

River Flood Modelling For Flooding Risk Mitigation in Iraq

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Abstract

River flood events have recently been increased due to many reasons such as climate change and excessive land usage. Thus, one of the greatest challenges is to control the flooding in urban areas. River flooding has become a phenomenon worldwide in general and in Iraq specifically. This is associated with the rapid increase of urbanization as well as mismanagement of land utilization; especially those located near the river banks, in addition to lack of consideration in terms of the design and implementation of drainage networks. In Iraq and especially in Al-Anbar governorate, studies in the field of flood simulation control have been rare. This study aims to suggest a fast and accurate methodology for local authorities, by providing a proposed solution and prediction of flooding area in the case study of the Fallujah barrage. Global Mapper software has been used to produce simulation photos on flooding area. Earth Explorer USGS website has been used to download water body data; and Global Digital Surface website has been used to extract and download the surface elevation data. The result of the simulation photos has predicted valuable information about the flooding area and proposed a general vision on the areas that are under threat of flooding. Four main areas were exposed to flooding, area 1, area 2, area 3, and area 4; A total flooding area of 11.89 km². The total maximum operational level for the barrage was designed to be 44.79 m above sea level. Also, the recommended maximum operation level for the barrage was 43 m ASL.

Keywords: Global Mapper; Flooding Simulation; Water Resource Management; Fallujah Barrage.

1. Introduction

River floods can be classified to be the most expensive and damaging disaster that affects many countries worldwide. Flooding occurs when the river water level rises and exceeds its total storage capacity, pushing the excess water over the banks, submerging the low-level land, causing a significant loss of human life, resulting in a negative impact on the population. In addition to loss of life, floods cause environmental, economic, and social impacts, as well as damaging the infrastructure, vegetation, animals, and influencing the spread of disease [1].

There are many contributing factors that cause river flooding such as heavy rain, melting snow, and extensive use of land (urbanization), which plays a crucial factor in river floods' impact. This extensive use of land has led to an increase in the impermeable surface area, resulting in higher runoff rates [2]. In addition, global warming and changes in precipitation have led to unexpected seasonal rainfall, particularly for the Middle East, when compared to other

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regions of the world [3]. The region of Iraq is considered one of the most vulnerable countries to climate change in the Middle East. Iraq has been through years of wars and conflicts and mismanagement that have put the people of Iraq at risk, and made them extremely vulnerable to any sort of natural disasters. Therefore, it has been projected that the effect of rainfall and flooding could be the worse in this area [4].

Due to the rapid increase in population, many agricultural areas are being utilized as residential areas especially; those that are close to the river banks and under the threat of flooding [5]. Iraq is considered one of the poor and developing countries where there are challenges in finding water data as well as the research studies in the water resource area have been rare and limited [6]. Therefore, finding a fast and accurate methodology to simulate the expected flooding area is an essential tool for effective mitigation and precautions planning.

Flood modelling of urban areas in developing country has not received adequate consideration, and is becoming an emerging event in the flood risk literature. Urban floods in developing countries are mainly characterized by fundamental factors, which seem to present limitations and knowledge gaps towards their analyses in the context of developing countries. First, the means of representing the hydrological, climatic, and human factors that drive urban flooding in these regions are complex, particularly in the formulation and solution of shallow water equations that underlies flood modeling [17]. Secondly, the urban geomorphology, flood hydrodynamics, and detailed topographic data are still completely inaccessible to many urban watersheds in developing countries. Finally, precipitation and river flood runoff data often required expensive tools and equipment that are not always available in developing countries [8].

Recently, solutions to these constraints have inspired the research and knowledge potential within the context of flood modelling applications. Many research efforts have been made towards enhancing flood management and analyses techniques. Table 1 provides some of the recent research modelling techniques and methodology tools that are applicable to flood risk assessment.

Table 1. Recent literature of flood modelling techniques

No.	Author(s) (Date)	Model name	Methodology
1	Chau, et al. (2021) [9]	HEC-HMS model	Use real-time data to measure spatial and temporal rainfall distribution
2	Ibeje & Ekwueme (2020) [10]	Index flood model	Use regional flood frequency curve with index flood equation
3	Ekwueme & Agunwamba (2020) [11]	Multiple linear regression model	Use meteorological variable and runoff data
4	Al-mansori & Al-zubaidi (2020) [12]	Numerical one-dimensional model	Use saint-venant equations
5	Latif & Mustafa (2020) [13]	D-vine model	Use 3-dimension vine (V, P, and D)
6	Mohammad (2019) [14]	1D flood model	Use GIS, GeoRAS, HEC-GeoHMS, and Global Mapper
7	Gharib et al. (2017) [15]	GIS ModClark model	Use GIS , flow accumulation, hyetograph data
8	Machekposhti et al. (2017) [16]	Stochastic model (ARIMA approach)	Use of ACF and PACE
9	Patel & Joshi (2017) [17]	ANN model	Use of artificial neural network

For example Chau et al. [9] used a real-time system which uses HEC-HMS model to generate a flash flood system based on bankfull discharge within 34 locations. This system showed important results in predicted real-time warning flooding, however, this kind of system is considered complex and requires expensive equipment that are rarely available in developing countries like Iraq. Ibeje and Ekwueme [10] presented in their research, the importance of using dimensionless index flood to produce flood frequency curve FFC for the area that has limited data or are seldom available. Very similar methodologies have been used by Ekwueme and Agunwamba [11] and Al-mansori, Al-zubaidi [12], and Mohammad [14], where one dimensional liner and numerical models were developed and tested in their studies. The dimensional flood models are widely adopted by researchers due to its simplicity compared to all flood models.

Machekposhti et al. (2017) [16] studied annual flowstream with two variables peak and maximum discharge for upstream Karkheh dam reservoir by using time series model. This can be achieved by the help of the Partial and Auto-correlation Function (ACF and PACF). The results showed this system is more suitable for short term flood forecasting. However, according to Latif and Mustafa [13], a three dimensional approach of using peak flow (P), Volume (V), and duration (D) can be an essential tool for flood risk assessment, due to its benefit of providing practical and comprehensive three dimensional flood variables that are applicable for long term flood forecasting.

Although Iraq is a developing country, where statistics and data are rarely available, there are some convenient flood models which can solve these constraints [18]. For instance, Gharib et al. (2017) [15] and Patel & Joshi (2017) [17] showed in their studies that the lack of availability of data can be avoided by adopting computer software for flooding simulation. For examples, GIS, Global Mapper, Artificial Neural Network (ANN), and rainfall-runoff modelling that can be used in specifically in developing countries, due to its simplicity and efficiency.

It can be summarized from Table 1 that there is no accurate flood model. Although these models are able to simulate risk flood assessment, these models have constraints that limit their applications, particularly in developing countries. Also, all above studies have never presented the flood simulation on satellites photos that will make the flood inundation modelling more visible and understandable. Thus, the objective of this study is to generate flooding simulation maps as inundation scenarios on satellite photos for the Fallujah barrage upstream side by using Global Mapper software integrated with GDS and USGS. This integration between Global Mapper and GDS and USGS can be a good tool to be used in flood modelling methodology where the data is not completely available. It is expected that the outcome of this study will enable the municipal department of Al-Fallujah city in Iraq to identify the expected flooded area. Also, it is projected that the outcomes of this study can give the appropriate barrage operation to control the water level in the upstream side of the barrage.

