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Implementation of Remote Sensing and GIS Techniques to Study the Flash Flood Risk in Tanezzuft Valley, Libya

Akram Abdulsalam Alkashih¹ Ans Mohamed Elmeshri¹ Salem Mahmoud Abdulla¹
Emhemed Mohamed Abdallah¹

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Authors affiliation:

The Libyan Center for Remote Sensing and
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elkaseh1972@gmail.com

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ABSTRACT

The Tanezzuft valley is located in the Southwest of Libya, and due to its fascinating location between Acacus - Tassili scraps, and sub-Saharan and northern regions, it is considered one of the largest and most important valley in the region. The valley is characterized by the extension of its basin from south to north for a distance of approximately 185 km, and many important parts of its drainage basins are located within Algerian territory. On this valley, there are a number of cities and villages including Al- Barakat, Thala, Al-Fuwait, and Ghat, which were exposed to a heavy rain and flash flood in June 2019, resulting in the destruction of many houses, roads, farms, and the displacement of thousands of citizens. This paper discussed the role of geographic information systems (GIS) techniques and tools in understanding the geomorphology of the valley especially in which Ghat is located, the risks of rain and flash flooding in the region, and proposed some technical solutions to mitigate the influence of the flood. The GIS analysis revealed that watersheds (3,4,5) have the main impact on the water surface and flooding in the valley, and all the modern cities are located at the lowest elevation inside the valley. The techniques helped to define proposed dam locations as well as to propose the geographical location of the destructive dams at some wadi streams. The study's findings and the final maps can be used to develop some solutions to reduce flood risks in the study area, such as the establishment of dam plans to reduce torrent flow, as well as the preparation of an urban plan for the area to avoid areas of rainwater flow and flash floods.

استخدام تقنيات الاستشعار عن بعد ونظم المعلومات الجغرافية لدراسة مخاطر الفيضانات المفاجئة في وادي تانيزفت، ليبيا.

أكرم عبدالسلام الكاسح ، أنس محمد المشري ، سالم محمود عبدالله ، احمد محمد عبدالله

يقع وادي تنزويفت في جنوب غرب ليبيا، وبفضل موقعه الاستراتيجي بين هضبي أكاكوس وتاسيلي يعد من أكبر وأهم الوديان بالمنطقة. كما يتميز الوادي بامتداد حوضه من الجنوب إلى الشمال لمسافة تقارب 185 كم، تقع العديد من الأجزاء المهمة من أحواض تصريفه داخل الأراضي الجزائرية، ويضم عدداً من المدن والقرى مثل البركيث، ثهالة، الفويت وغات، التي تعرضت لأضرار عذبة وفيضانات مفاجئة في يونيو 2019م، مما أدى إلى تدمير العديد من المنازل والطرق والمزارع، ونزوح آلاف المواطنين. تناولت هذه الورقة دور تقنيات وأدوات نظم المعلومات الجغرافية (GIS) في فهم جيومورفولوجية الوادي خاصة المنطقة التي تقع فيها مدينة غات، مخاطر الأمطار والفيضانات المفاجئة في المنطقة، وساهمت التحليل في اقتراح بعض الحلول التقنية للتخفيف من آثار الفيضانات. وتبين من النتائج ان أحواض التصريف (3، 4، 5) لها الأثر الأكبر على المياه السطحية والسيول بمنطقة الدراسة، وأن جميع المدن الحديثة بالمنطقة تقع بقاع الوادي، كما ساعد استخدام التقنيات في تحديد افضل مواقع للسدود المقترحة، وتحديد اماكن السدود التعويقية بمجري الأودية.

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INTRODUCTION

Floods are considered one of the most devastating natural hazards that can cause significant and widespread damages, loss of human lives, and losses of agricultural and livestock wealth wherever they occur, Maskong (2019). There are a number of types of floods and their causes that may occur in urban areas, the most important of which are river floods due to heavy rain or snow, seawater floods due to tsunamis and high tides, mountain torrential activity due to a lake outburst or the collapse of a river stream, and lake floods and water underground floods due to increased water levels, Boyvalenkov (2011).

