Assessment of flood hazard areas and its management using Remote Sensing and GIS Techniques: A Case Study of Tigris River – Salah Al-Din Governorate, Iraq

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Abstract. Flood is one of the most widely distributed hazards around the world and its management is an important concern for all decision makers. In Iraq, especially in Salah Al-Din Governorate, during the Spring 2019, the amount of water flowing has been increased into Tigris River, this led to a rise in the river level as a result of rains in close range and snow melting, as well as an increase in the drainage of the Small Zab, which is flowed into Tigris River at Salah Al-Din Governorate. Therefore, the flood hazard mapping and flood shelter analyses have been accomplished through the assessment of damage and determination the optimal location to make flood escape for mitigation the flood hazard processing. The Remote Sensing (R.S) technique and Geographic Information System (GIS) have been utilized to assess the damage by using the NDVI and NDWI indices. Arc Hydro tool in GIS software with the hydraulic model HEC-Ras software have been also utilized to find the flood escape and modeling the flood shelter. The result shows that the damaged areas at Salah Al-Din Governorate for agriculture land and flood inundation map.

Keywords. GIS, Flood Hazard, DEM, NDVI, NDWI.

1. Introduction
In the last decade, the climate is changed in the all world for many resins such as the increasing of urbanization, factories and population with decreased in the vegetation cover and water bodies. This led to inequality for the amount of rain through the season. Republic of Iraq is located in western Asia above the Equator. Also, it has been subjected to climate changing in the last decade. Especially in Spring 2019, heavy rain was fall in Iraq with snow melting in the north region. This led to increase the flow and water level in Tigris River and flooding areas around the river. Floods are one of the most effective dangers that lead to loss of life and property, and thus the need for appropriate mechanisms to mitigation their severity [1]. Therefore, flood management and control must be performed by conception the hydraulic flow in floodplains [2]. Remote Sensing techniques and GIS environment are sophisticated for monitoring and damage assessment of flood disaster by using multispectral images [3], [4]. Also, GIS is considered a powerful tool that can support flood plain management in detecting flood prone areas [5]. Also, DEM image was used for developing methodology to delineate the flood hazard through make flood escape by
using GIS and HEC-Ras hydraulic model [6]. Therefore, this study has two objectives. Firstly, the assessment of damages areas in Salah Al-Din Governorate is performed using multispectral images in GIS environment. Then, the mitigation processing is performed to determination proposed flood shelter using DEMs in Arc Hydro tool and make hydraulic modelling in HEC-Ras.

2. Materials and Methods

2.1. Study Area
This study covers all Salah Al-Din governorate by (43°, 45°) longitude, (35°, 33°) latitude as shown in figure (1). The Governorate of Salah Al-Din has an area of (24,363) KM². Tiger river passes through Salah Al-Din Governorate. Samarra Barrage has been located on the Tigris river for diverting the flood water to Therthar Lake by Therthar channel and protecting Baghdad city from flooding water of Tiger. The problem related to Salah Al-Din Governorate is the high level of Tigris river as a result of close periods of rain and the high drainage coming from Mosul Dam as a result of its filling and from Little Zab due to melting snow and rain. Therefore, all of these resins led to Tigris river flooding and the damages of agricultural lands [7].

![Figure 1. Location of the Study Area (General Authority of surveying)](image)

2.2. Data Source

2.2.1. Sentinel-2 images
European Wide-Swath launched high-resolution multispectral imaging mission in 23/6/2015. Sentinel-2 mission is a land monitoring constellation of two satellites (Sentinel-2a and Sentinel-2b), which was designed to give a high revisit frequency of 5 days at the Equator, because of the specification of the twin satellites flying in the same orbit but phased at 180° [8], and it provides global optical imaging with 13 spectral band using MSI (Multispectral Imager) instrument (four band at 10m, six band at 20m, and three
band at 60m spatial resolution) [9]. There are 5 rater images of Sentinel-2 that cover the entire area of Salah Al-Din Governorate, which is easily downloadable from https://earthexplorer.usgs.gov/. They are downloaded in the period before and after flood.

2.2.2. **DEM Data**

DEM is 3D representation of the of the Earth’s surface that contains real height points appearing the topography of surface. The Land Processes Distributed Active Archive Center (LP DAAC) lately sent out additional tiles in the NASA SRTM Version 3.0 Global 1 arc second dataset (SRTMGL1), which is coverage Africa, Europe, North America, South America, Asia, and Australia in 1° X 1° tiles at 1 arc second (about 30 meters) resolution [10]. The SRTM data is easily downloadable from https://search.earthdata.nasa.gov/.

2.2.3 Cross-Section

The Cross-Section are considered one of the most important data and inputs in the HEC-Ras software, because they provide the values of the heights Z, especially for the main channels. Therefore, data from the General Authority of surveying was used to create a hydraulic model in the HEC-Ras software for the area of the flood escape. The data consist of 33 cross-sections for the area of the flood escape, and due to the large number of this data, it has not been included.

