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Hydrological Modelling of Flash Flood at the UNESCO World Heritage Site Petra, Jordan

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Abstract

Wadi flash floods in the Middle-East-North-Africa (MENA) region are considered as one of the most catastrophic phenomena possessing hazardous threat to the coastal cities and infrastructures, and human lives as well as the UNESCO World Heritage Sites (WHS). As it was seen in November 2018 and April 1963 in the UNESCO WHS Petra in Jordan, flash floods pose a serious threat to the lives of the tourists and the locals living there as well as the monuments themselves. Despite the advanced technology that exist nowadays, there is an obvious lack of mitigation measures in Petra catchment such as check dams, vegetation, diversion channels and terraces. This study aims to apply the 2-Dimonesional Rainfall-Runoff-Inundation (RRI) model on the catchment to simulate different extreme events scenarios. Moreover, it aims also to develop and come up with the optimum flash flood mitigation measures that can be implemented at Petra to reduce the flash flood risk on the tourists and the locals as well as the monuments at Petra. The RRI model was adapted to simulate different flood events and to estimate their impacts on flood peakflow, inundation and runoff volumes. Several field surveys have already been conducted and some appropriate sites for some mitigation measures such as dams can be built based on the geomorphological features as well as inundation areas and the hydrological conditions. Using the hydrological model, dams as well as other mitigation measures such as diversion channels, terraces and afforestation are going to be estimated in the hydrological model. The results of mitigation measures impacts on flood peakflow and volume as well as the inundation in the area are going to be represented. Due to climate change, the risk of flash flood is increasing, especially in the MENA region. Therefore, the study is a way forward to promote the awareness as well as to propose possible flash flood mitigation measures in the MENA region.

Introduction

Many natural disasters affect the MENA region such as drought and flash floods. The intensity of such disasters became more frequent in the last decade. Climate Change could be the driving force or maybe it is just due to increasing media coverage. In this study, the focus is on the ancient city of Petra in Jordan. As shown in Figure 1, Jordan is located in the heart of Middle East, a strategic location that gave the country a prestigious role throughout history to be part of the ancient world and made it one of the most important ancient routes in ancient history. Consequently, many civilizations such as the Nabatean civilization were based there and carved their own city, Petra. Petra is one of the most important and famous attractions, not only in Jordan, but in the entire world. In 2007, it was voted as one of the "New 7 Wonders of the World". It is located in the south of Jordan, Petra is the major site with antiquities dating back to 7500 BC(Al-Weshah and El-Khoury 1999). The site plays a very important role in the tourism of Jordan. The tourism in the country is a major contributor to the national economy.

Historical records and other events related to flash floods threatening Wadi Musa and Petra have shown that flood protection and mitigation measures are urgently needed in order to protect the monuments, the locals and the tourists. Such measures should be

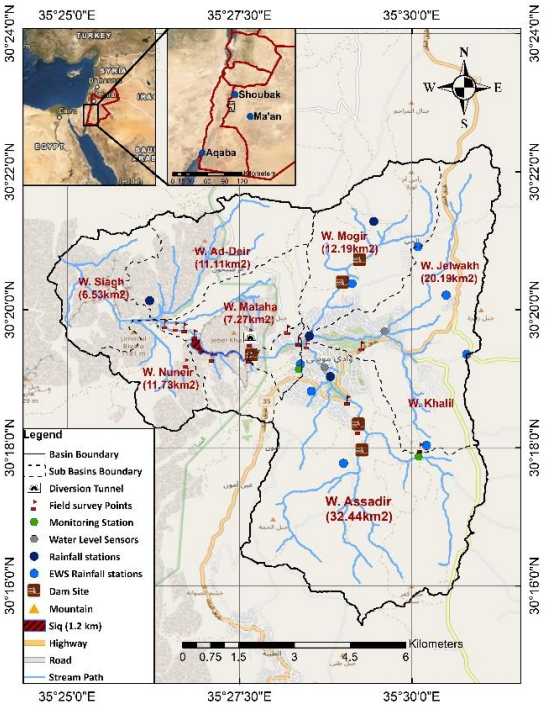

Figure 1: Detailed map of Petra showing the wadis in the catchment, the rainfall stations, the stream network, and the dams

implemented after a hydrological assessment and analysis considering the unique nature of the area.

