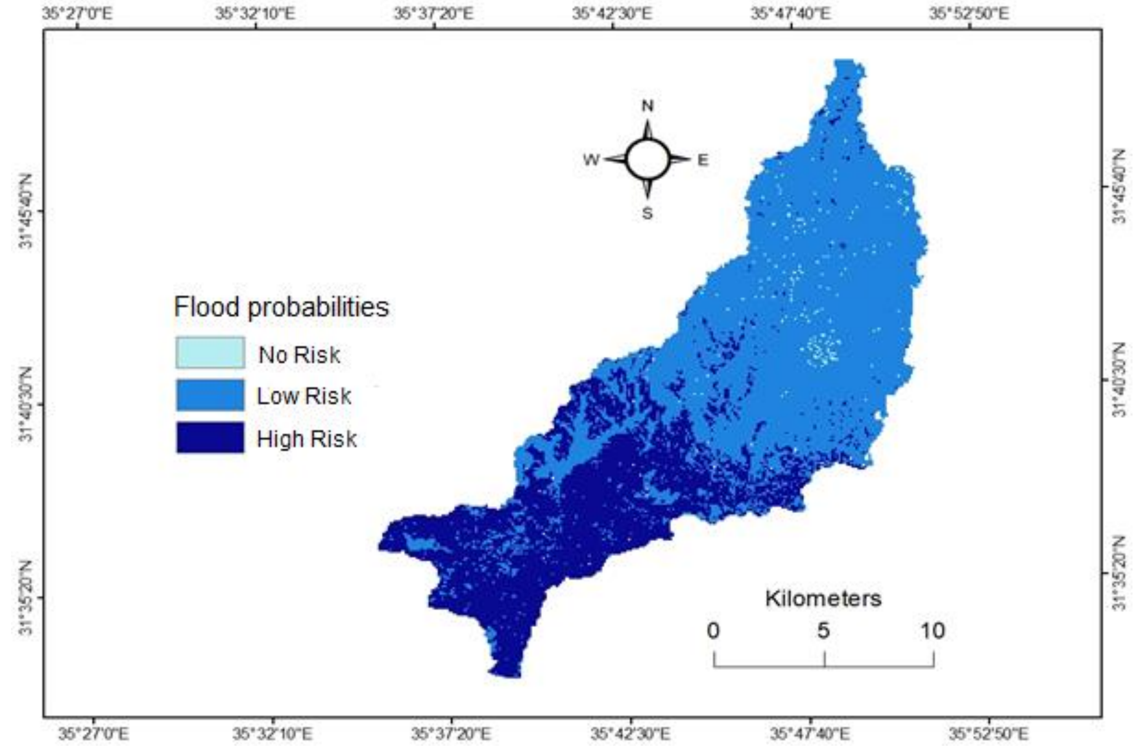

Figure 15. Flood probabilities in Wadi Zarqa Ma'in basin during the dry period

With a rainfall of 50 mm / hr. (Source: researcher's preparation)

The previous figure No. 15 shows the possibilities of flooding in the basin in the event of heavy rain of about 50 mm / hr., and through it appears that most areas of the basin are exposed to a great risk of flooding - even if the probability is weak in some parts - apart from the areas in which the human body is distributed , In addition to the existence of a zone that is not exposed to flooding in this case despite the absence of urbanization, which is the range that exists at the intersection of a circle of latitude 48'30 "° 35 north with longitude 41'30" ° 31 east, and the analysis of the vegetation cover factor NDVI during the season showed Autumn having vegetation In this range, what confirms the role of vegetation in intercepting floods, in addition to the fact that the area containing that range is a highly permeable area and flat surface to a gentle slope.

4- The fourth scenario: the wet period (the presence of vegetation cover in general during the winter season), rain abundance = 30 mm / hr., with the remaining parameters constant.

