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Factors Affecting Flash Flood Disaster in Ghat Town in Libya

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Abstract

Objectives: The research aimed to remove the ambiguity about the reasons that led to the occurrence of the flood disaster in Ghat town in June 2019 and to identify the factors that influenced its occurrence.

Methods: The analytical approach was used to analyze satellite imagery from the European satellite (Sentinel 2) to determine the areas where floods spread throughout the town and the area surrounding it as well as the pathways through which they invaded the town. In addition to conducting a field study to evaluate the damage and verify the accuracy of remote sensing data, wadi streams and basins that had an impact on the town were also extracted using digital elevation models (DEMs).

Results: The study showed that using remote sensing techniques in GIS environment was successful in determining the spread of floods and calculating their quantities, as well as extracting wadi streams and calculating the areas of their basins. It also became clear that the most significant wadis affecting the town are those descended from the Tassili-Nazjer series, led by Wadi Innaghen, Wadi Tahramet-Azzezjer, and subsequently Wadi Tinalkum, all of which are tributaries of the Tanezzuft Great Wadi. It became apparent that the floodwaters entered Ghat from three directions: the southern, western, and northern.

Conclusion: It was discovered that the main cause of the disaster was a severe rainstorm that lasted through ten days, as well as the construction of new town neighborhoods in the lowlands, which in fact represent a natural spillway for two large wadis

Keywords: Flash Floods, Geomorphology of Desert Wadis, GIS, Remote Sensing, Wadi Tanezzuft.

العوامل المؤثرة في كارثة السيول في مدينة غات بليبيا

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ملخّص

الأهداف: هدف البحث إلى إزالة الغموض حول الأسباب التي أدت إلى حدوث كارثة السيول في مدينة غات مطلع شهر يونيو 2019م، وتحديد العوامل التي أثرت في حدوث الكارثة.

المنهجية: تم الاعتماد على المنهج التحليلي في دراسة مرئيات الأقمار الصناعية من القمر الأوربي (Sentinel 2) واستنباط مساحة انتشار مياه السيول في المدينة وجوارها، وكذلك اتجاهات دخولها إلى المدينة. كما جرى استخدام نماذج الارتفاعات الرقمية (DEMs) من نوع (SRTM1) في استخلاص مجاري الأودية وأحواضها المؤثرة على مدينة غات، بالإضافة إلى الدراسة الميدانية لتقييم الأضرار والتحقق من دقة بيانات الاستشعار عن بعد.

النتائج: توصل البحث إلى أن استخدام تقنيات الاستشعار عن بعد في بيئة نظم المعلومات الجغرافية قد أثبت نجاحه في تحديد مساحة انتشار مياه السيول وحساب كمياتها، وكذلك في استخلاص مجاري الأودية وحساب مساحات أحواضها. كما تبين أن أهم الأودية التي تؤثر في المدينة هي الأودية المنحدرة من سلسلة تاسيلي ناآزجر وعلى رأسها وادي إناغن ووادي تاهرامت – أززجر ثم وادي تينالكوم، وهي جميعًا من روافد وادي تنزوفت الكبير. وقد اتضح أن مياه السيول دخلت إلى مدينة غات من ثلاثة اتجاهات هي الاتجاه الجنوبي والاتجاه الغربي ثم الاتجاه الشمالي.

الخلاصة: لقد تبين أن السبب الرئيسي في حصول الكارثة هو العاصفة المطرية الفجائية التي استمرت قرابة عشرة أيام، بالإضافة إلى بناء الأحياء الجديدة للمدينة في الأراضي المنخفضة التي تمثل في الواقع مفيضًا طبيعيًا لواديين كبيرين.

الكلمات الدالة: الجريان السيلي، جيومورفولوجية الأودية الصحراوية، الاستشعار عن بعد، نظم المعلومات الجغرافية، وادي تنزوفت.

Introduction

Flash flood = torrent = flashy flow is a temporary surface run-off in arid and semi-arid lands, or it is a large amount of water that flows rapidly in a temporary stream (Al-Hay 2000). The Dictionary of geography defined it as a very rapid flow of water towards the stream channel (Komarova 2007). It is characterized by a huge amount of sediments, so much so that a watercourse is not called a torrent unless the percentage of solid particles in it exceeds 5 or 10%. Both the speed of the torrent and the amount of its water decreases the farther away from its head (Al-Jadidi 1998).

The drainage basins in arid and semi-arid environments receive semi-seasonal rainstorms, which may not be sufficient to generate significant surface runoff, but the heavier rainstorms, and those classified as sudden storms, are more likely to generate higher amounts of runoff. It cannot be considered that all the rain that the drainage basin receives will go out in the form of surface runoff (Zekâi Sen 2008), as there are factors that lead to the loss of some of this water, such as evaporation, infiltration, surface storage, and usage by plants. The physical and human components of the drainage basin enhance or reduce these losses (Al-Nafi'i 2010).

Some authors studied flash flood hazards in arid and semi-arid zones, among them:

Al-Nafi'i (2010) estimated the surface runoff and its torrential hazards in the upper basin of Wadi Ornah near Makkah Al-Mukarramah (Saudi Arabia) and determined the areas that are at the most hazard of flooding. The study recommended the necessity of establishing channels to drain torrential water in residential plans located in Wadi Ornah, southeast of the holy city.

Belkhair (2008) built a mathematical model for surface runoff, to predict the occurrence of destructive floods and design an early warning system for emergency management. The model was applied to two Wadis in southwestern Saudi Arabia. The study aimed to apply the model in Wadis that do not have gauging stations, as is the case in the current study area. He found that it is possible to apply the model in other similar Wadis.

Suleiman (2011) studied the hydro geomorphological controls of the 2010 torrent of the Wadi Al-Arish basin (NE Egypt) using GIS, where he estimated the varying extent of the response of the sub-basins to the run-off, the possibility of torrential occurrence, their ability to recharge the underground reservoirs, and arranged them accordingly. In addition, he identified the sites that were highly affected by torrential floods. Finally, he suggested the most appropriate sites for the construction of dams of various types.