2. Study Area

Iraq is located in Asia in the southwest side under the coordinate (33.2232° N, 43.6793° E) with a total area of 438,320 km². According to Salman et al. [19] Iraq can be classified into four main zones based on climate and topography as shown in Figure 1.

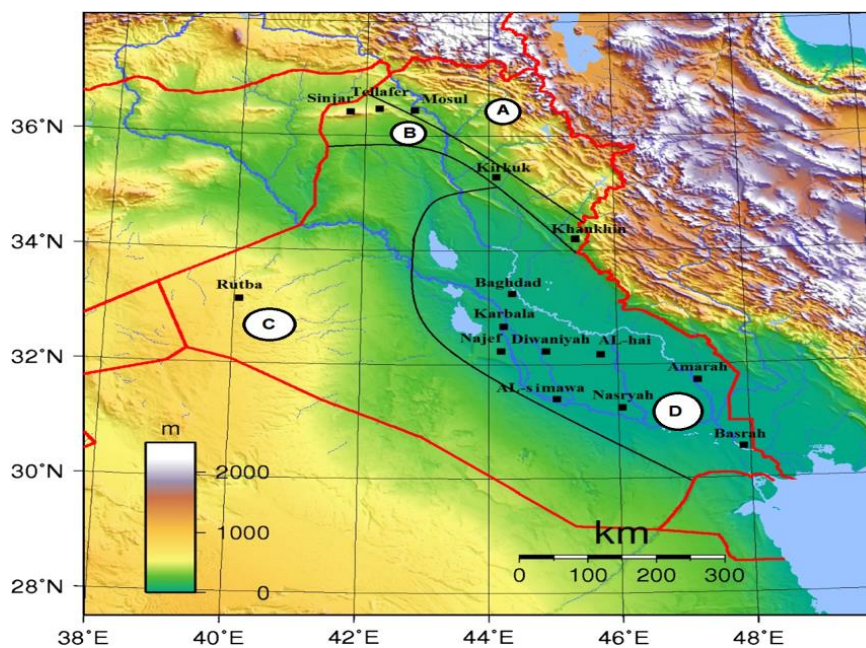


Figure 1. Climatic and topographic map of Iraq [19]

The first is zone A, the mountainous area in the North, having a Mediterranean climate and forms 21% of the country. The second is zone B in the south and the west undulating area, land having a steppe climate and forms 9.6% of the country. The third is zone C, the western plateau in the west, and is considered the extent of Arabian deserts and having desert climate, and forms about 39.2 % of the country. The last one is zone D, the great Mesopotamian land in the south and central part, having a subtropical climate and forms about 30.2% of the country [19].

The study region is Fallujah city which is located in the deep east side of Al-Anbar governorate at latitude 33° north and longitude 43° east. It is situated about 45 miles west of Baghdad city center as shown in the Figure 3 below. Al-Anbar province is considered the largest province in Iraq depending on the total land area. It has a total area of approximately 137808 km² which constitutes 31.7% of the total area of Iraq [20]. Based on population statistic website [21], Fallujah city is an urban community with intermediate population density over 350,000 people, as can be illustrated in the Figure 2. The population has rapidly increased in recent years; pushing the community to utilize the agriculture land as inhabited zones, which has led to decreasing the river bank land area [22].

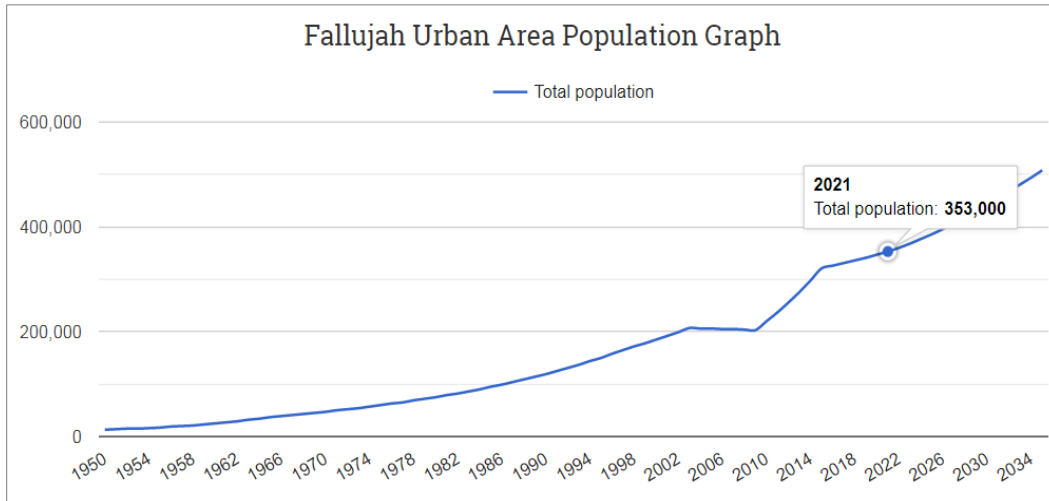


Figure 2. Fallujah urban area population graph [21]