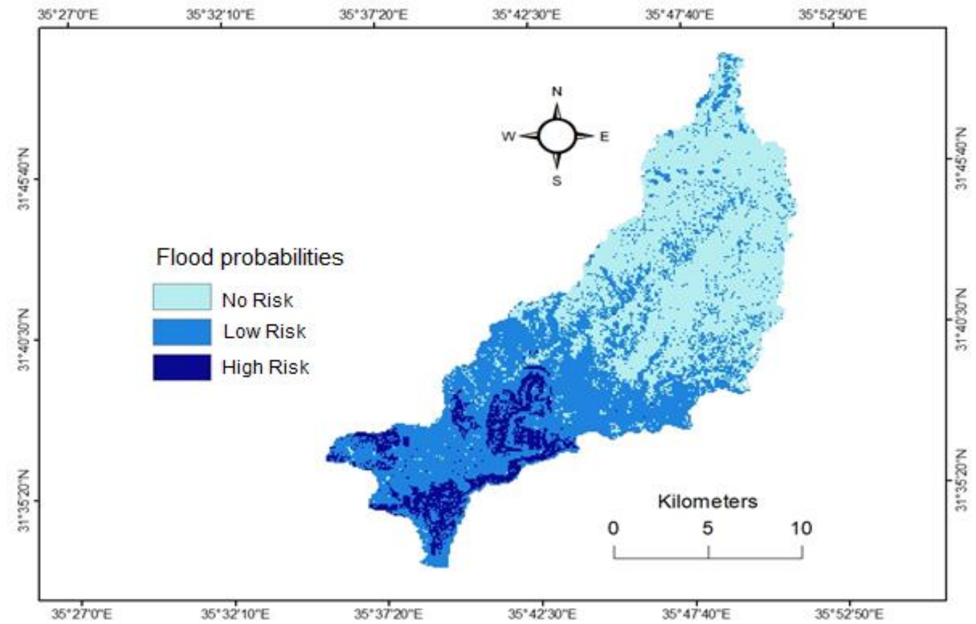

Figure 16. Flood probabilities in Wadi Zarqa Ma'in basin during the wet period

With a rainfall of 30 mm / hr. (Source: researcher’s preparation)

The effect of vegetation covers that results in rain in the winter season appears greatly in interrupting the movement of water and reducing the imposition of flooding in the basin, even if this vegetation cover is little. 27% to 48%, which is a noticeable increase (fig 16), while the percentage of areas exposed to flooding slightly increased from 54% to 44%, and the percentage of areas exposed to flood risk decreased significantly from 19% to 8%.

5- The fifth scenario: the wet period (a real presence of vegetation cover in general during the winter season), rain abundance = 40 mm / hr., with the remaining parameters constant.

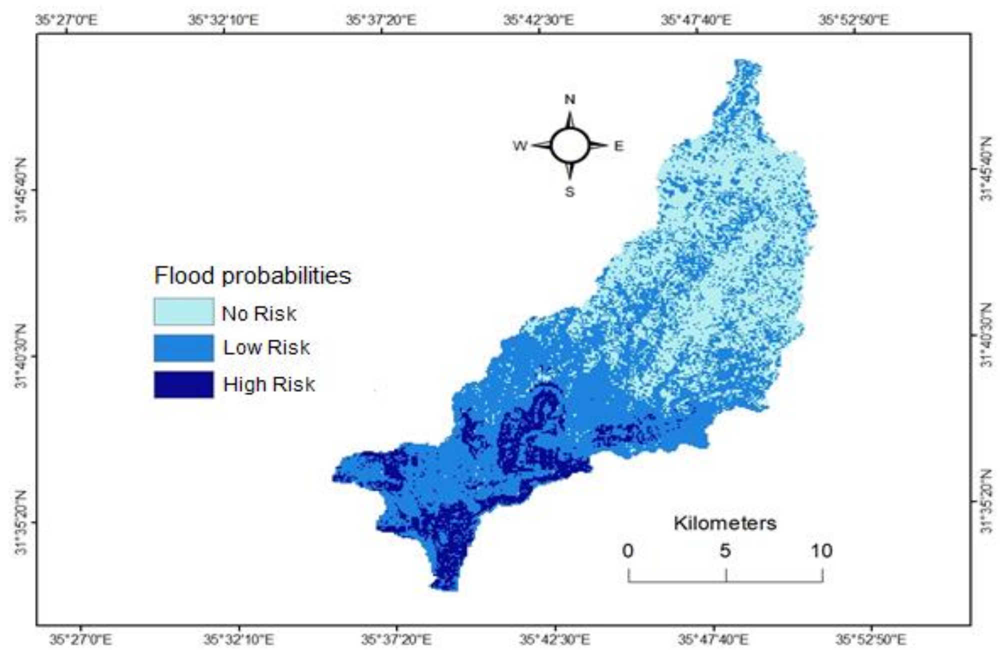

Figure 17. Flood probabilities in Wadi Zarqa Ma'in basin during the wet period

With a rainfall of 40 mm / hr. (Source: researcher’s preparation)

