FLASH FLOODS: RISK ASSESSMENT AND MITIGATION

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In recent years, United Arab Emirates has experienced several flash flood events and extreme cyclonic events that resulted in flooding various parts of the country. This in return raised concerns on the preparedness of the infrastructure to such events considering the damage caused by them. Roads were blocked from the excessive rainfall water leading to heavy traffic jams, houses were drowned and cars were swept away. Therefore, an in-depth study was performed on a selected area of interest in the city of Ras Al-Khaimah (UAE) to explore the risks associated with flash flood events and to propose solutions for flood management. Hydrological and hydraulic models were used to simulate precipitation runoffs and calculate flood magnitudes in order to plan and design new flood control and hydraulic structures. Using the output of the hydrologic and hydraulic models, a dam and a protection channel were proposed as possible solutions to resolve flood issues in the selected area. It was concluded that with proper hydrologic modelling, flash floods can be managed to a great extent and damage to the infrastructure can be minimized. It is even more important in context of climate change that such modelling techniques should be part of urban planning and design of infrastructure drainage systems for areas that are prone to heavy rainfall and floods.

Keywords: Climate change, Rainfall, Infrastructure, Drainage system, Urban planning.

1 INTRODUCTION

Climate change has been a subject of concern for the last two decades and the risks associated with it continue to increase. One of the most endangering aspects of climate change is the flood events happening due to the rise in sea level and heavy rainfall events (IPCC 2013). According to the World Meteorological Organization (WMO) (2020), the global temperature as of 2020 is 1.2 ± 0.1 °C warmer than the pre-industrial (1850-1900) baseline, the sea level has been rising on an average of 3.29 (+/- 0.3) mm per year, and no. of extreme events such as fires, floods, droughts, heat waves, cold waves and severe cyclone storms have also increased across the globe.

1.1 United Nation’s Sustainability Development Goals

The United Nations has developed several Sustainable Development Goals (United Nations Sustainable Development 2015) targeting the environmental, social and economic factors on a global scale that are set to be achieved by its 2030 agenda. One of the goals in the SDGs targets climate change and emphasizes on taking urgent action to combat climate change. Following up with the development of the SDGs, the Paris agreement, which is a legal binding international treaty on climate change, was also adopted by 196 parties at COP 21 in Paris in 2015 (UNFCCC 2015). The United Arab Emirates (UAE) is one of the contributing countries in the UN SDGs. The UAE
has set a National Climate Change Adaptation Program NCCAP 2017-2050 developed by UAE Ministry of Climate Change and Environment (MOCCAE 2020) to make it stand out as one of the climate-resilient countries worldwide. The program focuses on assessing the impacts of climate change on key sectors such as health, infrastructure, environment and energy, and to identify the associated risks in order to build resilience, take urgent actions and develop well-established adaptation measures towards them (MOCCAE 2020).

1.2 Flash Floods in The United Arab Emirates

In the recent years, UAE has experienced several flash floods as well as cyclonic events from neighboring countries that resulted in flooding the coastline areas and causing extensive damage (Davies 2017). In April 2024, the gulf region was hit by a massive storm with a record 254 millimeters of rainfall in Al Ain, a city in the UAE. It was the largest ever in a 24-hour period since records started in 1949 (Cornwell 2024). In 2020, the UAEs National Center of Meteorology NCM reported the highest rainfall record since 1996 in UAE with 190.4 mm of rainfall. Several government initiatives (Celestial 2020, WAM 2020) have been taken to mitigate the issue; however, a long-term plan is needed to tackle the climate change, or more specifically, the flooding issue. Therefore, it was deemed necessary to conduct an in-depth study on the risks associated with heavy rainfalls events in the United Arab Emirates and suggest possible solutions. The research was conducted in collaboration with the Ministry of Energy and Infrastructure UAE (formerly known as Ministry of Infrastructure and Development) on a selected case study area, for which geographical and hydrological details were provided by the ministry. The research aims to offer a reliable methodology that can be applied in designing and executing dam or drainage system projects throughout the United Arab Emirates.

2 THE RAS AL-KHAIMAH CASE STUDY

2.1 Background

This research is focused on analyzing the floods occurring in Shamal area located in Ras-Al-Khaimah. The study area has a hot desert climate with high temperatures and infrequent irregular low rainfall. The minimum temperatures never go below 0 degree in water, but the maximum temperature rises to more than 45 degrees in summer. The mean annual rainfall is around 119 mm; however, this level varies greatly from year to year, ranging from 282 mm to 24 mm and almost 90% of these rainfalls occur during winter, with a mean annual evaporation of 3322 mm. This area is characterized by a rugged mountain terrain, bare and rocky with little or no vegetation, with elevations of around 600 m that transition down to 100 m, making the wadi area and its surroundings be the lowest point, thus, it is where all the water accumulates. The soil types of the study area were subdivided into five series on a basis of texture and carbonate content: wadi gravel soils, sierozems, non-saline alkali soils, saline non-alkali soils, and saline alkali soils.