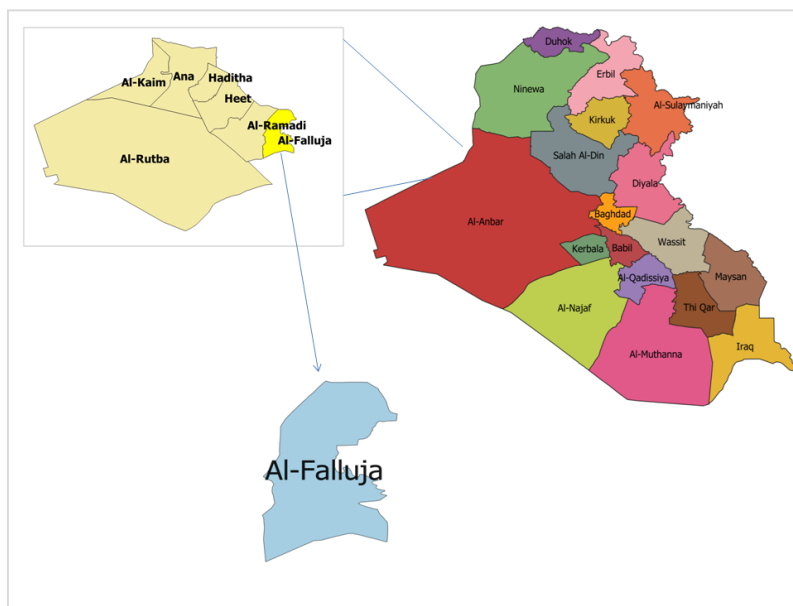


Figure 3. Study area of Fallujah city relative to Iraq map

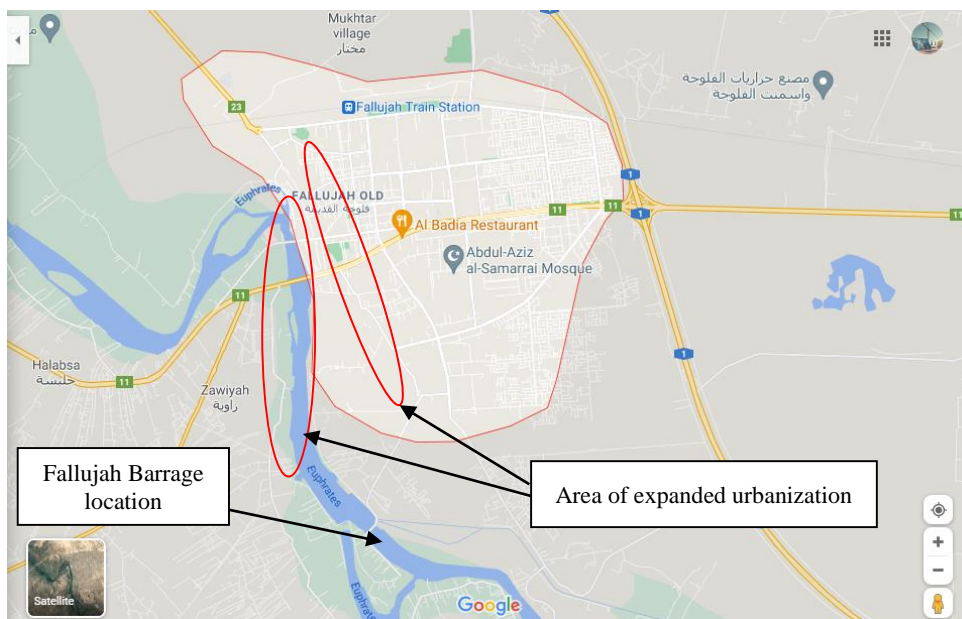


Figure 4. Falluja city map

Population expansion is occurring towards the Euphrates River which surrounds the city from the west part as shown in the Figure 4 in the areas that are highlighted in red. According to the municipality of Fallujah, these areas are considered river banks and that are under threat of flooding and are not recommended to be inhabited by people or implement for any kind of construction. Based on worldweather website [23], the climate of central part of Iraq (including Fallujah), is mostly dry with short cold winters and very dry summer, with average temperature of 48° C in summer and 12° C in winter, and average annual precipitation of 20mm. However, this number has jumped in the recent year as shown in the Figure 5.

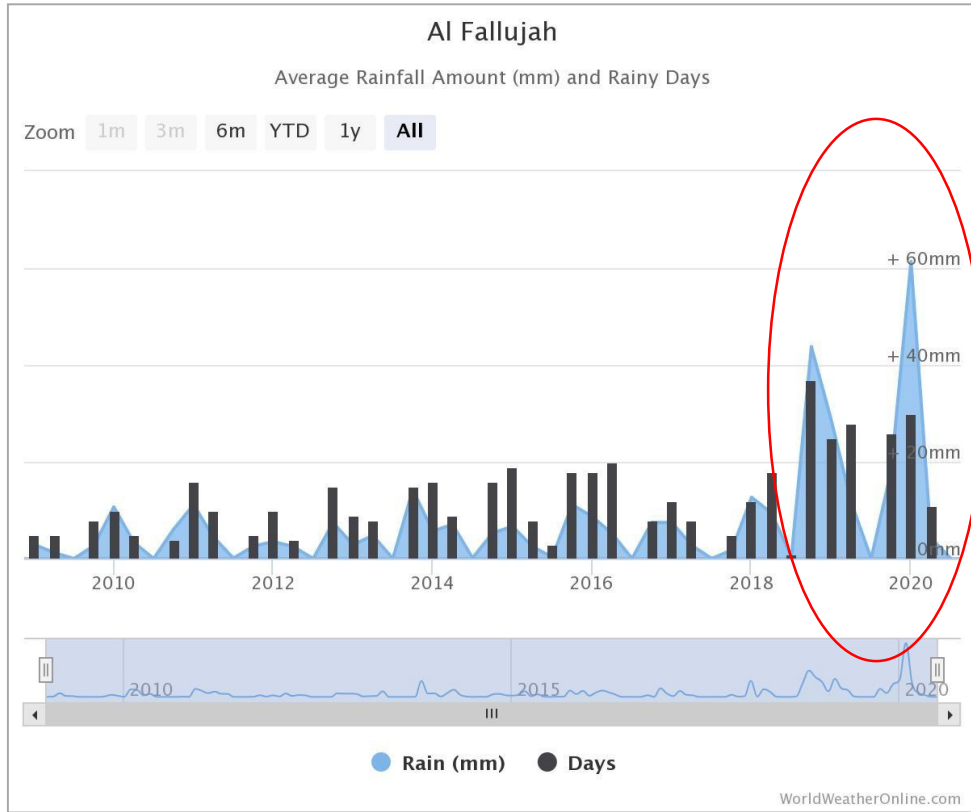


Figure 5. Average rainfall amount in Fallujah city from 2010 to 2020 [23]

Worldweather website [23] also describes in the Figure 6 below, that there has been a gradual increase in the trend of total rainfall amount per year, particularly in the past 3 years.

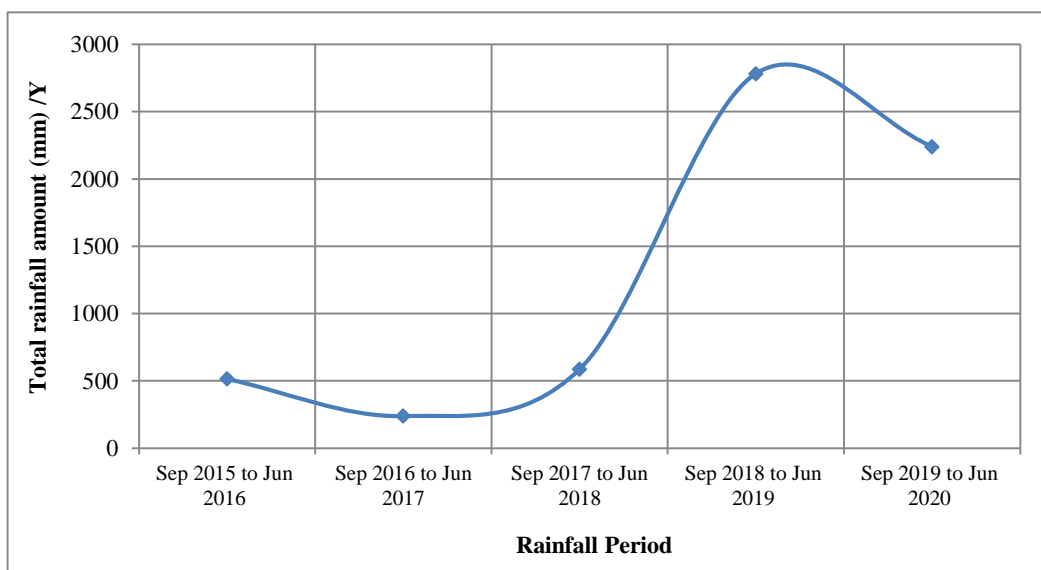


Figure 6. Total rainfall amount in Fallujah city from 2010 to 2020 [23]

This has been proved by the recent devastating floods that hit the regions of Iraq and have left many casualties as well as damaged houses and properties [24].