The Great Ghat region, located at the basin of Tanezzuft valley, exposed to heavy rain in the first days of June 2019, resulting in flash flood in the cities after these rains fell on the southwestern region of Libya and the southeastern region of the state of Algeria. The flash flood caused the destruction of some homes, the displacement of thousands of residents, the damage to a large number of farms, and the destruction of roads in the city, as shown in the pictures in Figure (1).



Figure (1): Photos from the Ghat city after the flash flood (top), Water surface is generated by MisBar platform from Sentinel 2 imagery on 5-June-2019 (Bottem).

According to Abdallah (2019), morphometric analysis is an important tool to provide quantitative expression of drainage basins, and is providing simple and accurate measurements to document the drainage systems and all aspects of the drainage networks. It establishes evaluation parameters for the hydrological system's behavior and brings out the basic characters of the river basin which would be helpful in understanding the hydrology. The morphometric analysis are defining, measuring and

analyzing the quantitative indices related to flow plane geometry, and bed form of river basins (Azzam 2019, Abdallah 2022) .

Remote sensing RS and Geographic Information System GIS are essential tools for geomorphological analysis. In addition of using geomorphology and geology, RS and GIS can contribute to develop a primary hydrological diagnosis that can be employed to forecast drainage basins behavior during heavy rainstorms, Mohamed (2019). The HEC-RAS tool along with GIS have become the key tool and have played an important role for flood modelling and monitoring, and in understanding various flood scenarios and expedite the location of areas that are likely to flood, and can support an effective quick response to emergency management and flood risk assessment (Pallavi H & Ravikumar 2021, Manamno 2023).

LOCATION OF THE STUDY AREA

This study was conducted in the South-eastern part of Libya, the bottom of Tanezzuft valley and surrounding mountains are located between latitudes $24^{\circ} 16' N$ and $25^{\circ} 85' N$ and longitudes $9^{\circ} 23' E$ and $10^{\circ} 31' E$ as show in fig. (2).

The study area covers around 11,260 square kilometres, and it is generally hot for most of the year, averaging from $10^{\circ} C$ to $34^{\circ} C$ during the day and cooler after sunset.

The study area is considered one of the dry areas with rare rainfall, and there is no seasonal rainfall system during the year. Through rainfall data for previous years, it was found that rainfall in the region is concentrated on a few days of a particular month. The absolute range between the highest and lowest temperature for the day and month as well as the shortage of the rain has a significant geomorphological impact.

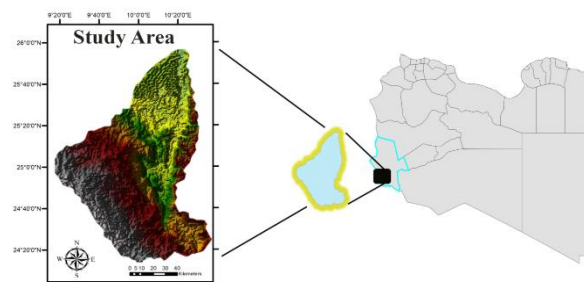


Figure (2): Location of the study area.

The rocks of the Archean base (granite), which are very hard rocks from the Ordovi-cian and Cambrian periods that spread on the south western edge of the Tanezzuft valley drainage basin and represent the upper sources of the valley's tributaries, and cover a large area of the valley basin, make up the geology of the western mountain range. Between the Archean base rocks and the Quaternary sediments that cover the valley's belly, which date from the first geological period, Ahmed (2017).

From the longitudinal sector of the Tanezzuft valley basin (fig. 3), we can see that the high areas southwest of the basin are made up of granite and gabbro rocks and are very steep, causing a rush of water. It pours heavily and quickly, reaching a height of over 1800 meters above sea level. The mudstone rocks extend from a formation that bleeds beneath the sediments of the valleys through which it runs, resulting in the earth's inability to absorb the water that flows in the valley quickly.