2.3. **Methodology**

Figure (2) gives a summary of the procedures performed to achieved the two objectives of this study.

![Flow chart of Methodology](image)

**Figure 2.** Flow chart of Methodology

2.3.1. **Pre-Processing Methods**

2.3.1.1. **Sentinel-2**

The Sentinel-2 Level-1C data has been used in this study. Therefore, this data does not need to be radiometrically and geometrically corrected, because it has produced with ortho-rectification and spatial
registration on a global reference system (UTM/WGS84) projection, also it is providing the Top-Of-Atmospheric (TOA) reflectance [11]. However, the 5 raster images are mosaiced using rater calculator tool in GIS and resampled the Short-Wave Band from 20m to 10m using resample tool in GIS.

2.3.1.2. STRM DEM
Terrain pre-processing is preformed using Arc Hydro tool, which includes DEM Recondition and Fill Sink. DEM Recondition is used Burning in Streams technique to adjusted Z value using equation [12]:

\[ Z = E - (G/G+D))^k \times H \]  

Where: \( Z \) = newly calculated grid cell elevation (m), \( E \) = old grid cell elevation (m), \( G \) = grid resolution (m), \( D \) = distance from a stream cell (m), \( k \) = decay coefficient and \( H \) = elevation decrement (m)

Fill Sink is utilized Topographic Depression technique to ensure that problematic DEM depression is corrected and removed from features as show below in figure (3) [13].

![Figure 3. Fill Sink Process (www.google.com)](image)

2.3.2. Processing Methods
Figure (1) shows the methodology of this study, which is divided into stages, the first includes assessing the extent of damage resulting from the flood and the second includes proposing a flood escape site to prevent future damage.

2.3.2.1. Vegetation Index
There are many of vegetation indices. But, Normalized Different Vegetation Index (NDVI) classification is considered the most common index, which is used to extracting the vegetation cover for Salah Al-Din Governorate before the flood by applying the equation 2 [14].

\[ NDVI = \frac{(NIR-RED)}{(NIRRED)} \]  

For Sentinel images, Band 4 and Band 8 are utilized to extract NDVI, which are represented the RED Band and Near Infrared Band respectively.

2.3.2.2 Water Index
For monitoring natural resources such as water bodies and also to enable a time and cost operative detecting of water resource with reliable data [15], Normalized Different Water Index (NDWI) is calculated using equation 4 after the flood, which is presented by McFeeters [16]. NDWI is utilized Green Band and NIR Band (Band 3 and Band 8 respectively) for Sentinel-2 images.

\[ NDWI = \frac{(Green - NIR)}{(Green + NIR)} \]
2.3.2.3. Drainage Model
For modelling drainage line, Arc Hydro tool is utilized to perform the Flow Direction, Flow Accumulation, Stream Order and Slope Map. The process of distributing and transporting of water across the ground have been employed flow route to calculated and extracted the hydrological attributes from DEM surface as show in figure (4). The direction of water from one grid cell may be distributed to any down slope (neighbor grid cells), has been determined by using developed flow routing algorithm (Deterministic 8 Neighbor (D8)) [17].

![Figure 4. Deterministic 8 Neighbor (D8) (www.google.com)](image)

2.3.2.4. Hydraulic Model

2.3.2.4.1. HEC-RAS
The hydraulic model (1D HEC-Ras) is intended to simulate a one-Dimensional unsteady flow of a complete network of natural canal. Therefore, physical laws are used to preserve mass and momentum that govern water flow in the current. The laws of maintaining momentum are expressed through Newton’s second law mathematically in the form of partial differential equation (4) [18]:

\[
\frac{\partial Q}{\partial t} + \frac{\partial Q v}{\partial x} + g A \left( \frac{\partial z}{\partial x} + S_f \right) = 0
\]

Where, \( Q \): the total flow (m\(^3\) s\(^{-1}\)) as a function of the distance, \( x \), and time, \( t \). \( V \): the control volume (m\(^3\)). \( g \): the gravitational acceleration (m s\(^{-2}\)). \( A \): the total area (m\(^2\)). \( \partial z / \partial x \): the water surface slope. \( S_f \): the friction slopes.