3. Fallujah Barrage

This study is going to assess and evaluate Fallujah barrage upstream side (as shown in Figure 7, the general view of Fallujah barrage upstream side). The Fallujah barrage is considered as the water regulator structure of Great Abu Ghriab Irrigation project. It was first suggested in 1911 by William Wilcocks on Euphrates River and was completely constructed and opened in 1985 by Selkhozpromexport soviet company [25].



Figure 7. General view of Fallujah barrage from the upstream side (Photos taken on 15/5/2021)

As mentioned above, the barrage is located at Euphrates River, roughly 5KM downstream from the city of Fallujah, towards the south (as illustrated in the satellite photo in Figure 8).



Figure 8. Satellite view of Fallujah Barrage

The Fallujah barrage has 10 radial gates of dimensions 8.5×16 m with a maximum operational level of 44.79 m above sea level. The barrage feeds the Great Abu Ghriab Irrigation canal by raising the water to the combined canal that is branched from Fallujah barrage and is located on the left side (shown in the Figure 9). This combined regulator has 4 openings gates of dimensions 3.5×6 m. After the barrage was constructed and operated, the water level raised and put some areas under threat of flooding particularly those are near the river banks [25, 26]. The barrage recently experienced structural damages during the last war against ISIS in 2014 which led to huge operational issues particularly in the left regulator canal, which is currently not operational.

4. Research Methodology

The methodology process of modeling flood simulation was completed for Fallujah barrage upstream side by using the main steps that are presented the in Figure 10.

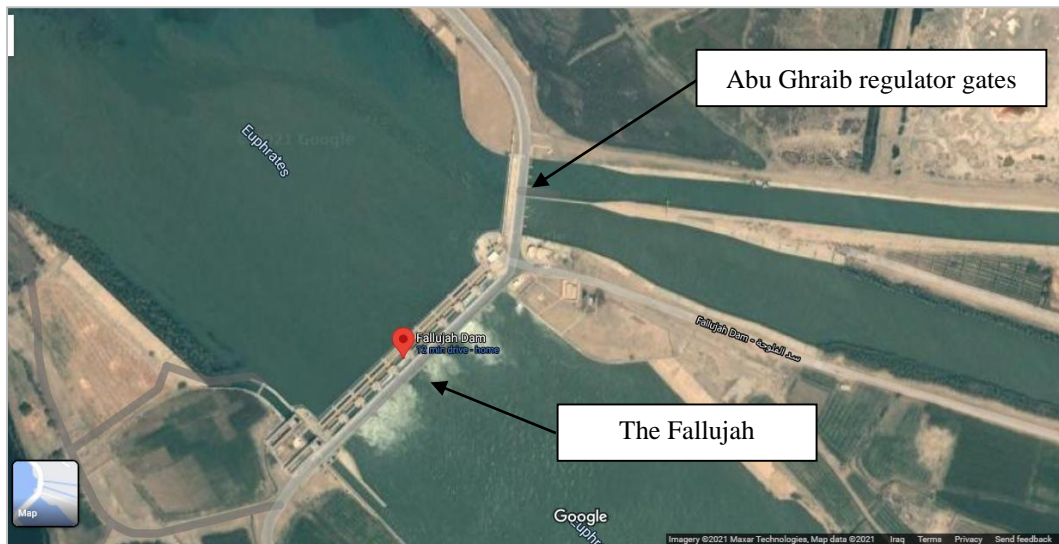


Figure 9. Satellite view of Fallujah Barrage with the combined canal

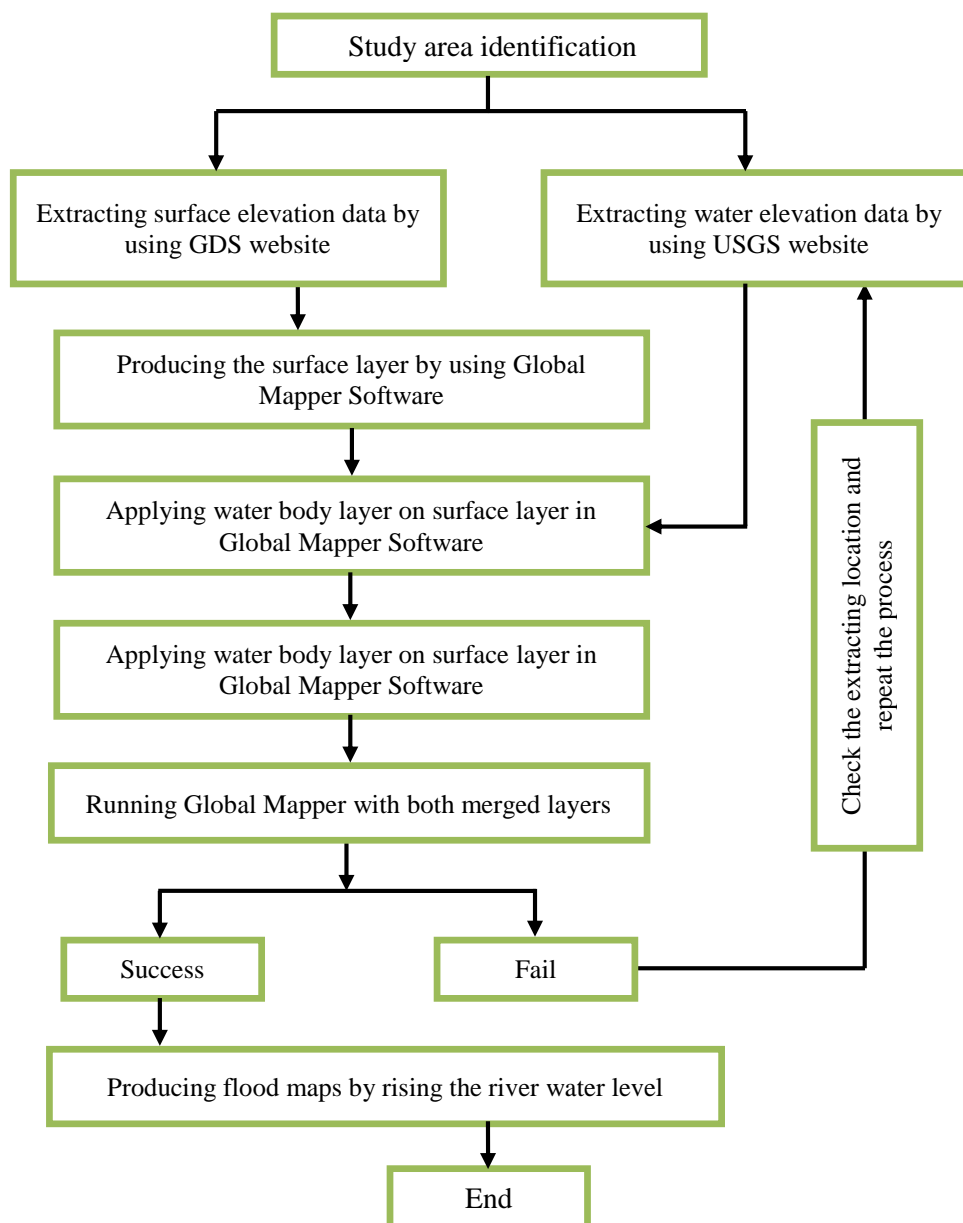


Figure 10. Flow chart of the research methodology

4.1. Using Earth Explorer USGS website / Water Body Data

The first step of the modeling involves extracting the water data for the Fallujah city area. This can be done by using Earth Explorer USGS and inserting the targeted location at latitude 33° north and longitude 43° east [28]. The water body data can be extracted and downloaded by clicking on Data sets and then digital elevations, followed by STRM water body Data, then clicking on Result and downloading the water body data as a Sup file; Figure 11 shows the steps of downloading the required water body data.