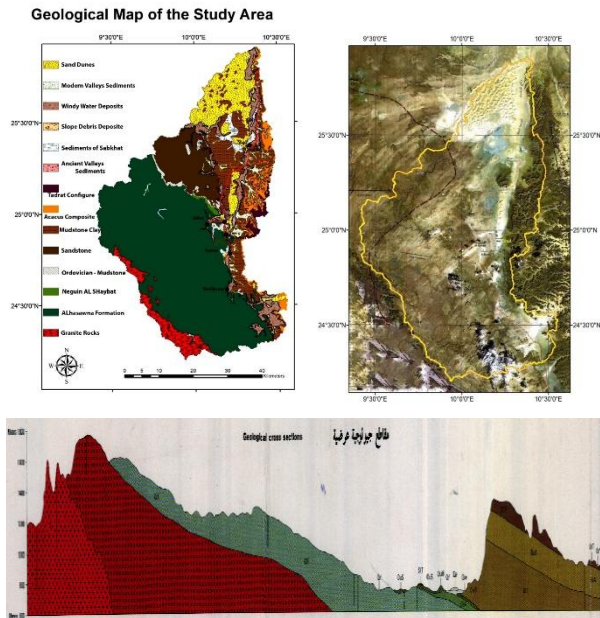


Figure (3): Geological map and a cross section of the study area, Ahmed (2017).

MATERIAL AND METHODOLOGY

To achieve the study's objectives, we used the following procedures including:

- Gather of the theoretical dataset by reviewing sources and references, including geographical, climatic, and geological data for the study area.
- Use Spot 6 satellite imagery and obtaining a Digital Elevation Model (DEM) with spatial resolution 12.5 meters, this DEM was taken from ALOS PALSAR produced by (ASF).
- Employ the GIS software tools (ArcGIS 10.8) for hydrological analysis including drainage networks and morphologic characteristics, database preparation, and map production.
- Use the morphometric equations for determining the ratio of elongation and roundness of the basin, the gear ratio, the density of river drainage, the river frequency, the bifurcation ratio, the shape coefficient of the basin, the roughness value, and the calculation of ranks and tributaries, Abdallah (2022).
- Generate Rainfall-rainoff hydrographs using HEC-HMS software.

- Generate flood plain maps using unsteady simulation by HEC-RAS (v. 6.5) for estimating the approximate amount of damages in the study area.
- Use ArcGIS 10.8 to calculate and evaluate the catchment areas, and dam sites location.

RESULTS AND DISCUSSION

Hydrological Analysis of the Study Area

Baseline morphometric information at a sub basin level is essential to develop appropriate strategy for sustainable, and knowing the watershed geometry characteristics include watershed area, watershed length, and watershed circumference measurements is the initial step in the extraction of morphometric features.

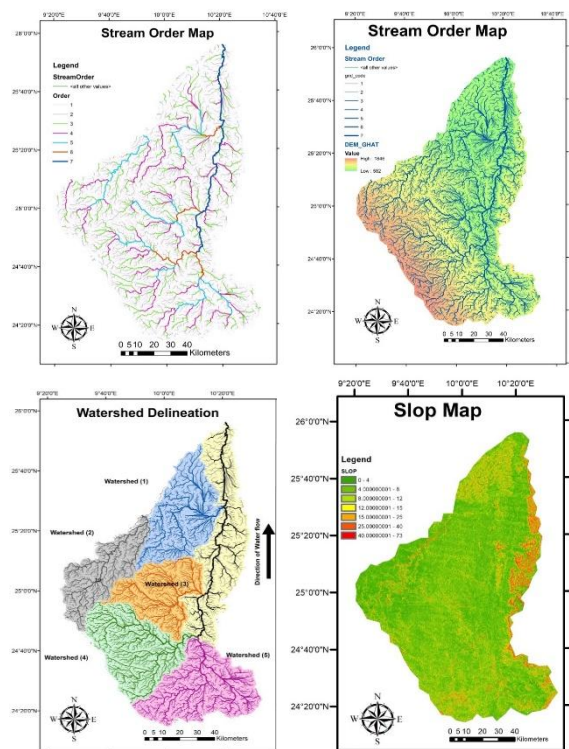


Figure (4): Watershed delineation, slop map, and stream order and elevation of the study area.

The basin area is defined as the area of the basin that supplies water to the tributaries, it is important as a morphometric variable due to its impact on the volume of water discharge within the basin. In this study, the basin has a total area of 12,882 square kilometres.