Shamsheer (2008) studied the causes of floods and the extent of their damages in Hadhramaut, Yemen, and recommended the removal of all barriers, whatever their type, from the places where the torrents pass in the natural Wadi streams, and to work on cleaning these Wadis periodically. In their search for mapping torrential hazards in Wadi Al-Laith, southwest of Saudi Arabia, the researchers recommended the construction of some dams and barriers at the confluence of the tributaries of the fourth order with the tributaries of the fifth order, to protect from torrential rains and to gain benefits from the water (Bajabaa, Masoud & Al-Amri 2013). Bentaher (2022) discussed Flood Estimation in the Al Qattara basin, in Benghazi- Libya, depending on the morphometric analysis and the US Soil Conservation Service (SCS) model. She recommended designing a rainwater drainage network in the city in addition to using the integration of remote sensing and geographic information systems techniques to study the morphometric and hydrological characteristics of drainage basins in Libya to develop plans to reduce flood risks by creating an available morphometric, climatic and hydrological database.

There are several definitions of a natural disaster, including the profound and immediate impact of the natural environment on the social and economic system, or it is the sudden imbalance between the forces unleashed by the natural system and the forces confronting them in the human or social system. The severity of such disequilibrium depends on the relation between the magnitude of the natural event and the tolerance of human settlements to such an event (Alca´ntara 2002).

It is noted that the natural disaster consists of two parts: the natural factor (the natural system), and the human system, or in other words, the natural causes and ways of human response to them. Some authors refer to the term (vulnerability) to express the weakness of the natural system in terms of causing disasters, as well as the weakness of the human social and economic system's intolerance of these disasters, or the way it responds to them (Alca´ntara 2002). This is what

happened in the case of Ghat in June 2019.

Disasters are usually classified into several types: in terms of speed, they are divided into sudden and slow, and in terms of cause, they are divided into natural, technical, and human (Vilímek 2009). What happened in Ghat is certainly a natural disaster in terms of cause and sudden in terms of speed.

When torrential rains swept through Ghat town and its neighboring lands at the beginning of June 2019, the local municipality declared Ghat a disaster-stricken town, as it had been subjected to an unprecedented disaster. This necessitated the influx of aid from all parts of the country and some international organizations.

Statement of the research problem

During the first third of June 2019, Ghat town was swept away by flash flood water caused by a rainstorm that lasted for about ten days. This water inundated most of the town's neighborhoods and caused severe damage to the residents and their property.

The research is concerned with clarifying the reasons for the floods invading the town, determining the paths of the torrents and the wadis that caused them, and showing the relative importance of each of these wadis in affecting the town and causing the disaster. By using remote sensing techniques and geographic information systems, the research clarified the results or the effects of these torrents on the town and its surroundings.

In order to clarify the problem, the study focused on the following questions:

1- What were the reasons of the floods?
2- What were the factors that magnified the disaster in Ghat town?
3- Where from the water inundated the town came.
4- Which are the Wadis affecting the town, and what is the relative importance of each of these wadis in causing the disaster.

Research Goals and Importance

The research aimed to reach a scientific logical analysis using the latest methods, such as analyzing satellite images and DEMs, to understand the causes of the flood disaster in Ghat at the beginning of June 2019, to be able to develop solutions to confront it in the future.

The research provided a scientific analysis of the reasons for the floods which inundated Ghat town and used remote sensing techniques (DEMS analysis) to determine the streams of wadis affecting the town, and (MNDW) to calculate the areas affected by torrential water and the quantities of that water. Thus, the research acquired theoretical importance represented in the use of modern technologies, in addition to the practical importance of developing useful solutions to an existing and potentially recurring problem.

Research Methodology, tools, and Procedures

The research depends on the analytical approach in analyzing satellite images and digital elevation models (DEMs), extracting wadi basins and their paths, determining their drainage networks, ranks, and overflows, in addition to calculating the quantities of water that drained into the town at the time of the disaster and the area of its spread. Therefore, the research relies on advanced computer programs to analyze satellite images and (DEMs). It also relied on the modern satellite images available for the region, especially the European satellite (Sentinel 2), in addition to (SRTM1 DEM**)** with a spatial resolution (30 m or one Arc second).

Two adjacent tiles of (SRTM1 DEM**)** were used and combined to form a mosaic covering the entire study area. Some of the hydrologic analysis was done to extract the network of stream network and drainage basins affecting Ghat town, (Relying on Hydrology tools, like flow direction, flow accumulation, watershed, and stream to feature). After that, the area required for analysis was clipped, then calculations were made on it using (Arc GIS 10.3) program.

To determine the areas that were subjected to flooding, and the paths of water flow during the flood disaster, satellite imagery was relied on from the European satellite (Sentinel 2) on June 7th, 2019, i.e. at the time of the peak of the flood, and then the combination of spectral bands (Bands 1-7) were was performed. Using the program (ERDAS IMAGINE 14)

to perform analyses and calculations on it in the environment of (Arc GIS 10.3) program. To extract the area, which was covered by the flood, the MNDWI (Modified Normalized Difference Water Index) was used because it was found to be efficient in distinguishing water and urban areas. (Gautam et al. 2015). This index was calculated by the raster calculator tool in (Arc toolbox) using the following equation:

(1) $MNDWI = \frac{Green-MIR}{Green+MIR}$

In (Sentinel 2) images the formula of $MNDWI$ becomes as:

(2) $MNDWI = \frac{Band\ 3-Band\ 11}{Band\ 3+\ Band\ 11}$

Finally, field study was used to evaluate the damages in infrastructure, in addition, to ensuring the accuracy of RS data and (DEMs).