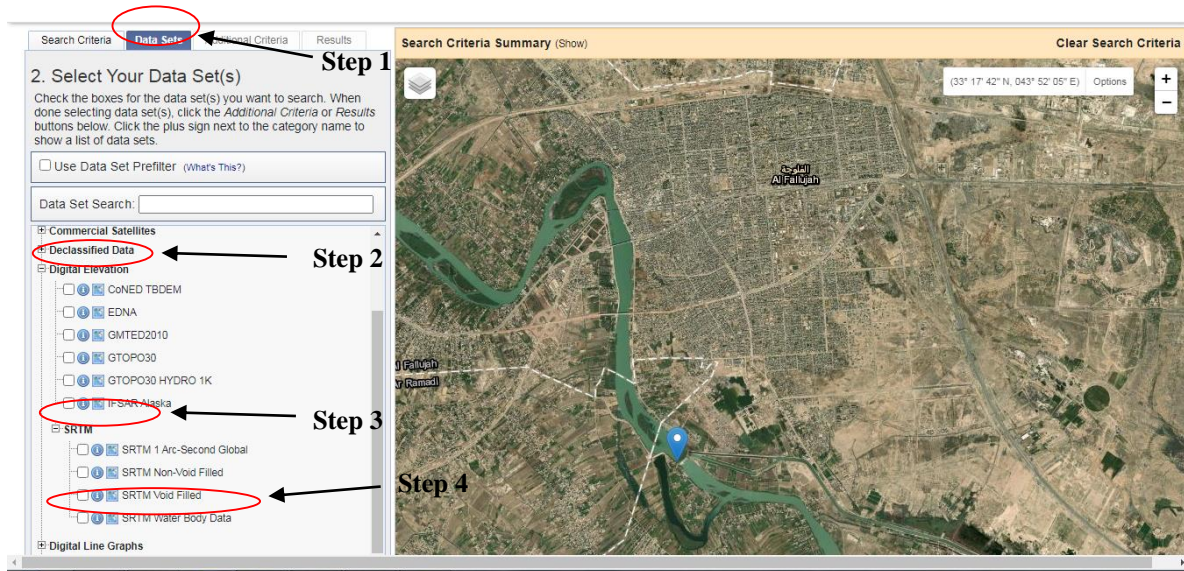


Figure 11. Steps of extracting Water body data for targeted area of Fallujah city [28]

4.2. Using Global Digital Surface Model website / surface layer Data

The second step of the methodology is downloading the surface layer of the study area. Global Digital Website can be used to download the surface layer (*.tif file) for the coordinate location at latitude 33° N and longitude 43° E, shown in Figure 12 [29].

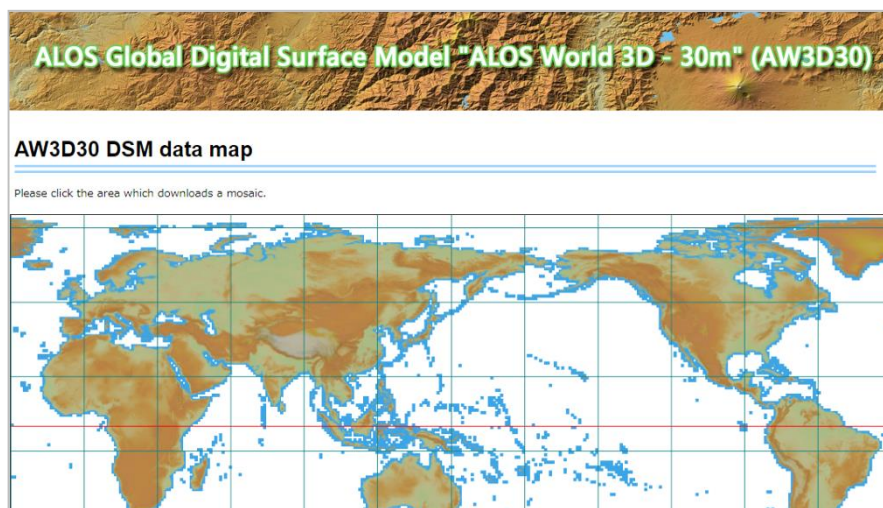


Figure 12. Extracting surface layer data for the targeted area of Fallujah city [29]

4.3. Inserting water and surface layers in Global Mapper

The final step of the methodology is to upload the above downloaded files into Global Mapper software. The Global Mapper version that has been used is Global Mapper V18.0. The final result of merging both layers is shown in the Figure 13 below, which demonstrates surface and water layer for the whole area of coordinate location at latitude 33° N and longitude 43° E.

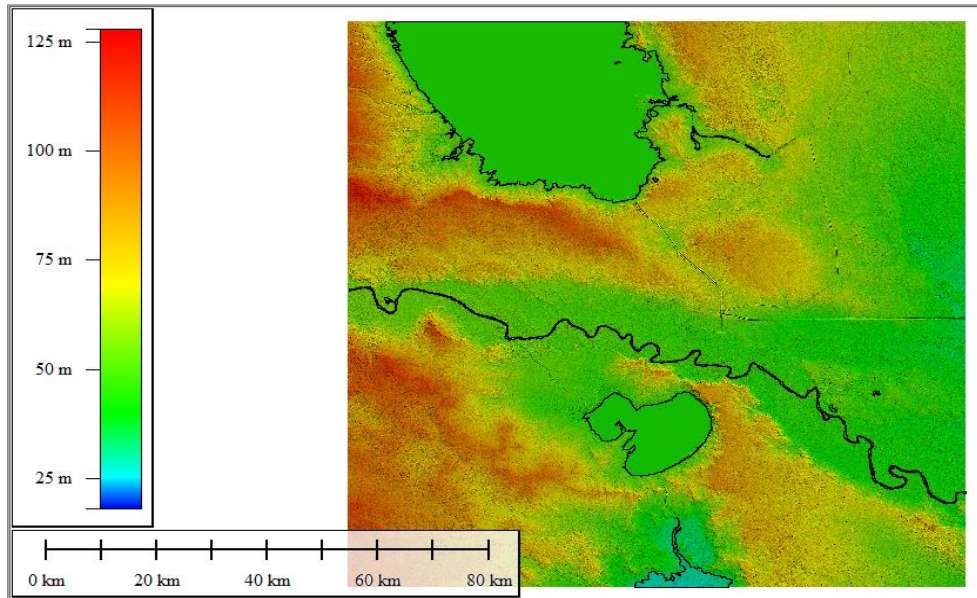


Figure 13. Water and surface layer for the area of latitude 33° N and longitude 43° E

Since the area of interest is only the study area of Fallujah city and where the barrage is located, by using zoom, cropping, and edit tools, the study area layer can be identified and cropped to be prepared for conducting the simulation scenarios, as illustrated in the Figure 14. The upstream river side was also split from the downstream side so as to conduct the simulation for just the upstream side; in addition, the river color was changed into blue color to be more visible with simulation photos.