2.3.2.4.2. Design Unlined Channels
Unlined channels in which there are no leaks are considered fixed channels and designed on the basis of the maximum permissible speed and their surface are of mud or rock fragmentation [19]. Therefore, the channel modification is designed to extraction the dimension of channel using equations (7) and (8) depends on the Q value that considered the maximum discharge value to this channel and velocity of flow \( V \) [19], which is extracted from the below table (1). The table (1) [20] below shows the permissible speed for types of soils.
Table 1. Permissible Velocity

| Type of Material | Permissible Velocity (m/s) |
|------------------|---------------------------|
| Clay             | 0.41 - 1.67               |
| Heavy Clay       | 0.45 - 1.7                |
| Sandy Clay       | 0.52 - 1.83               |
| Hard Moorum      | 1.2                       |
| Gravel           | 1.5                       |
| Boulders         | 1.5 - 1.8                 |
| Hard Rock        | Greater than 3            |

\[
A = \frac{Q}{V} \quad (5)
\]

\[
P = \frac{A}{R} \quad (6)
\]

\[
A = (B + zD)D \quad (7)
\]

\[
P = B + 2D\sqrt{z^2 + 1} \quad (8)
\]

Where, \( A = \) cross-section area, \( P = \) wetted perimeter, \( R = \) hydraulic radius, \( z = \) side slope, \( B = \) bed width and \( D = \) depth flow.

2.3.2.4.3. Manning’s Formula

The Manning equation is a commonly utilized experimental equation, which was developed by the French engineer, Philippe Gauckler 1867, for regular open channel flow of water. It offers an association between several open channel flow parameters of attention: flow rate, average velocity, bottom slope of the channel, cross-section area of flow, wetted perimeter and Manning roughness coefficient for the channel. However, the flow in open canals may occur in natural channels such as rivers, or in man-made channels such as irrigation channels [21]. The Manning Equation and the units for its parameters are as follows:

\[
Q = \left(\frac{1.94}{n}\right)A\left(R_n^2\right)^{1.55} \quad (9)
\]

Where, \( Q = \) discharge, \( A = \) cross-section area, \( n = \) manning’s coefficient, \( R = \) hydraulic radius and \( S = \) bed slope of channel.

3. Result and Discussion

3.1. Damaged Areas

Firstly, the NDVI index is extracted before the flood event to found the vegetation cover as show in figure (5a). Secondly, NDWI index is extracted to detection water bodies after the flood event in Salah Al-Din Governorate as show in figure (5b).

\[
\text{Damaged area} = (\text{NDVI} == 1) \& (\text{NDWI} == 1) \quad (10)
\]
The damaged areas as shown in figure (6) were calculated at (51,350 m²) in the Governorate of Salah Al-Din by applying band math as shown above in equation (10), which intersects a value of 1 for NDVI and a value of 1 for NDWI using raster calculator tool in GIS.

![Figure 5. (a) NDVI index, (b) NDWI index](image)

![Figure 6. Damaged Area for Salah Al-Din Governorate](image)
3.2. Mitigation processing

To mitigate future flood, a flood escape location has been chosen to transport excess water to Therthar Lake using streams and the slope map, which differs in the topography of the flood escape area. Therefore, a channel was designed to transfer the water from escape site to the stream that drainage in Therthar Lake as show in figure (7). This channel has been adopted on the basis of low topography for the area, the smallest distance that can be obtained and the least possible number of features that intersect with the channel.

Also, a model is designed using HEC-Ras model for an Unlined channel (depending on the area’s soil type) as show below in figures (8a) and (8b). Therefore, the value of manning’s coefficient (n) depends on the type of surface in which the water runs, so the General Authority for Designs in irrigation projects is 0.015 for the lined channels and 0.025 for the unlined channels. Then, the lateral slope of channels is designed from clay soil is 1:1 or 1:1.5, while in rocky soil it is 1:0.5 or 1:0.25. The channels are designed using Manning’s Formula. Finally, depending on the equations (6) and (7), the depth of flow (D) is 4m after adding the free board and the bed depth (B) is 25m.
After finding the flood damaged areas for Salah Al-Din Governorate and making an analysis to reduce the size of the flood damage by proposing a flood escape location and designed a canal linked to Therthar Lake, a hydraulic model (1D) is performed using the HEC-Ras with data of the cross-section for the Tigris River. This model is simulated a flood for the flood escape area to finding the inundation area as show in figure (9).
Finally, a flood map is produced for the area of the flood escape, which includes the size of the damage caused by the flood with the inundation area, as well as the location of the proposed escape and the proposed channel for transporting water as shown in figure (10).

Figure 10. Flood Map

4. Conclusion

In this study, Remote Sensing Techniques and Geographic Information System (GIS) were used for the purpose of managing the floods hazard that occurred in Iraq / Salah Al-Din Governorate at Spring 2019. This study has two objectives, the first is to assess and determine the amount and location of the damages caused by the floods using the multispectral images classification for Sentinel-2 satellite. The second is to find a way to mitigation and avoid flood hazard in the future. Therefore, flood escape makes on the Tigris River to drain the flood water in the Therthar Lake through the work of a hydrological analysis using DEM to extract the catchment area and suggesting a suitable location for the flood escape. Then, hydraulic model is formed to design a channel from the flood escape to the Lake Therthar and extracting the flood inundation map using HEC-Ras model.

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