Location of Ghat town

Ghat town is located at the intersection of 11° 10´ longitude E, and latitude 24° 58´ longitude N, in the southwestern corner of Libya near the Algerian border, (Figure 1). Ghat town, like the rest of the surrounding settlements, is located in the low parts of Wadi Tanezzuft and its tributaries, where the soil is suitable for agriculture and the groundwater is easily reachable. The depression of the Wadi Tanezzuft extends from south to north, and the height of its bottom at Ghat is about 700 m above sea level. Looking to the east you can see the Acacus Tadrart Mountains, with a maximum height of more than 1400 m, and to the west, the Tassili Na Azger Mountains extend, reaching more than 1800 m a.s.l.

The urban area of Ghat town is currently more than 8.8 sq. km. It can be divided into old town, old neighborhoods, and modern neighborhoods, in addition to open lands and green lands (Figure 2).

Geographical situation of Ghat town

Ghat town is divided topographically into two parts: the first is the relatively high part, where the old town, the citadel, and the old neighborhoods are located in the west central part. The second is the low part that extends to the east, north and south of the first part. It represents the modern neighborhoods of the town.

The current town extent of Ghat represents the natural spillway of Wadi Tahramet Azzezger, which enters it from the northwest, as well as a reserve spillway for Wadi Tanezzuft, which enters the town from the south, in cases of extreme flow, when its northward course is unable to drain all the quantities of water flowing into it from its southern tributaries. That is why part of its water goes to the Ghat overflow. In this case, the lower parts of Ghat turn into a lake until it evaporated, that which eventually turned these parts into a sabkha (marshland). This is the reason for the salinity of the soil in those parts of the town, and therefore we find that it was not cultivated since ancient times (Dinosaury 1967).

The ancient town of Ghat was built on the southern slope of a hill called locally (Mount Kokmen). When some residents wanted to move outside the old town, they established some neighborhoods near that hill, in relatively high lands, among these neighborhoods: Tadramet and Tonin (Al-Subai'i 2007).

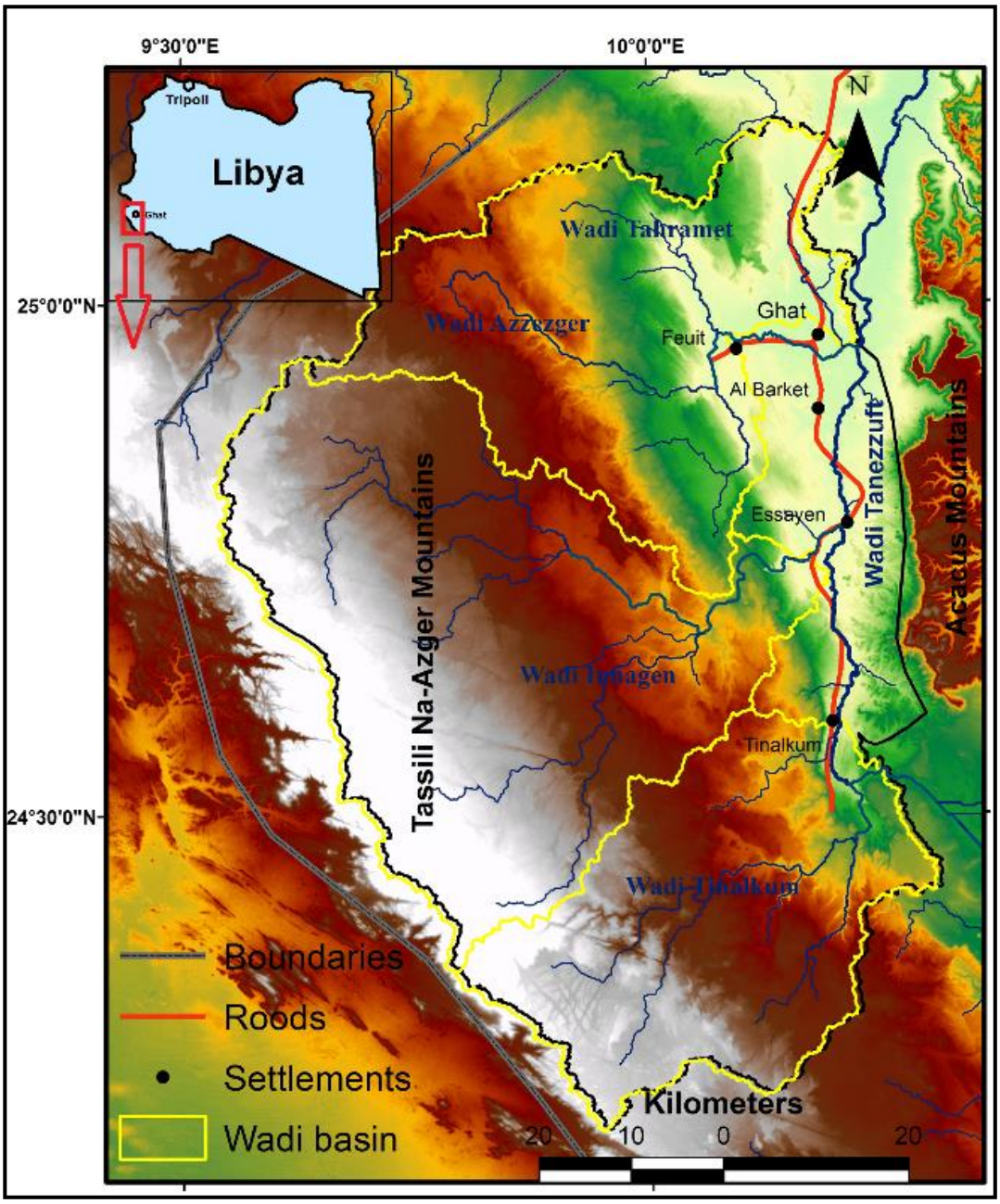

Figure 1: The location map of the research area

When the Libyan state began urban planning processes at the end of the sixties of the last century, it began to move towards the lowlands; perhaps because these lands are free of usage, and because of the ease of planning and construction in them! Disregarding the experience of the people of the region through centuries, who have never inhabited those lowlands. Most Ghat residents believe that the main reason for choosing the high place to build the ancient town of Ghat is due to its distance from the danger of floods (Al-Subai'i 2007). The awareness of Ghat residents from flood danger is evident from a study conducted in 2006, in which most of the residents of Ghat explained that the construction of the modern town in low-lying areas makes it vulnerable to floods (Al-Subai'i 2007).