Methodology

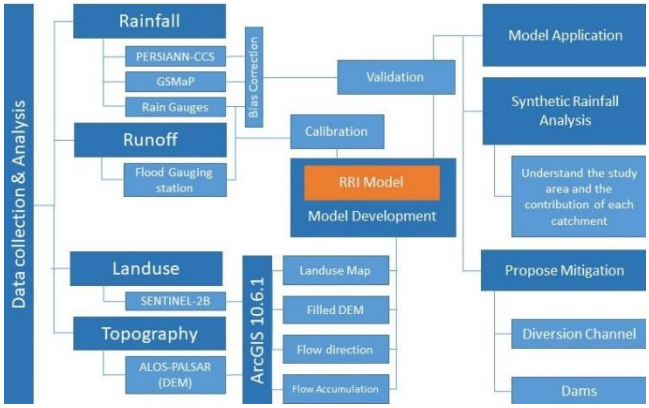

Figure 2: Flow Chart of the Methodology for RRI model

Rainfall-Runoff-Inundation Model (RRI Model) has been applied for flash flood events in Petra Catchment after its calibration and validation(Sayama, Ozawa et al. 2012; ABDEL-FATTAH, KANTOUSH et al. 2016). Flood simulation was performed based on daily time series rainfall data because of the lack of hourly observed data. For the channel cross-sections settings, two locations were used: one in the upstream in Wadi Assadir and the other one is downstream next to the archaeological park entrance in addition to Google Earth Images to estimate the channel width and depth parameters area information were $W=C_W\ A^{SW}$ and $D=C_D\ A^{SD}$(C_W= 2.86, S_w= 0.449, C_D= 0.766 and S_D= 0.413). The rainfall and the peakflow records for the events in 1968, 1970, and 1974 were used for the calibration(Al-Weshah and El-Khoury 1999)(. The model was calibrated by using each of the three events and validated based on the other 2 ones. The major sensitive RRI model parameters setting by assigning case-a to Urban and Sandstone, case-b to Limestone and case-c to Vegetation. Figure 2 shows the methodology of the application of the model. First the topographic data were obtained by using ALOS-PALSAR 12.5m DEM data. The flow direction and flow accumulation using ArcMap 10.6.1. Moreover, the land use map was developed using the classification of sentinel 2B satellite image using ArcMap. Regarding the rainfall data, the observed daily data were obtained from 3 different stations distributed around the catchment. There were a lot of missing records in the data. Therefore, it was better to use satellite data. However, in order to use the satellite data some bias correction needed to be done (Lafon, Dadson et al. 2013). In this case, the linear correction method was used. A comparison was made to choose which satellite data should be utilized in the area. PERSIANN-CCS was chosen since it has better performance to record the rainfall in the area as well as its resolution, 4km, which was better than GSMaP data's resolution, 10 km. The validation of the RRI model was done based on the calibrated RRI model, the corrected PERSIANN-CCS data and the water depth level recorded by the Petra Development and Tourism Regional Authority (PDTRA). The locations of the dams were chosen during on the field campaign based on the geomorphological features and the hydrological conditions of the selected areas.

Results and discussion

It was found that the water level records used in the Early Warning System EWS are not reliable at all and their corresponding hourly rainfall data had to be treated first. The R^2 of the GSMaP data was lower than the R^2 of the PERSIANN-CCS. Therefore, the later one was chosen for the bias correction. It was found that the PERSIANN-CCS data is underestimated in the study area by 56%. The bias factor obtained is 2.23. Regarding the calibration of the RRI, Table 1 shows the results of the simulation used in the events chosen for the calibration.

Table 1: Results of the calibration of RRI model

Event	observed	simulated	Daily Rainfall
1	1.79	1.53	21
2	2.18	2.58	46.1
3	0.41	0.36	15.7

Regarding the validation of the RRI model, the model showed a good performance in simulating the recent events: January & February 2013, November 2013 and November 2018.

Conclusion

The RRI model showed a great performance in simulating the extreme events in Petra. It showed also that such mitigation measures in the area are needed. Moreover, the rainfall stations in the areas need to be checked and maintained from time to time. Despite the importance of the area, there was only one hydrological study that has been done on the area in 1999. This study is a recent study that considers the new technics that can be utilized as well as the importance of the implementation of such mitigation in the study area.

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