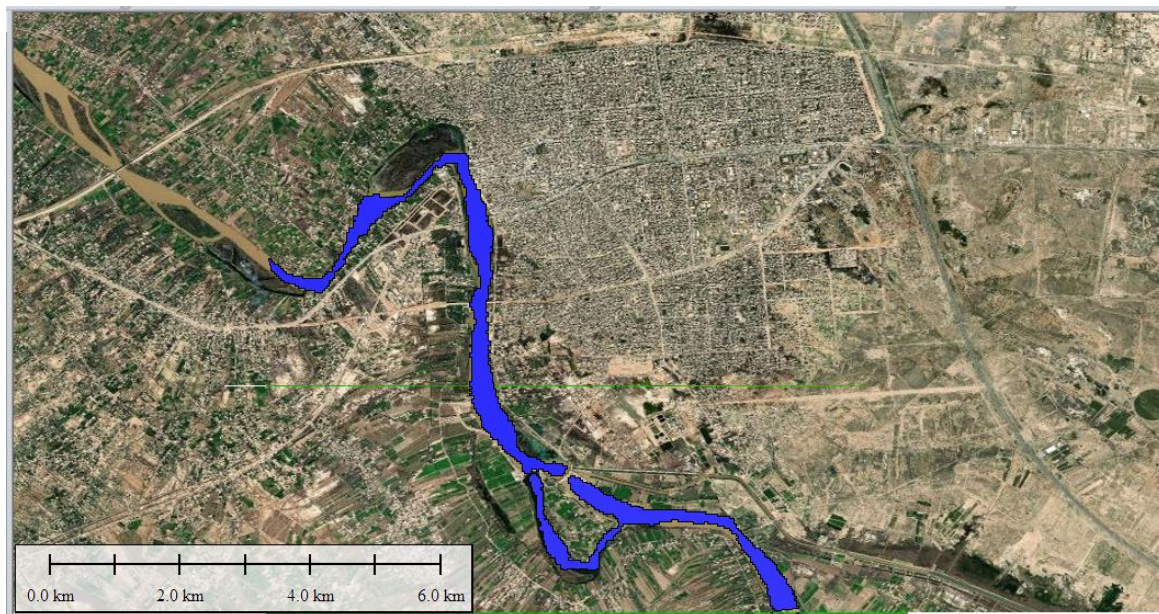


Figure 14. The upstream and downstream side of Fallujah barrage

5. Result and Discussion

For the methodology modelling adopted in this study, the upstream side of the Fallujah barrage was modeled based on the concept of changing the water level in the river. Global Mapper was used for the river simulation level which is governed by using USGS website. The river water level was modeled based on the different suggested value of the water level.

According to Table 2 (which was obtained from the water resource department of Fallujah city), the maximum operational water level reached is 42.86 m above sea level (ASL) [30]. This table demonstrates the small fluctuation changes in the upstream side during the period of 2006 to 2020. Despite the fact that the water level for this period appears to be stabled with small fluctuation from 42.5 to 42.86 m ASL, based on Mohammed, and Murphy [14], the small changes in water depth can lead to inundation occasions.

Table 2. Water level records for Fallujah barrage (obtained from water resource department/Fallujah Barrage centre) [18]

Year	Maximum water level / upstream side (m)	Average water level / downstream side (m)
2006	42.6	42.1
2007	42.5	41.2
2008	42.5	41.7
2009	42.55	41.3
2010	42.86	41.4
2011	42.85	41.3
2012	42.6	40.89
2013	42.55	40.4
2014	No records / war events	-
2015	No records / war events	-
2016	No records / war events	-
2017	42.65	40.23
2018	42.7	40.7
2019	42.66	40.54
2020	42.68	41

The modelling of the base water level before making any changes resulted in the water profile shape as presented in Figure 15. This is considered to be presented as the first scenario of flooding simulation with water level of 42.5 m (ASL); the result of the first model revealed that no indication of a flooded area was observed at this scenario.

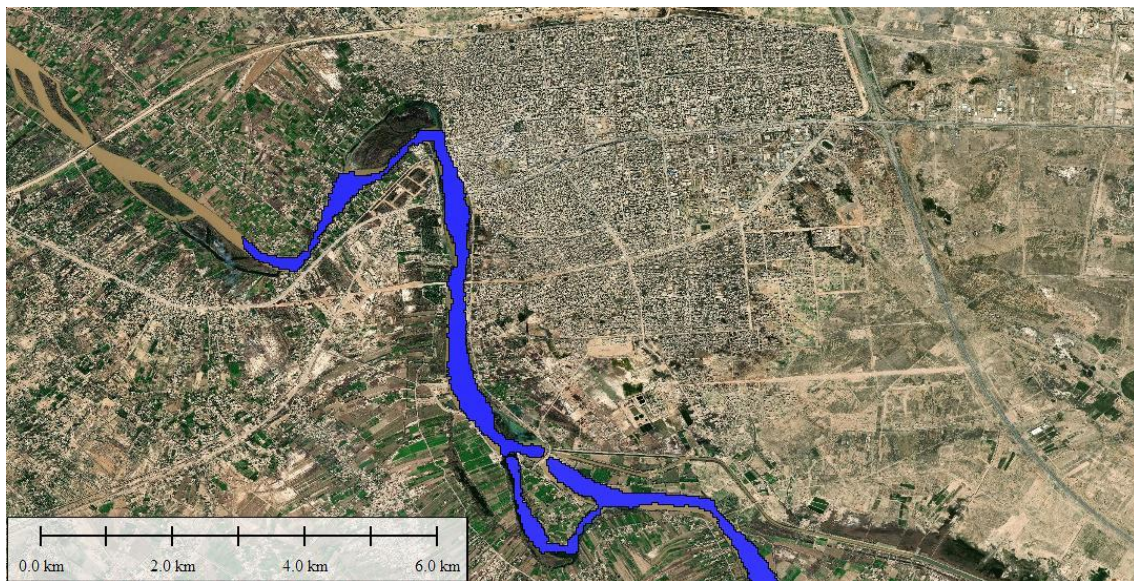


Figure 15. First scenario of river simulation – elevation 42.5 to 42.8m (ASL)

The second scenario was conducted by increasing the water level by 0.5 meters. Figure 16 shows the modeled water profile of the river based on 43 meters ASL. Two main flooded zones were exposed to be affected (shown in the areas that are highlighted in red dashed circles). The simulation continues to be conducted by keep rising the water level by 0.5m in each scenario.

Figure 17 demonstrates the water profile for the third scenario that was modeled based on 43.5 meters ASL. In this scenario the same flooded spots that have been observed in the previous modelling continue to expand with no sign for new flooded spots. However, for the fourth scenarios with 44 meters water level simulation, two others zones were spotted on the north side of the river (shown in the Figure 18 for the areas that are highlighted in the red dashed circles).