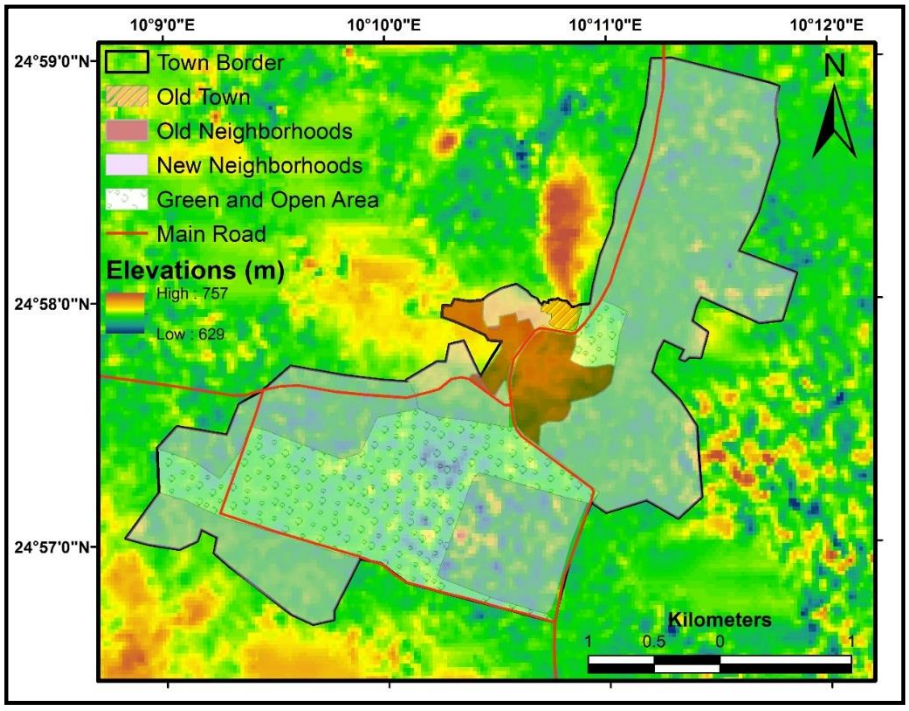

Figure 2: Ghat town boundaries and neighborhoods

The geology of the area

Rocks of geological formations belonging to three main groups cover the surface of the area (Figure 5):

1- The igneous rocks (basement) which are composed mainly of Granite are found in a narrow strip on the southwestern edge of the region on the tops of the Tassili Na - Azger Mountains above an altitude of 1600 m (Industrial Research Centre 1984). They represent the upper heads of the western and southwestern tributaries of the great Wadi Tanezzuft, such as Wadi Innaghen and Wadi Tinalkum. In addition to the steep slopes in these areas, it is characterized by extreme hardness and low permeability, so most of the precipitation in it turns into surface runoff.

2- Paleozoic formations, which start in the age of deposition from the Cambrian to the Lower Silurian, are represented in the formations of Al-Hassawna, Al-Shabiyat, Mamuniat, Melaz Shoqran, and Tanezzuft. They cover most of the study area, which is the mountainous region where the greatest runoff occurs. All of these formations consist of sandstones with grains ranging from fine or medium to coarse, with intercalations of shale and mudstone, except for the Tanezzuft Formation, which consists mainly of clay (Industrial Research Centre 1984). The most prevalent in the region is the Hassawna Formation, which covers more than 80% of its area. It dates back to the Cambrian and is located directly above the Archaean base rocks. It consists of quartzite and fine-grained sandstone interspersed with layers of mudstone (Cepek 1980), so it is the least of these formations in terms of permeability (Figure 3). It covers the western and central parts of the area, where the tributaries of the aforementioned great wadis flow in addition to Wadi Tahramet. As for the Shabiyat, Mamuniat, and Melaz Shoqran formations, their rocks consist of slightly rougher sandstone, but they are much less prevalent than the Al-Hassawna formation, as they are spread in areas of lower altitude and slope, so they contribute less to the occurrence of runoff. Tanezzuft Formation, which belongs to the Lower Silurian, consists mainly of thick layers of clay intercalated with thin layers of mudstone and fine sandstone, so its rocks are impermeable. The rocks of this formation do not allow surface water to infiltrate the groundwater, so the water stays in the low areas until it evaporates.

Figure 3: The hard, low permeability of the Hassawna Formation rocks in the Wadi Innaghen stream

3- Quaternary deposits, represented in old and recent wadi deposits, colluvial deposits, sabkhas, and water-eolian deposits. These deposits are found in depressions and wadi bottoms, and most of them have high permeability, except for sabkha deposits, which consist of fine particles of clay and sand mixed with salt. Most of the runoff in the area is shed to sabkhas, creating some ponds that evaporate completely after a short time, leaving behind the salts that accumulate constantly (Figure 4).

Figure 4: Quaternary deposits covering the bottom of the Wadi Tanezzuft, south of Al-Barket

A large part of Ghat town was built on sabkha land represented in the natural spillway of Wadi Tahramet Azzezger, and this contributed to the accumulation of water in the town until it evaporated completely during the last disaster.