The basin length is one of the key variables that influence many other aspects of the drainage basin, the most important of which is the basin's shape. The shape of the basin is influenced by several factors and processes, the most important of which are tectonic and structural factors, and retrograde induction processes, the basin is approximately 184 kilometres long.

The width of the drainage basin plays an important and complementary role. The width of the basin influences hydrological processes in the basin by influencing the

amount of accumulated rain, surface runoff, seepage, and evaporation, the basin is approximately 78 kilometres wide.

The slope is uneven surface vary in angles between the basin surfaces and the horizontal plane, it is also known as open geomorphic systems in which rain collects and produces the running water. The slop map (fig. 4B) has shown that slopes of the Tanezzuft valley’s basin range from 0 – 72.3.

The speed of surface water flow and the amount of drainage are directly affected by the shape and severity of the slope, knowing slopes are importance because of their relationship in determining the shape of the surface basin and the water drainage system.

The studies of water drainage network characteristics can gives a clear picture of the nature and hydrology of the water basins, and also reflect of the natural conditions represented by the geological structure, the nature of the rocks, terrain, and climate characteristics. The drainage basin, according to the Strahler 1957 classification, includes a number of streams and their distribution pattern; the drainage basin in our study has a stream order of seventh rank (fig. 4C).

More details on geometric characteristics (watershed shape, rotation rate, elongation rate), topographic characteristics (erosion ratio, riverbed constant), and morphometric characteristics (stream classification and length, bifurcation ratio, drain density) of the study area can be found at the reference .5.

Flood Susceptibility zones Simulation Using HEC-RAS

The study area has witnessed a rarely flash flood due to a heavy rain in six consequences days, the rain and the flood have displaced people and destroyed many houses, farms and infrastructures of the Ghat city and other villages placed in drainage basin of the Tanezzuft valley. It is important to study these events and use the techniques and models for flood risk assessment and mitigation. Flood modelling has evolved into a crucial instrument in the management of flood risk, assisting academics in comprehending and predicting the behaviour of floods, as well as making defensible choices to lessen their effects. In addition, rain data including duration, intensity, and distribution, and surface runoff are important factors in the transport system of various materials that will be carried into river flows. If the intensity of this rainfall exceeds the infiltration rate, then excess water begins to accumulate as surface reserves. When the surface reserve capacity is exceeded, the surface runoff begins as a thin layer flow. Surface runoff is the part of runoff that passes above the ground surface into river channels, Adynata (2022).

There are five watershed sub-basins at Tanezzuft valley as show in (Fig. 4A) with a difference in elevation of 1,264 meters. For the purpose of this study, we will only use the three sub-basins that have effect on the city of Ghat in case if there is a flash flood in the region.

We downloaded rainfall precipitation at the study area at the desire dates from NASAPOWER website (<https://power.larc.nasa.gov/>) as shown in fig. (5).

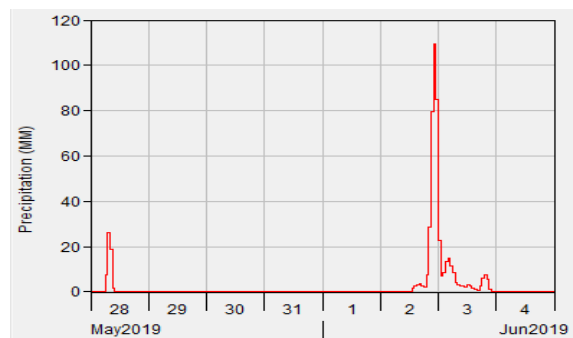


Figure (5): precipitation hydrograph of the event.

HEC-HMS was used to delineate the watersheds, and calculate the hydrograph (discharge vs. time) for well patterned rainfall intensity from watershed area (3) and (4&5), GIS parameters such as identify stream area of 20km², and calculation time interval of 1h were used. Method such as the SCS curve number method with estimated CN=78, and parameters including calculated lag time (eq. 2) were used to control the overall simulation. The results are shown in fig. (5).

$$T_c = \frac{L^{0.8} \times (1000/CN-9)^{0.7}}{1900 \times S^{0.5}} \tag{eq. (1)}$$

Where,

L is the length of the longest flow path in the sub basin.