In the event that the estimate result from 40 mm / hr. rain precipitation is compared with that resulting from the same characteristics and the same intensity of rain but during the wet period; Once again, it will become clear that vegetation has a significant effect on preventing runoff; As the areas not exposed to the risk of flooding in the first case were confined to areas with a large distribution of urbanization, at a rate of 5%, (fig 17)while the percentage raised the presence of vegetation cover in the wet period to 36%, and the areas exposed to flooding also declined significantly from 27% to 10%.

6- The sixth scenario: the wet period (the presence of vegetation cover in general during the winter season), rain abundance = 50 mm / hr., with the rest of the parameters fixed.

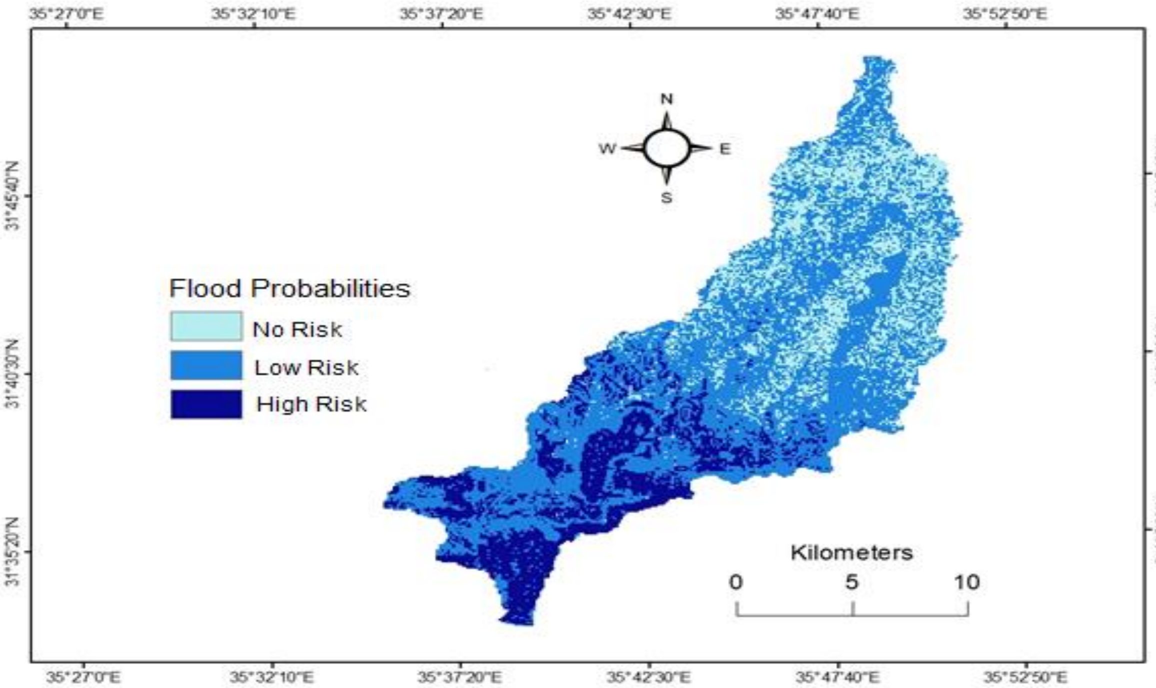

Figure 18. Flood probabilities in Wadi Zarqa Ma'in basin during the wet period
With a rainfall of 50 mm / hr. (Source: researcher's preparation)

It is not possible to say which of the two is the most influential on surface water flow, the intensity of the rainfall or the vegetation cover, and the reason for this is that the different scenarios that the researchers reached in this study proved the effect between them - rain and vegetation cover - as the percentage of areas exposed to flood risk increased. Significantly in this scenario, which witnessed a rainfall of 50 mm / hr. (fig 18). of the same degree in the previous scenario, which witnessed a rainfall of 40 mm / hr., knowing that the vegetation cover in the two scenarios is the same, but the areas not exposed to the risk of flooding in this scenario have increased to include a greater extent across all basin directions compared to the same data in the dry period. Table 5 shows the percentages of flood probability levels relative to the area of the basin under the different scenarios.