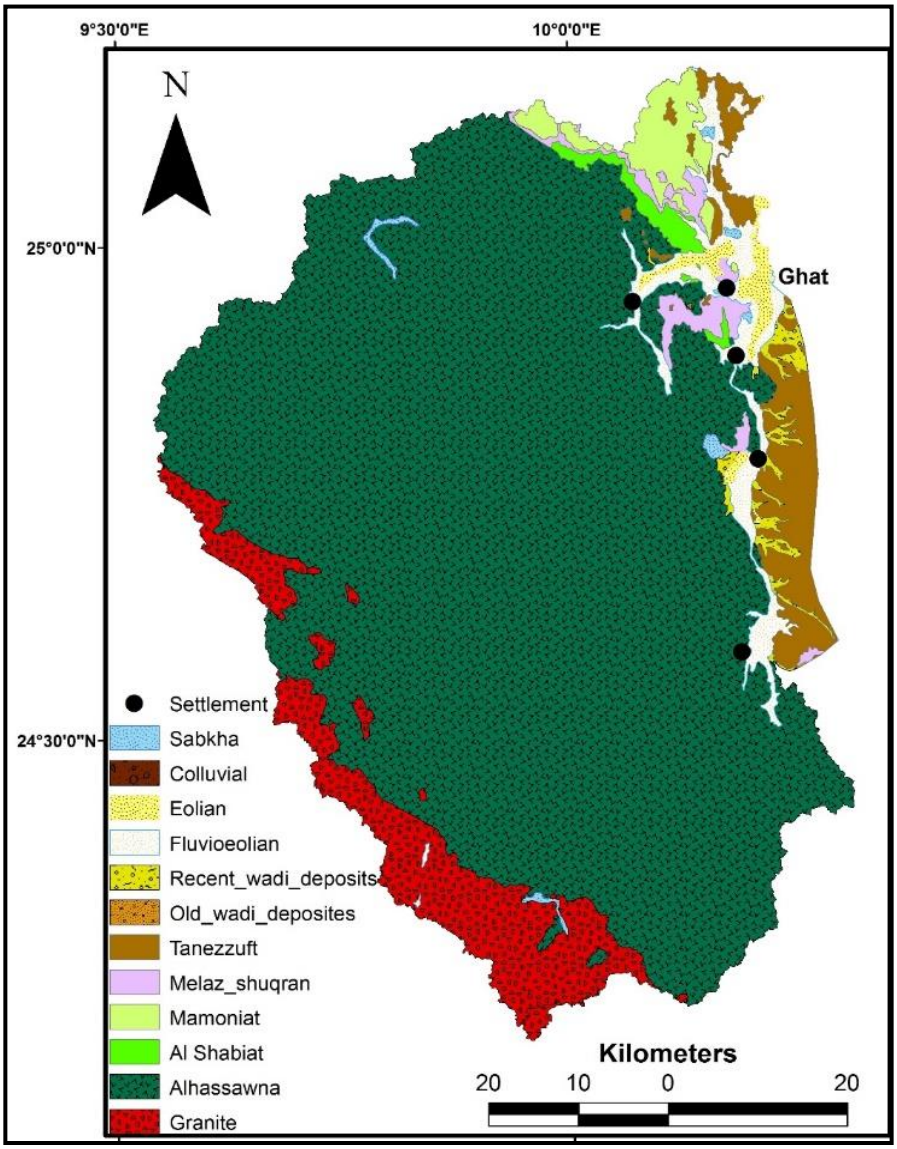

Figure 5: Geological formations and deposits covering the study area

The Wadi basins affecting Ghat town

The main Wadi Tanezzuft runs from south to north, and its main course passes to the east of Ghat town. Dozens of tributaries drain to this main wadi from the east, where the Acacus Mountains rise, about 700 m in height from the wadi bottom. These tributaries are short and have small drainage basins. They do not affect Ghat town, as for the tributaries that descend into the Wadi Tanezzuft from the western and southwestern sides, where the Tassili Na - Azger series extends with a height of more than 1000 m from the Wadi bottom, these tributaries are the ones that affect Ghat town. Because of their big drainage basins, as well as the height of their upper heads, they can carry huge amounts of water in the event of sufficient rain to run off, and the most important of these tributaries are as given in Figure 6.

1- Wadi Tahramet and Wadi Azzezger, meet before reaching Ghat near Al-Feuit village in the west. This united wadi enters Ghat town from the northwest, with a basin area reaching more than 1452 sq. km. This wadi at present is overflowing in the depression in which most modern neighborhoods of Ghat were built. Unfortunately, it cannot reach the course of Wadi Tanezzuft, which is separated from it by a sand sheet, which blocked the Wadi outlet from this spillway during recent droughts. Therefore, the Ghat depression is a natural flow for this wadi.
2- Wadi Innaghen, which descends from Tassili Na - Azger Mountains and meets Wadi Tanezzuft to the southwest of

Essayen village, with a drainage basin area reaching more than 2,212 sq. km. It is the largest tributary of Wadi Tanezzuft and the most abundant in water. Its water reaches Ghat town, Essayen, Al-Barket, and even Tahala to the north sometimes. This wadi does not affect Ghat town except in the case of an extreme runoff, when the narrow course of Wadi Tanezzuft passing to the southeast of the town cannot drain the huge quantities of runoff, and part of it overflows to the northwest entering the aforementioned Ghat overflow. Accordingly, the Ghat spillway is mainly a spillway of Wadi Tahramet-Azzezger and a backup spillway of Wadi Tanezzuft in cases of extreme runoff. This case occurred in June 2019.

3- Finally, the wadi comes from the southwest near Tinalkum village, which is farthest from Ghat and the smallest in drainage basin area and therefore, in importance. The area of its drainage basin is about 1262 sq. km, and runoff from it rarely reaches the Ghat area, except in cases of extreme runoff as happened in the June 2019 flood.