CN is the curve number.

S is the slop in the sub basin.

$$T_{lag} = 0.6 T_c \tag{eq. (2)}$$

1. HEC-RAS 6.5 software was used to analyse the water level at the drainage basin, and to simulate flood plain and ensuring inundation areas. The basic computational procedures to simulate the water flow are based on the solution of conservation of mass, the energy equation, and the momentum equation (HEC-RAS User’s Manual V 6.5. March 2024.)

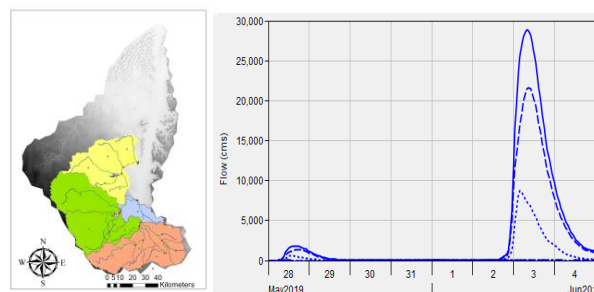


Figure (5): HEC-HMS hydrological analysis (left), Hydrograph profiles for watersheds3 and 4&5(right).

We used unsteady flow analysis method to simulate the flood plan, 2D flow area was drawn by demarcating a

polygon around the river basin and the flood plains, computation cells of size 40m by 40m were created inside the 2D flow area, hydraulic properties of each computation mesh were calculated, boundary condition lines were drawn at upstream reach (Inflow) and downstream boundary condition was drawn at the outlet in the arc-map window. Flood hydrograph was assigned to the upstream boundary conditions whereas normal depth was assigned to the outflow boundary condition with a friction slope of 0.05. The resulted hydrograph profile from HEC-HMS for watershed (3) and watershed (4&5) were used as upstream flow hydrographs at HEC-RAS software.

For stability simulation, we selected in the advanced time step control the flowing values:

Maximum courant: 3.

Minimum courant: 0.5.

Number of steps below minimum before doubling: 4.

Maximum number of doubling base time step: 4.

results are shown below (fig. 6).

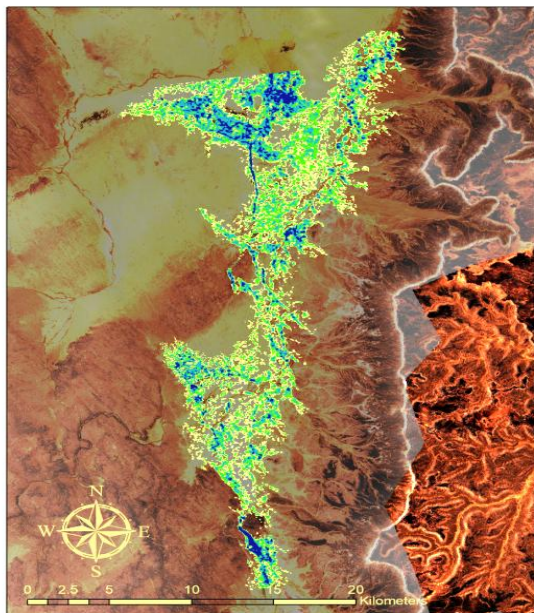


Figure 6: Water depth on study area by unsteady state simulation.

Rainfall in a watershed can turn into a river flow, this is depends on the peak flow discharge which is dependent on the watershed's parameters, the evaluations of rainfall – runoff analysis contributes to the mitigating disaster and decision making for sustainable water resources management.

The results from precipitation on grid model in HEC-RAS based on the data from NASAPower have shown a very small runoff at a certain areas at the watersheds as shown in fig. (7), It also shows the flood inundation maps for the city of Ghat where around 84% of the city was immersed, and 78% of Al Berkit valley was immersed.