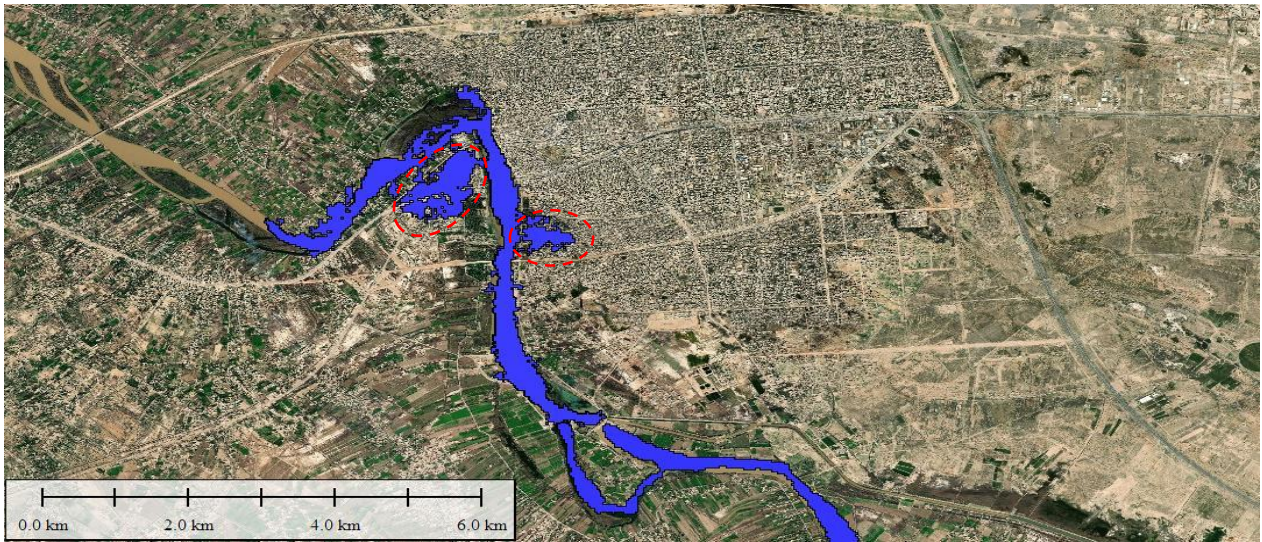


Figure 16. Second scenario of river simulation – elevation 43m (ASL)

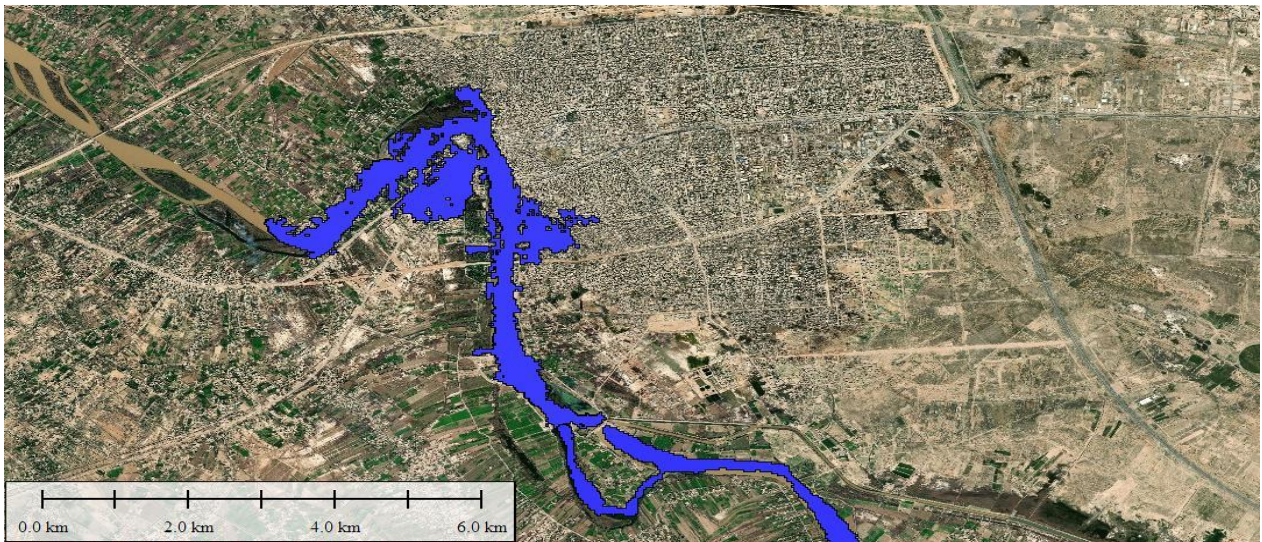


Figure 17. Third scenario of river simulation – elevation 43.5m (ASL)

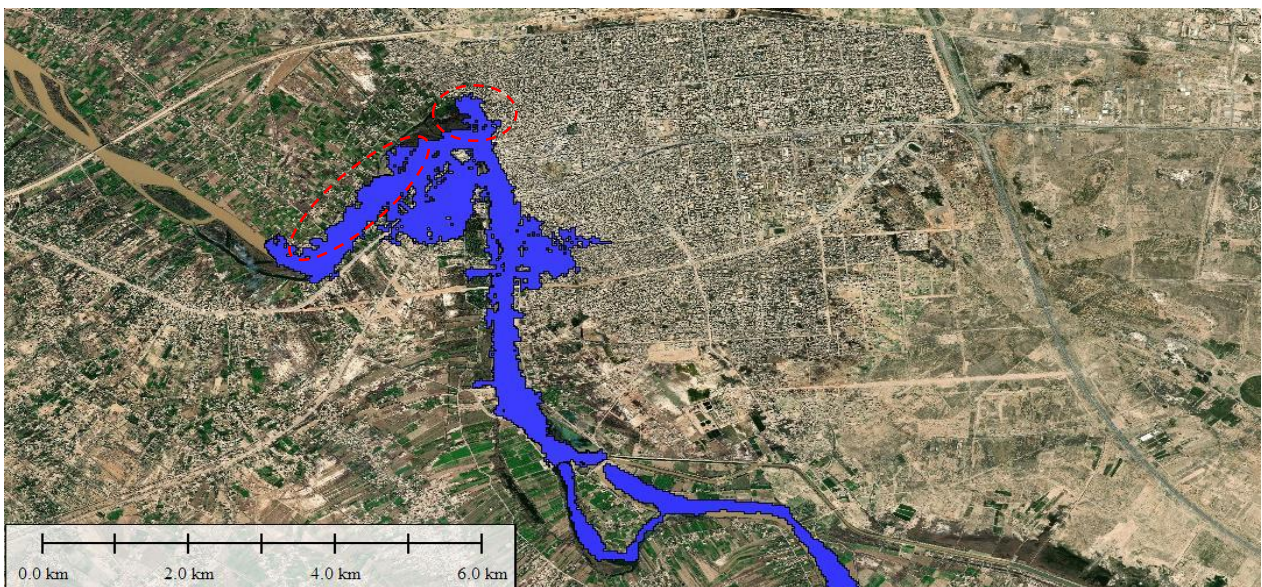


Figure 18. Forth scenario of river simulation – elevation 44m (ASL)