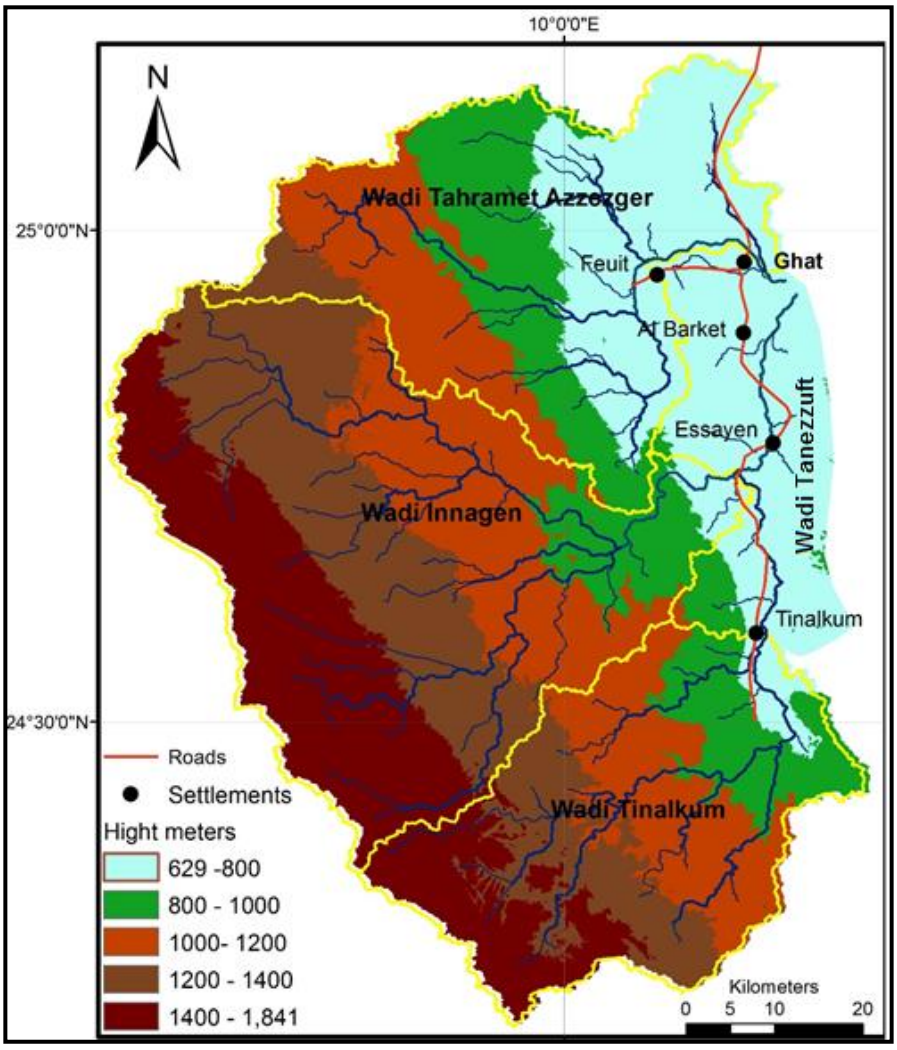

Figure 6: The Wadi basins that affect Ghat town

Conclusion and Discussion

The reasons for the flooding of Ghat town in June 2019

The amount of rain that fell in Ghat town from May 30 to June 8, 2019, amounted to about 116 mm, according to the data from the rain gauge station in Ghat town (Figure 7). This is a huge amount for a desert area with an average annual rainfall of about 10 mm (Nasser 2017). There will likely be much more rainfall in the neighboring mountainous areas, where, unfortunately, there are no rain-gauging stations. It appears through the analysis of satellite images captured for the entire mountainous area during this period that the rains covered all parts of the region, including the Tassili Na - Azger Mountains, the Acacus Tadrart Mountains, and the depression of Wadi Tanezzuft and its tributaries.

This coverage rarely happens but rather leads to local runoff, so people in the area often talk about floods coming to them without any rain falling directly over them.

Some studies that dealt with desert drainage basins indicate an inverse relationship between the area of the drainage basin and the amount of surface runoff; where it was found that most rainstorms cover only a small part of the basin surface, especially in large valleys (Suleiman 2011). This is the prevailing situation in the study area, where water often flows in one of the sub-basins and not in another, but the case that occurred in June 2019 was different, as the floods took place in all sub-basins of the drainage basin of Wadi Tanezzuft, because the rainstorm covered the entire area.

The widespread of rainfall for several consecutive days saturated the soil and rocks with water, which helped increase the risk of run-off and disaster. Floods began sweeping Ghat town on 3 June, and the amount of rain that fell during the previous four days was about 50 mm, but on 3 June, it amounted to 37 mm. Indeed that is what increased the risk of the disaster.

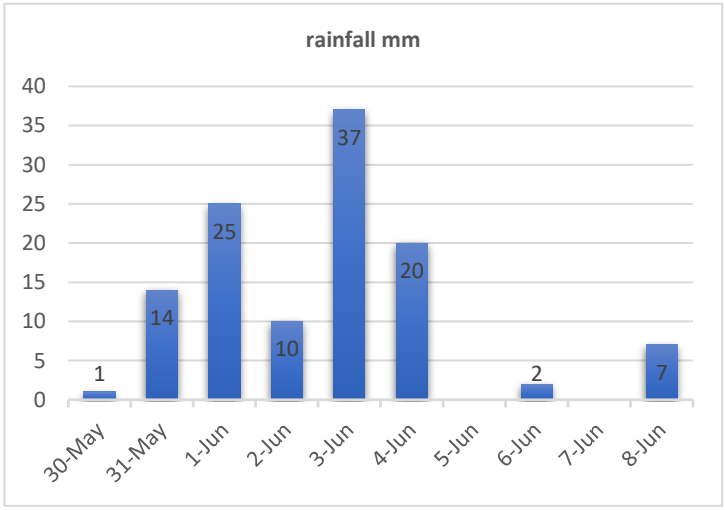

Figure 7: Rainfall amounts in Ghat town during the rainstorm. (Ghat Town Rain Gauge 2019 - unpublished data).

By analyzing satellite images and photos taken by residents, it was found that the torrents entered the town from three directions: (Figure 9)

1- The southern direction, where one of the two branches of Wadi Tanezzuft enters the town. It is the most dangerous although water rarely flows into it because it is an additional branch of the great Wadi Tanezzuft coming from the south, bringing with it the total drainage of all the southern, southwestern, and even the southeastern parts of the Wadi Tanezzuft basin. These wadis unite in one stream, which is the course of Wadi Tanezzuft. Its main course does not enter Ghat town but rather deviates from it towards the northeast at a point located southeast of Ghat and northeast of Al-Barkat. This particular point becomes the branching point in cases of extreme flow only, when the relatively narrow course of Wadi Tanezzuft fails to drain the amount of runoff in it, and the excess water overflows in the branch heading to Ghat. Residents reported that a similar situation occurred in 1966 or 1967. There is other

evidence that a similar flood occurred in Ghat in 1976 (Al-Subai'i 2007).

