Flash Flood Risk Mitigation Plan: Zarqa Ma’in Basin, Along The Dead Sea In Jordan

Hüseyin Gökçekuş, Youssef Kassem, Nour Alijl and Mohammad Tawalbeh

Abstract—Flash flooding risk impacts can be reduced through the implementation of mitigation strategies plan (MSP) on flood management. Flood risks and natural hazards, which have been increased due to changing physical characteristics of the hydrological system caused by climate change in the Middle East in this decade and all over the world. The presented paper proposes a flash flood risk mitigation plan (FFRSM) to be implemented by municipalities, provincial administrators and authorities to reduce impact of flash flood based on identified strategies, risk matrix and generated flood inundation map using 2D HEC-RAS software based on unsteady flow analyses for rainfall with limitation of measured data, applied on wadi Zarqa Ma’in (hot springs) in dead sea area, a fill sink digital elevation model (DEM) was extracted to analysis catchment area, flow accumulation, channel networks, basins, slopes, flow path using SAGA and QGIS.

Index Terms—flash flood, risk matrix, DEM, QGIS, HEC-RAS, mitigation, strategies plan.

1 INTRODUCTION

Flash floods are natural hazard frequently occurred over the world and a harmful risk for human beings, and flood impact is about a 30% of the economic losses mete out to natural hazards [25]. Over 175,000 people were killed in a total 1816 flood worldwide in 1975–2001[11] Moreover, around 2.3 billion people from the third of the world’s population has been affected by floods in last 20 years due to climate changes which have been estimated by the United Nations [24]. Conducting and planning for the flood risk which is identified as ‘hazard’[2] can be translated into maps developed by computer modeling showing the boundary of the terrain at risk as well as flow depth, water surface elevations (WSE) and velocities to inform the public, planners, decision-maker about prone areas inflicted by flood. Previous studies over the world have used the same criteria as summarized below.

1. a hydrological model considering the wetness index using QGIS and SAGA software by using the Digital Elevation Model (DEM) of the study area. In addition to analyzing the hydraulic model using HEC-RAS under a wide range of return period-flood events to generate flood inundation maps. That results in taking safety measures against flood impact on human beings and economic losses in urban areas particularly [1].

2. The study proposed a scheme integration of hydrological models based on runoff simulation and rainfall data mutually with FIM to assess the flash flood risk impact for Wadi Fatimah in an arid region in Saudi Arabia (SA) Using GIS techniques. This concludes the integrated scheme is a useful tool to evaluate the impact of flood risk and hazard, in addition, the dam construction with limited measured hydrological data [7].

3. The study is conducted the United States, including Iowa - Cedar River watershed and Alabama - Black Warrior River to compare two new generated hydrodynamic model for flow inundation maps using 2D HEC-RAS, and low-complexity tools HAND (AutoRoute and Height Above the Nearest Drainage), which result as fast predictions tool in large-scale hyper-resolution operational frameworks [5].

4. The study proposed a risk flood matrix technique applied in Taibah and Islamic universities catchment in Saudi Arabia (SA), developed matrix based on the probability of flood occurrence and inundation flood map generated by HEC-RAS software. A quantitative analysis was conducted to assess flood economic losses impact [8].

5. The study proposed an integrated model using KINEROS2 and HEC-RAS software to forecast flash flood occurrence in Northern Vietnam which is a heavy flash flooding prone area. using different precipitation datasets which conclude a relation between flow velocity, water level and streamflow power to predict flood occurrence on the gauged data [14].

2 STUDY OBJECTIVE

The study proposes a flash flood risk mitigation plan to be implemented by municipalities, provincial administrators, authorities to reduce impact of flash flood using flood inundation map generated by SAGA, QGIS and 2D HEC RAS software’s in addition of flood risk matrix to identify local communities and structural strategies to be used in a
quantitative analysis for future work.