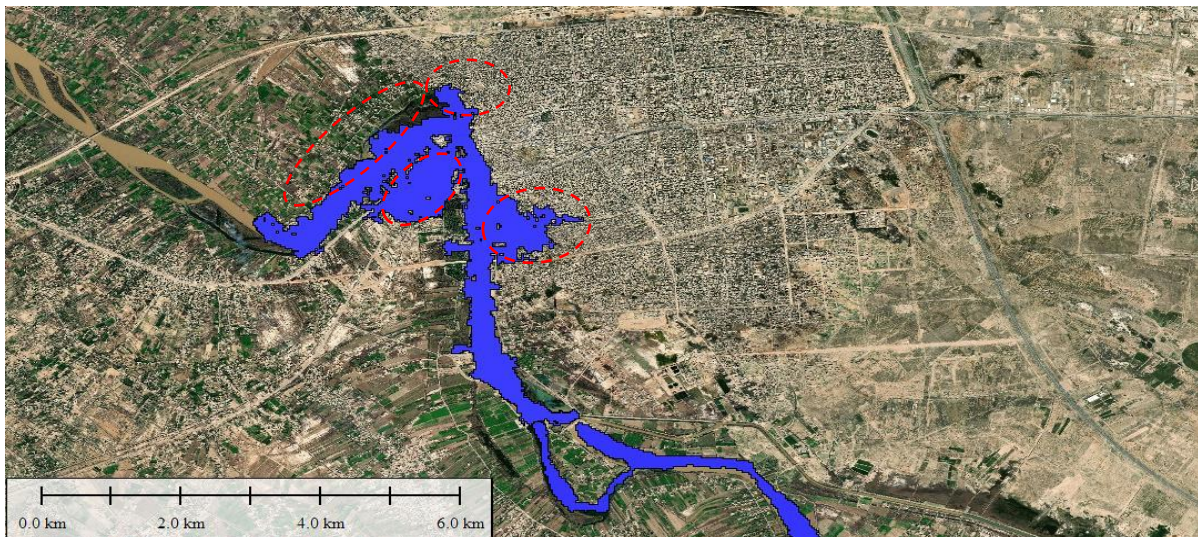


Figure 19. Fifth scenario of river simulation – elevation 44.5m (ASL)

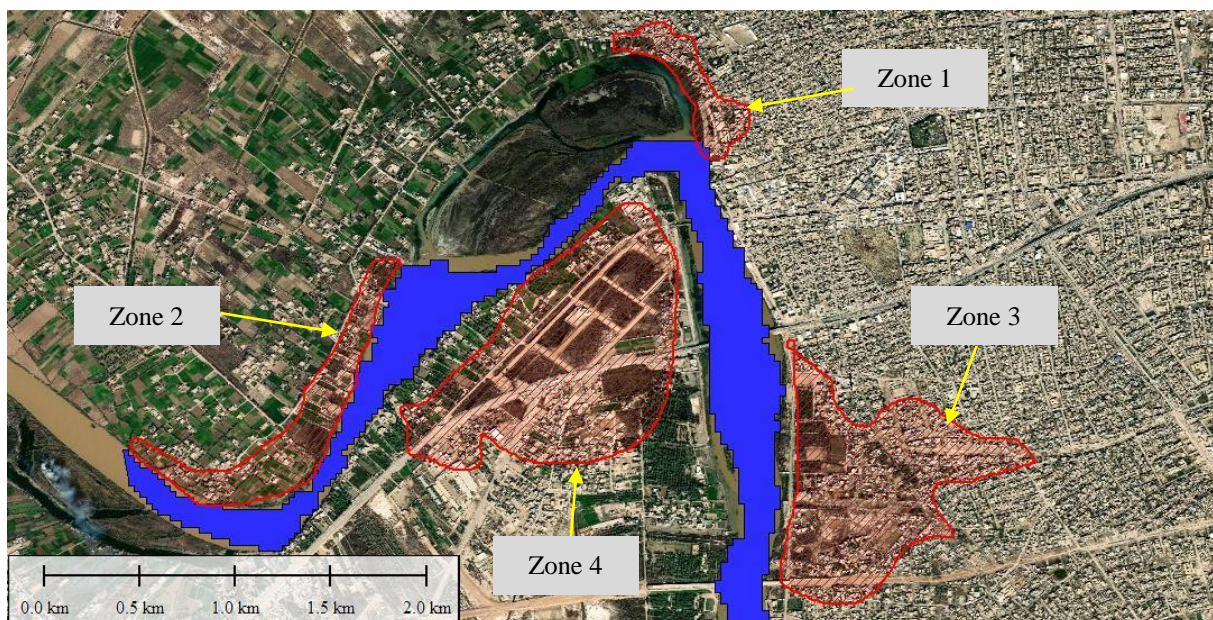


Figure 20. Main flooded zooms

With 44.5m water level simulation, the same flooded zones were expanded further with no sign of flooding on the other spots, shown in Figure 19 which is the fifth scenario of simulation. As a result of all simulation scenarios, four main flooding zones were exposed to be under threat of flooding (illustrated in the Figure 20). According to this study of modelling, the total affected area to be flooded is roughly 11.89km² with approximate population of 396 households living within the flooded zones (highlighted in red mesh polygons in the Figure 20).

Table 2 illustrates that the affected total areas of each flooding simulation for scenario 1, 2, 3, 4, and 5 are 0, 4.6, 5.2, 8.9, and 11.89 m² respectively, and the effected populations are, 0, 103, 147, 223, and 396 HH, respectively. This gives an indication that the continuous usage of land that is classified as a submerged area can put more houses prone to flooding.

Table 3. The results of the simulation scenarios

Scenario	Simulation water level (ASL)	Flooded area (km ²)	Affected population (House Hold)
1	42.5 m	0	0
2	43 m	4.6	103
3	43.5 m	5.2	147
4	44 m	8.9	223
5	44.5 m	11.89	396

6. Conclusion

The flood mapping based on Global Mapper with Earth Explorer and Global Digital surface website is a valuable tool for flood risk analysis. This tool can help the local authority and water resource planners to focus on particular areas so as to conduct detailed flood risk assessment. This approach has some advantages such as the simplicity of use, flexibility, and produce new data where there is a lack of detailed information. In addition, it can make the process more convenient when it comes to producing flooding maps on a large-scale or when a rapid flood risk assessment is required. There are however some limitations that undermine using this kind of modeling. For example, inserting incorrect surface elevation data can give different results. Also, extracting the water data should always be compared to those that are stated by literature or presented by other's studies to make sure that the extracting data are valid to be used accordingly. Based on the presented approach, this study concluded that the barrage should not operate above 43 meters (ASL), as the inhabited area will be under the risk of flooding. This methodology also gives an indication of the increasing danger of using the agricultural land as residential and populated area. Therefore, it is highly recommended the local authorities and the department of water resource in Fallujah adopt this for conducting further and detailed field assessment. It is also recommended to continue to maintain and clean the upstream side of the barrage and widening the river's banks. This can aid in the management of unexpected flooding cases that may hit the area during periods of heavy rainfall in winter seasons

7. Declarations

7.1. Author Contributions

Conceptualization, M.S.; methodology, M.S. and D.A.; formal analysis, M.S.; investigation, M.S.; resources, D.A.; data curation, M.S.; writing—original draft preparation, M.S.; writing—review and editing, M.S. and D.A. All authors have read and agreed to the published version of the manuscript.

7.2. Data Availability Statement

The data presented in this study are available in article.

7.3. Funding

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7.4. Acknowledgements

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7.5. Conflicts of Interest

The authors declare no conflict of interest.

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