2- The western direction, as Wadi Tahramet - Azzezger enters the town from the northwest. Before runoff water enters the town from this direction, it is noted that it spreads widely at the bottom of this flat wadi, so water does not enter the town from one point, but enters it in the form of a sheet flood along the road out of the town towards the north as shown in figure 8. Two small valleys follow this direction, coming from the north, as detailed below.
3- The northern direction, which is the least important, due to the small basin areas of the wadis descending from it. They are wadis descending from the area around Ghat International Airport and heading south in two small courses that flow into Wadi Tahramet Azzezger, and they enter the town from its northern gate with the water coming from the west.

The MNDWI equation (mentioned above), was used to extract the area covered by floods. The results of the MNDWI analysis were between (-0.7106 – 0.4994). They were classified into two classes: covered by floodwater (0- 0.4994) and not covered (-0.7106 - 0).

As a result, torrential water flooded most parts of Ghat town and surrounding lowlands on June 3, 2019. A lake was formed with about 22 sq. km area (Figure 10). The author estimated the amount of water in this lake to be about 11 million cubic m (assuming that the average depth of the lake = half a meter).

Figure 10 showing the spread of floodwater in the town, derived from satellite images. It was found that the submerged parts are often the modern parts of the town. The flooded area reached 5.56 sq. km out of the town's total area of 8.8 sq. km (more than 63%).

Figure 8: The entry of water from the western direction of Ghat town in the form of a sheet flood

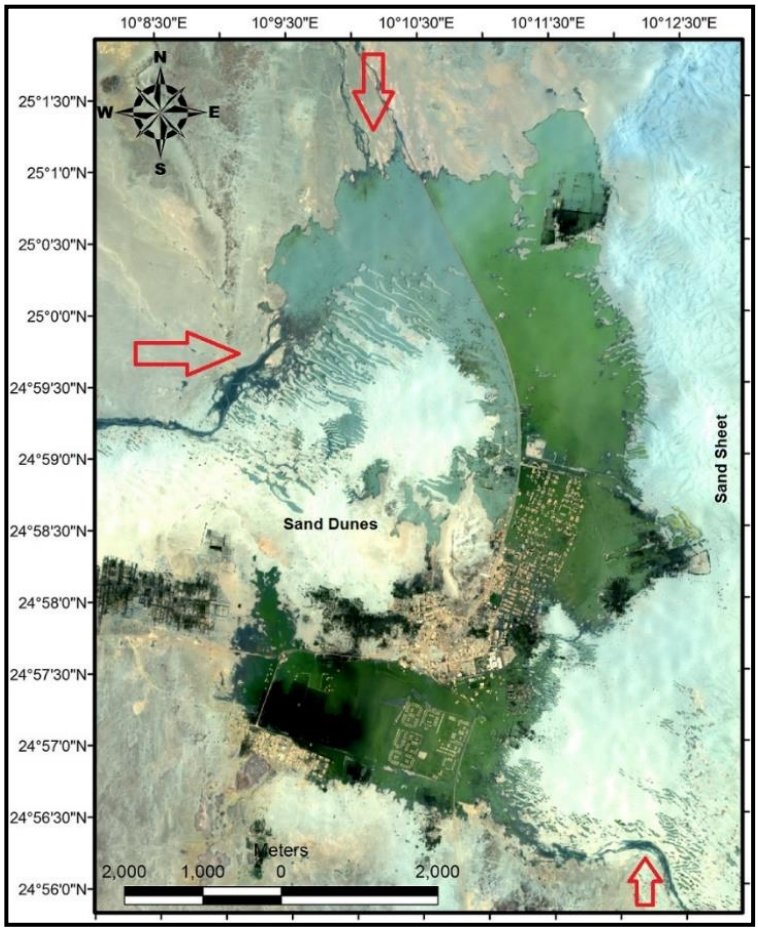

Figure 9: Directions of water entering Ghat town and the lake formed at the beginning of June 2019

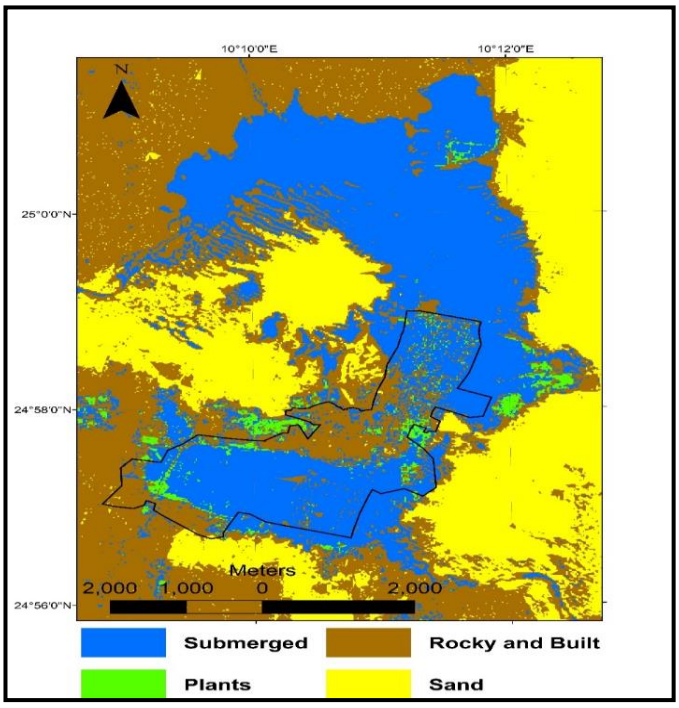

Figure 10: The areas that submerged by floods in Ghat on June 7, 2019

Most of the modern neighborhoods of Ghat town were built at the bottom of the natural spillway of Wadi Tahramet Azzezger, which is one of the largest tributaries of the great Wadi Tanezzuft. According to the analysis of geological maps, DEMs, and satellite images, it was found that the above-mentioned Wadi was able to pass through the modern neighborhoods of Ghat town on its way to meet the great Wadi Tanezzuft to the east of the town,

After a gradual drought that started nearly ten thousand years ago (Al-Hakim 1997), the sand began to invade the area and formed a relatively high barrier to the east of Ghat town (Figure 11). This sand blocked the exit of Wadi Tahramet Azzezger, towards the east, leading to the formation of a lake in the location of the current modern town of Ghat. Although the aforementioned lake began to shrink gradually until it dried totally in the last centuries leaving a marshland (sabkha), it continues to turn into a temporary lake when sufficient rain falls on the region.