3 STUDY-AREA BACKGROUND

The catchment area of Wadi Zarqa Ma’in (hot springs) is located between 35° and 36° longitude and 31° 40’ and 31° 60’ latitude within dead sea area which considered is the lowest point on the world as shown in Fig. 1 below. Which received a flash flood on the 25th of October 2018 that caused death for 22 people mainly school students and teachers also destroyed a bridge on the Dead Sea Cliffs. The temperatures of Wadi Zarqa Ma’in (hot springs) area are ranged from 30 to 63°C, receiving their water from the Lower Cretaceous and older sandstones with groundwater for Wadi aquifers is the main supply for Madaba water demand [23] Agricultural activities have been developed in the study area which is supported by rainfall with major corps of wheat, tobacco, olive, barley, and grapes.

4 METHODOLOGY

The proposed methodology is shown in Fig. 2 consists of the analysis of catchment area and flow delineation using QGIS and SAGA plug, gathering available precipitation data from the nearest CC02 station in the study area. The collected and analyzed runoff and precipitation to be used as input into the 2D HEC-RAS model used by US federal emergency management agency (18) to determine the flood depths, a risk flood matrix is generated to estimate probability and impact of flood hazards. Quantitative risk analysis to be conducted in future works; define strategies for local communities and structure

Fig. 1. : Wadi zarqa ma’in catchment area location— QGIS-street map

The proposed method requires the main set of input data as summarized below.

- Extracted a Digital Elevation Model (DEM) in Geo-Tiff format.
- Extracted hydrologic model by wetness indices.
- Rainfall data.

4.1. EXTRACTED DIGITAL ELEVATION MODEL (DEM)

Extracted digital elevation model (DEM) using USGS earth explorer after fill sink area by using saga plug 2.3.2 based on wang Liu method, updated DEM was used to extract network channel, flow accumulation based on top-down method, basin, slopes, flow path cross-sections and profile using Quantum geographic information system (QGIS10.3) software as shown in Fig. 3 below.

Fig. 3. : catchment area with fill sink -DEM using SAGA and QGIS.Map scale 1:250000

4.2. EXTRACTED HYDROLOGIC MODEL BY WETNESS INDICES

A hydrologic model by wetness indices has been extracted using Saga 2.3.2 based on sink DEM and using basic analysis terrain tool as shown in Fig’s 4 & 5 to extract Topographic Wetness Index \(TWI\) which is widely used in hydrological analysis [13, 19, 23] and defined by Beven and Kirkby [4] as

\[TWI = \ln\left(\frac{A_s}{\tan\beta}\right)\]

(1)

Where, \(A_s\) is the upslope area of flow accumulation (6) and \(\beta\)
is the slope angle, assuming the soil is homogeneous and isotropic for study area as constrain.

![Fig. 4. basic terrain analysis by SAGA 2.3.2](image)

![Fig. 5. Hydrologic model by wetness indices using SAGA ,Map scale 1:250000](image)

### 4.3. Rainfall Data
Precipitation data is available in the nearest stations CC01 and CC02 in the surrounding of the study area as shown in Fig. 6, also there is no ungauged station to measure flow.

![Fig. 6. Rainfall stations within the study area and average rainfall over Jordan Intensity-Duration-Frequency Relationship Manual IDF Curves,2011.](image)

### 5 Discussions and Recommendations
#### 5.1. Catchment Area and Flow Delineation
The catchment area is 266 km² which is considered the smallest catchment within the dead sea area (16) and heterogeneous area as a result of the pervious study (15) and Madaba water demands were supplied by wadi aquifers. The extracted flow path with a total length 50,126m profile shows a high difference in elevations range between 771 to 293 and non-uniform slopes which result in increasing water velocity to reach 10 m/s and non-uniform cross sections of wadi as illustrated in Fig. 7 below.

![Fig. 7. flow path plan as per HEC-RAS model.](image)

In summarized table 1 and Fig. 8 below slopes variances along flow path in station 0+000 to 20+420 is a gentle slope will not increase flow velocity, following stations from 20+420 to 44+230 the slope is moderate but the velocity is increased but still within accepted velocity limit which is around 5 m/s, for stations 44+346 to 50+126 slope is steep which result to increase it to 10 m/s which require structural mitigations such as wadi bed lining, adding sand bags, chutes, Baffles or wadi diversion.