Table 5. The percentage of the different flood probabilities in the parts of the basin under the various scenarios (Source: researcher's preparation)

Flood probabilities	Expected rainfall Intensity	wet period (%)	dry period (%)
No probability		48%	27%
Low probability	30 mm/hr.	44%	54%
High probability		4%	19%
No probability		36%	5%
Low probability	40 mm/hr.	54%	68%
High probability		10%	27%

Flood probabilities	Expected rainfall Intensity	wet period (%)	dry period (%)
No probability		22%	1%
Low probability	50 mm/hr.	59%	65%
High probability		19%	34%

Results:

This study found the following results:

1- The researchers identified the most prominent characteristics that are included in the estimation of floods and built a database for them within the environment of information systems, and dominant slopes were gentle ones with 0-2 degrees, which covered 16.4% of the study area (43.5 km²), while the lowest percentage was the slope semi level (more than 2-5 degrees) by 11.7% and its area was 31.5 km².

2- The rain abundance, land use and vegetation cover, soil shallowness, and drainage density that reached 0.85 km / km² in the basin, which means that it is a weak density, and permeability, which were divided into categories and areas with high permeability have largely dominated the basin; their areas amounted to approximately 170 km² (64% of the basin area) and large permeability areas 8 km² (3% of the basin area) as for the level of medium permeability, as the areas covered by a total of 30 km² were approximately (11.27%). Finally, the low permeability was 58 km² (21.73% of the basin area).

3- The researchers have reached a prediction of the dangers of floods in the parts of the basin, according to the previous characteristics, within several scenarios set out below:

• The dry period is characterized by almost no vegetation cover. If a rainfall of 30 mm / hr. was recorded during the summer and autumn seasons, the diversity of flood opportunities would appear between areas not at risk of 27% of the basin area, and areas with weak exposure by 54% and others are exposed to a great extent by about 19% of the basin area. In the same dry period, if the rain intensity was 40 mm / hr., most of the areas not exposed to the risk of flooding in the basin will move to areas exposed to a weak degree, and also the areas that were within the level of low probability will move to the level of great potential in the rest of the basin. As the rainfall rises again to 50 mm / hr., most areas of the basin are at risk of flooding.

• In the wet period represented by the winter and spring seasons, which witness the presence and expansion of vegetation cover in the parts of the basin, the percentage of areas not exposed to the risk of flooding increased at the expense of areas exposed to a weak degree and those exposed to a great extent from 27% to 48%, which is a significant increase, while the percentage of areas exposed to flooding slightly increased from 54% to 44%, and the percentage of areas exposed to flood risk decreased significantly from 19% to 8%; what cuts off the importance of vegetation in intercepting the movement of water. Also, the areas not exposed to the risk of flooding in the first case were confined to areas with a large distribution of urbanization, at a rate of 5%, while the percentage - with an amount of rain of 40 mm / hr. - increased the presence of vegetation in the wet period to 36%, and the areas exposed to flooding also declined, significantly from 27% to 10%.

4- It was found that the opening of the Zarqa Ma'in Dam was not related to the flood that killed a group of children in 2018; Heavy rain had the first role in the occurrence of flooding, in addition to the fact that the areas in which the water flowed are steep, rocky areas with little permeability to water.

Recommendations:

Considering the findings of the study, the researchers recommend the following:

• The use of field surveys supported by the Global Positioning System (GPS) to study the natural and human causes that are involved in the assessment of floods, and the expansion of various geographical studies using modern technologies and global models being the most effective option to produce accurate results.

• An expansion work must be done on the Wadi Zarqa Ma'in dam to increase its capacity, and then its ability to reserve a larger amount of water, which would reduce the amount of running water, especially since the areas following the dam and up to the Dead Sea are the most vulnerable to floods. The specialists and decision-makers must provide means and methods for awareness and guidance regarding the dangers of floods and areas exposed to these dangers, and take decisive decisions to prevent trips, hiking, or approaching areas threatened by flood dangers, especially in times when severe rains or atmospheric instability are expected. And the prohibition of giving residential licenses or any of those that grant permissions by establishing, constructing, or building any humanitarian existing, whether commercial, residential, industrial, or otherwise, in the aforementioned areas, unless the necessary protection means are available to preserve life and property.

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