As the drought became more and more severe, the lake occurrence became rare, so the recent inhabitants of Ghat town may do not remember that situation during their lifetime. Maybe that is why they began to build their houses in the lowlands although it is noted that their ancestors were more careful. The ancient people did not dare to live in the spillway, so you find all the old neighborhoods were built on hill slopes overlooking the spillway, such as the hill called locally (Mount Kokmen) on which the ancient Ghat was established and later expanded in the neighborhood of Tonin and the neighborhood of Tadramet near the old town.

Figure 11: The eastern sand sheet that separates Ghat town from Wadi Tanezzuft

What added to the flood disaster that occurred in June 2019 was that the great Wadi Tanezzuft coming from the south was subjected to a great runoff supported by synchronous torrential flow from all the southern, western and eastern tributaries, to the extent that its natural course was unable to drain the huge amounts of flow, especially when reaching Ghat. It branched into two branches, one of which took the natural course away from the town towards the northeast, and the other branch headed to Ghat town, where it entered it from the south. Thus, this branch met with the Wadi Tahramet Azzezger in Ghat and together submerged most of its parts, deepening the severity of the disaster.

Effects of the flood disaster in Ghat

Although the disaster resulted in many damages and property losses, it brought attention to the need for proper planning when building urban constructions and other human facilities in desert areas.

The damages resulting from the disaster in Ghat town can be summarized as follows:

1- The floods covered more than 63% of the town's area, and more than two-thirds of its homes, shops, and main government facilities, such as the general hospital, the municipality building, the Faculty of Education building, and most schools. This flooding resulted in many property losses.

2- The submerging of the houses resulted in the displacement of its residents to other neighborhoods and areas, which created a housing crisis that lasted for several months, for some residents. When they came back, they found most

of their tools and furniture had been completely damaged.

3- Many of the goods in the shops that were subjected to submerging during the period of the floods were damaged or completely lost.
4- The paved roads were completely or partially destroyed in the locations of the intersection between Wadis and these roads, as in Ghat - Al-Barket road, where Wadi Tanezzuft destroyed the road in two points, one of which contained relatively large hollows to drain water beneath it, but it could not bear the huge quantity of water that time. (Figure 12). The Ghat - Tahala road in the north was also severely damaged, especially near the northern entrance of the town. In other parts, the road holes increased in number and expanded in diameter.
5- The infrastructure in the electricity and telecommunication sectors was severely damaged, as communications were cut off from Ghat for nearly two weeks and the electrical network needed to be reconnected for a longer period in some parts of the town, in addition to damage in the internal networks of homes and public and private facilities.

Figure 12: The destruction of Ghat - Al-Barkat road

Results

1- The topographical situation of Ghat town, and the construction of most of its modern neighborhoods in the lowland that represents the natural spillway of two large Wadis descending to it from the neighboring Tassili Na Azger Mountains, in addition to the flooding of Wadi Tanezzuft coming from the south, contributed to the flood disaster.
2- The floods entered Ghat town from three directions almost simultaneously, these directions were: the southern direction, the western direction, and the northern direction, and this doubled the severity of the disaster.
3- The unprecedented severe rainstorm, which lasted about ten days, contributed to saturating the soil and rocks with rainwater, and maximizing surface runoff, whether inside the town or in the entire surrounding area, leading to the occurrence of the disaster.
4- During the disaster, a lake formed in Ghat and the adjacent lowlands, with an area of about 22 sq. km, and an amount of water estimated to be about 11 million m^3. The percentage of the area that was flooded with water inside the town was more than 63% of its total area. This lake lasted for several weeks until it dried up completely by evaporation. The infiltration of the depression is almost non-existent due to its impermeable silty layers soils deposition (sabkha).
5- The wadis descending from the Tassili Na-Azger Mountains, the greatest of which is Wadi Innaghen, whose basin area is more than 2,212 sq. km, are the most significant wadis that impact Ghat town (and its surroundings). This Wadi is the most significant tributary of the southern Wadi Tanezzuft and is well known for its frequent discharge. It is followed by the combined Wadi Tahramet-Azzezger, which enters Ghat from the northwest before passing to the northeast of Al-Feuit hamlet. More than 1452 square kilometers make up its basin, and the majority of the existing town of Ghat is situated within this Wadi's natural spillway. Wadi Tinalkum, the smaller one, is situated far south of Wadi Tanezzuft.

6- It was possible to use the satellite imagery from the European satellite (Sentinel 2), with a spatial resolution of 10 m and revisit frequency of 5 days, in extracting the flood areas in and around the town, as well as the directions from which the floods entered into it. It was also possible to use digital elevation models (SRTM1) with a spatial resolution (30m or 1 Arc second) in extracting drainage networks and calculating the areas of wadis drainage basins affecting Ghat town.

7- The most important results and effects of the flood disaster are the heavy losses in infrastructure; especially roads, electricity, and communication networks. Houses were severely damaged, including, furniture and furnishings. As well as vehicles and shops, most of the town's residents lost their houses for several weeks; indeed, some of them for several months.

Recommendations

The author recommends researching strategies to protect Ghat and its surrounds from future floods by preventing any new construction in flood channels and their natural spillways, as well as strengthening the town's infrastructure for rainwater drainage.

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