![Fig. 8. flow path profile.](image)

**Table 1.: Calculated slopes for flow path.**

<table>
<thead>
<tr>
<th>Stations From</th>
<th>To</th>
<th>Distance (m)</th>
<th>Top (m)</th>
<th>Bottom (m)</th>
<th>Slope %</th>
</tr>
</thead>
<tbody>
<tr>
<td>0+000</td>
<td>17+00</td>
<td>17,000.0</td>
<td>771.7</td>
<td>707.96</td>
<td>0.375</td>
</tr>
<tr>
<td>17+000</td>
<td>20+42</td>
<td>3,420.00</td>
<td>707.9</td>
<td>682.61</td>
<td>0.741</td>
</tr>
<tr>
<td>20+420</td>
<td>22+22</td>
<td>1,805.00</td>
<td>682.6</td>
<td>662.51</td>
<td>1.114</td>
</tr>
<tr>
<td>22+22</td>
<td>23+98</td>
<td>1,763.00</td>
<td>662</td>
<td>636.65</td>
<td>1.467</td>
</tr>
<tr>
<td>5</td>
<td>8</td>
<td>1,763.00</td>
<td>.51</td>
<td>636</td>
<td>2.399</td>
</tr>
<tr>
<td>23+98</td>
<td>30+80</td>
<td>6,821.00</td>
<td>636</td>
<td>473.01</td>
<td>1.213</td>
</tr>
<tr>
<td>8</td>
<td>9</td>
<td>6,821.00</td>
<td>.65</td>
<td>254.03</td>
<td>3.201</td>
</tr>
<tr>
<td>30+80</td>
<td>41+12</td>
<td>10,317.00</td>
<td>473</td>
<td>254.03</td>
<td>2.123</td>
</tr>
<tr>
<td>9</td>
<td>6</td>
<td>10,317.00</td>
<td>.01</td>
<td>154.68</td>
<td>3.201</td>
</tr>
<tr>
<td>41+12</td>
<td>44+23</td>
<td>3,104.00</td>
<td>254</td>
<td>154.68</td>
<td>3.201</td>
</tr>
</tbody>
</table>
Cross sections shown in Fig. 9 along flow path is not regular and require retention shaping to reduce flood wave.

<table>
<thead>
<tr>
<th>6</th>
<th>0</th>
<th>.03</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>44+34</td>
<td>44+62</td>
<td>277.00</td>
<td>82.</td>
</tr>
<tr>
<td>6</td>
<td>3</td>
<td>8</td>
<td>%</td>
</tr>
<tr>
<td>44+62</td>
<td>47+22</td>
<td>2,605.00</td>
<td>82.</td>
</tr>
<tr>
<td>3</td>
<td>8</td>
<td>4</td>
<td>%</td>
</tr>
<tr>
<td>47+22</td>
<td>50+12</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>8</td>
<td>6</td>
<td>2,898.00</td>
<td>144</td>
</tr>
</tbody>
</table>

Accumulated flow as QGIS analysis equal 1409 cu.m/s which compared to reported flow (1000 -1500 cu.m/s) when the flash flood happened last year.

5.2. RAINFALL DATA

As per a pervious study conducted the flow of the main wadi was decreased from 37.5 cu.m/s in 1981 to .23 in 2010 cu.m/s during 31 years measurement (17), the reported data in the Fig. 10 below was used as input to estimate flood depth using unsteady flow analysis.

Collected data for daily precipitation dated from 22nd October 2018 to 31st December 2018 which received from the municipality of water and irrigation was used as input for flood map inundation as shown in the Fig. 11 below the maximum daily precipitation recorded in October is 50 mm and 46.7 mm respectively. November and December the maximum daily precipitation recorded is 12.3 mm and 12.1 mm.
In the event of dead sea flash flood, the intensity of rainfall, which reached 50 mm in a period of time not exceeding 20 minutes, the frequency as per IDF is 25 years which has been checked from below IDF diagram shown in Fig. 12 for the collected fall depth from 1980 to 2005.