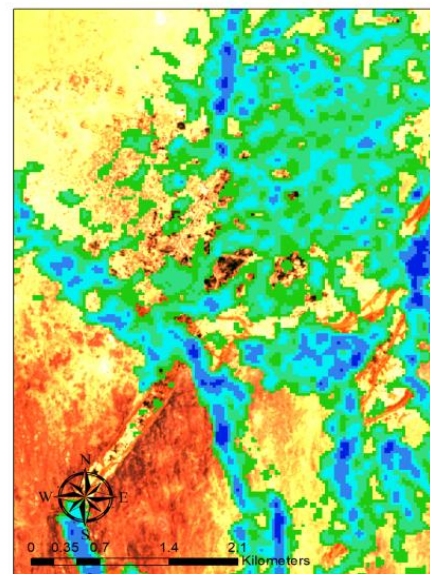
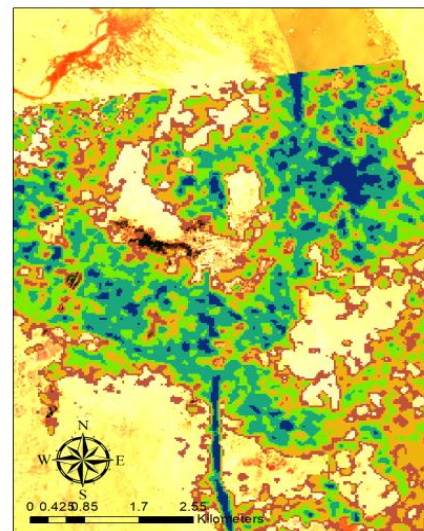


Figure 7: Flood inundation map for rain precipitation in Ghat (Top), and Al Berkit (Bottom).

The depth of water surface varies from 2.8m to up to 18m at some places near the city of Ghat as well as some places on the river basin. The results shown the cities of Ghat, Alfiut, and Albirkit are all in the risk area of any future flood events.

The amount of infiltration depends on soil type and its water, land use, vegetation cover. In the study area, most of the soil at the watersheds and river basin are clay loam and have slow infiltration rate, consequently resulting in a very high surface runoff rate.

Dam suitability sites:

One way to mitigate flash flood risk is to store rainfall water by construct dam at suitable locations in the watershed. ArcGIS tools are powerful elements for simulate and calculate the water reservoir parameters, using stream order and contour layers, added feature classes.

Figure (8) shows some selected dams locations, and table 1 shows the dam’s parameters.

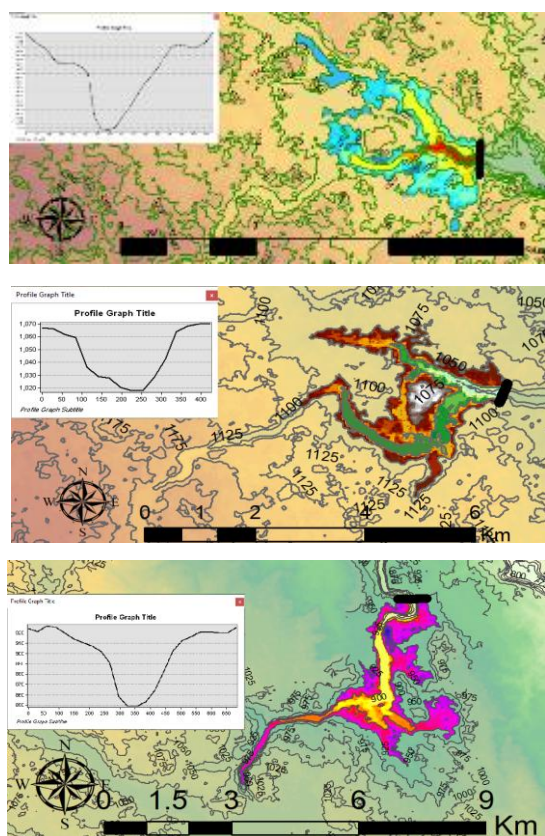


Figure 8: Suitable dam sites simulated by ArcGIS.

Table 1: Selected dam’s parameters.

Dam No.	1	2	3	4	5
Main watershed No.	5	4	5	4	3
Contour (m)	850	925	1100	1075	825
Dam width (m)	220	395	530	280	320
Dam Height (m)	6	70	88	48	65
Watershed Area (km2)	201.575	5.482	5.514	4.813	1.041
Dam Capacity (Million m3)	592.765	103.669	102.111	82.893	20.633

Dam can help by storing rainfall water at the catchment areas and reducing the amount of water rain off in the river basin. In this study, the drawback of construct dams are the cost especially at rural area, most of the dam’s locations were in the Algerian territory, and the rare occasion of the extreme flood events.