**5.3. Generate Inundation Flood Map**

Using HEC-RAS software to generate a 2D hydraulic model based on unsteady flow analysis to estimate the water surface elevations, depth and velocity using precipitation, flow hydrograph and normal depth data as shown in Fig’s 13, 14 & 15.

**5.4. Generate a Risk Flood Matrix**

Proposed risk matrix shown in the Fig. 16 below based on the impact of flow depth in horizontal row with classified consequences namely: low, minor, major, sever and catastrophic and probability of occurrence of return period in vertical row classified to almost certain(every time), likely (1-5 years), possible(25 years), unlikely(25-50 years), rare(100-200 years), which used to define degree of risk by multiply impact by probability and the results classified into low, medium and high, represented green, yellow and red respectively. Quantitative and cost analysis for the risk to be conducted in future works.

**5.5. Define Strategies of the Vulnerable Local Communities**

Due to the lack of warning system the response of emergency was weak as reported and discussed in the...
previous studies [21, 9]. The strategies summarized in table I below are essential to eliminate risk.

**TABLE 2.: STRATEGIES OF THE VULNERABLE LOCAL COMMUNITIES**

<table>
<thead>
<tr>
<th>Strategies</th>
<th>Indications for evaluation</th>
</tr>
</thead>
</table>
| Warning system & response | - Flood warnings to be increased to reach the most flooded areas.  
- Warning responses to be identified  
- Provide evacuation paths.  
- Implement flash flood warning system based on the France experience using AIGA (method in 2017 (10)). |
| Response after the flood | - Flood insurance.  
- Provide flood assistance plan. |
| awareness raising through learning | - warning systems and responses to be learned in schools and companies  
- Internet pages,  
- Accessibility of information for risk map locations. |
| Mental models analysis | Improving flash flood risk communication and public decision making (12). |
| Spatial Planning | Flood damage limitation, Natural retention protection for catchment area.  
Negative environmental fallout limitation from second flood hazard. |

**5.6. DEFINE STRUCTURAL STRATEGIES:**

The aim of defined structural measures summarized in table II below to delay speed of flow which reached 10 m/s and to control flood spread for the non-uniform wadi path cross sections to reduce impact of flood culmination.

**TABLE 3.: STRUCTURAL STRATEGIES**

<table>
<thead>
<tr>
<th>Strategies</th>
<th>Examples and goals</th>
</tr>
</thead>
</table>
| catchment area and flow path activities | - Terraced surrounding land and farms, constructed stone walls.  
- Small wadi branches bed stabilization.  
- Add barriers and sand bags  
- Add dikes |
| Wadi diversion to redirect flood water | - Depth Control  
- Slope Control using chutes, concrete lining |
| Shaping retention to reduce flood wave | - Propose small reservoirs to collect water in a permanent or temporary fashion |

**5.7. RECOMMENDATIONS**

Proposed flash flood mitigation strategies as provided in this paper to minimize flood losses human life and constructed structures across Jordan, the likeliness of climate change to result in an increase in intense short-duration precipitation in most of Jordan and human alterations of the landscape to further increase flash flood risk, being aware of the experiences and lessons learned during flash flood in dead sea area.

1. Generate flooding risk maps to assess planners and decision makers for potential impact of floods to avoid.
2. A developed web platform data and information to be shared among NMHSs (National Meteorological and Hydrological Services), Authorities, civil defense educational institutions on flash floods awareness.
3. A global meteorological data and flash flood guideline to be provided, monitored based on NWP (Numerical Weather Prediction) and now casting procedures.
4. Local authorities such as ministry of water and irrigation to undertake spatial planning considering flash floods hazards.
5. Proposed flood risk mitigation plan as per Fig.17 below.

Fig. 17. : Flood Risk Mitigation Plan

**REFERENCES**


Digital Terrain Analysis in Terrain Analysis Principles and Applications.