Destructive dams are stone barriers designed in an engineering manner with the aim of conserving soil and water and reducing the speed and the amount of the surface water flow, they are considered as one of the most effective methods used in dry valleys with low rainfall due to its financial cost, its simple and they do not require high technology or huge resources when constructing them fig. 9.

The water reserved behind dams gives residents of dry and semi-arid lands valuable opportunities to establish agricultural and pastoral activities.



Figure (9): Destructive dams.

After the study of the geological structure, the soil characteristics, and elevation and slope of the main river basin of Tanezzuft valley, we have chosen location of twenty nine destructive dams as shown in fig. 10 which can reduce the flash flood risk on the river basin, they are distributed as following:-

- Thirteen dams south of the Ghat city, as the area is open, and mostly flat, the two ends of the dam reach an area with a height of more than 720 meters (yellow areas), the length of the dams, as shown in the map, ranges from 750 to 1850 meters.
- Six dams can be located at the north of Ghat city on the main fifth order stream. The length of the dams varies from 700 to 3400 meters, reaching both ends.
- Ten dams can be located at west of Ghat city on one of the sixth and fifth streams of the valley, extending from west to east towards the city of Ghat and mitigating the flooding in the city of Ghat, the length of the dams ranges from 550 to 1200 meters.

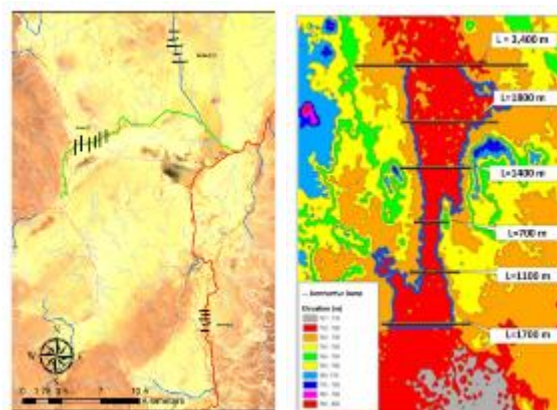


Figure (10): The proposed destructive dams on Tanezzuft valley.

CONCLUSION

We discussed in this paper the contribution of RS and GIS in study the flash flood event on Tanezzuft valley, the morphometric analysis and classification of seven sub-basin of the valley catchment were implemented using a 12.5m DEM. Using GIS techniques, the generated slop and watershed geometry characteristics helped to define the rain-off paths and patterns in the study area using

HEC-HMS, hydrograph at the inflow for watershed 3,4, and 5 was successfully simulated.

The software created models from the HEC-RAS simulations are extremely useful in determining the extent of floods, associating high flood levels, and generating flood plain maps that can be used in urban planning or estimating the approximate amount of damages.

Integrating HEC-RAS hydrologic modelling tools with ArcGIS software helped to map the flash flood Susceptibility zones, the simulations have shown of cities and villages including Al- Barakat, and Ghat are located in the flood risk zone with surface water depth ranged from 2.8m to 18m, and it has been analysed that flood effects are extended to agricultural lands at maximum. However, results could be better when accurate climate and on-ground data were used.

Enhancing flood risk assessments can be achieved by essentially integrating GIS with comprehensive hydrological and meteorological data, and utilizing the geospatial techniques for simulation of flood scenarios (based on different weather conditions) is a powerful tool in predicting potential flash flood events, in empowers communities, building resilience, and agriculture areas changes through increased awareness, and in post-disaster verification of mapped floodplain extents and depths.

Dam characteristics and suitable sites were achieved by using ArcGIS tools, we noted that the bigger water reservoir behind dams are located on watershed 4 and 5, this could be due to their morphologies compare to watershed 3. The proposed destructive dams may not be practically used, as their length exceeding 300m.

Finding results and maps could be useful tools to decision making to mitigate any future coming extreme events in the study area, and for flood risk management strategies. Besides, the outcome of this paper can be used as a start of any further studies in future.

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