It is also observed that this area is affected by the flash floods coming from wadi Haqeeq which has a catchment area of 24.7 km² according to the data provided by MOEI. The residential areas are being constructed in the direction of the wadi flow pattern, which automatically obstructs the natural flow of water, thus, resulting in endangering the livelihood of the citizens. In addition to that, there is lack of protection channels embedded in the area, which again increases the risks of flood occurrence.
2.2 The Hydrological Modeling Process

After defining the characteristics of the study area, a Hydrological Modeling System, HEC-HMS (U.S. Army Corps of Engineers 2020a) was used to develop the hydrologic model. The simulations are based on an event or continuous model, where a single storm event can range from few hours to days and a continuous model for longer periods, predicting watershed response both during and between precipitation events (U.S. Army Corps of Engineers 2000). The single event model was run for a period of 24 hours. In addition, for hydraulic modelling and simulations, a hypothetical (virtual) day of storm is required as an input which was also provided. For modelling the runoff volume, the model parameters are combined from each of the runoff-volume models, direct runoff models and base flow models along with routing choice models. The process is described briefly below.

2.2.1 Defining the physical characteristics of watershed and calculation of runoff volumes

A basin model is used to define the physical characteristics of watershed. Interconnected hydrologic elements are created to simulate runoff processes and subsequently, the infiltration losses. For computing the runoff volumes, the watershed is considered as a pervious surface and cumulative volume losses for the study area are computed using the Initial and Constant-Rate loss model and the Soil Conservation Service (SCS) curve number loss models, details of which can be found in HEC-HMS User’s Manual (U.S. Army Corps of Engineers 2020b).

2.2.2 The kinematic wave modelling technique

In order to select the drainage system required, kinematic wave modelling technique is used to showcase the watershed responses. The model usually presents the watershed as an open channel with inflow equal to the excess precipitation. Different flow components are defined, such as shape of the cross-section, principal dimension, side slope, length of the reach, slope of the energy grade and the Manning’s roughness coefficient for channel flow (U.S. Army Corps of Engineers 2000).

2.2.3 The annual runoff coefficient

The annual runoff coefficient was based on the specific flows at the most appropriate flood gauge stations. Five wadi gauging stations and their historical flood data were selected and analyzed. However, it is worth noting that the flood gauges are not related to respective rainfall stations data for a direct relationship between rainfall and runoff. Furthermore, during the on-site visits, it was observed that the flood gauges are usually installed in the boundaries of the wadi beds instead of being in the wadi bed, which refers to the likelihood of the flood flows to not pass in the direction of the installed gauges. For this reason, a minimum runoff coefficient of 10% to 14% was deemed suitable for this area and an average runoff coefficient of 12% was used. For higher intensity rains and using the Probable Maximum Flood (PMF), the maximum runoff factors range from 50% for gravel hills to 75% for mountainous areas. Lastly, an initial loss of 10 mm and 6 mm per hour as constant loss was considered for the analysis (Fig. 1).

2.2.4 Probable Maximum Precipitation (PMP) and the design storm rainfall

The most intense storm recorded in the gulf region was at the air-force base on Masirah Island off the south-east coast of Oman in 1977 with 431 mm of rainfall over a 24-hour period. Other significant rainfall events in the gulf were two storms in Jeddah, Saudi Arabia that occurred in November 2009 with over 90 mm rainfall over a period of 4 hours and in January 2010 with over 111 mm of rainfall in 3 hours, respectively.
In order to estimate the Probable Maximum Precipitation (PMP), the relationship derived by the World Meteorological Organization (WMO) (2020) for the UAE mountains is used, where \(\text{PMP} = 170D^{0.475}\) (D is the storm duration in hours). This equation estimates a rainfall of 769 mm over 24 hours. The design storm rainfall is calculated using the index flood method, \(\text{MAF} = 23.17\ \text{AREA}^{0.2136}\), where MAF is the Mean Annual Flood in \(\text{m}^3/\text{s}\) and AREA is the catchment area in \(\text{km}^2\).

![Diagram of hydrological modeling process](image)

**Fig. 1.** The hydrological modelling process (adapted from U.S. Army Corps of Engineers 2020a) and the input parameters for the model.

### 2.2.5 Collection of the digital topography and precipitation data

In this study, GIS files provided by Ras Al-Khaimah municipality were used to illustrate the topography of the area along with detailed digital terrain models DTM extracted from high resolution satellite imagery. As for the precipitation data, it is sourced from the Ministry of Climate Change and Environment for a period of 1979 to 2009 for wadi Bih and Burayrat Station that are closer to the area under study. No data is available after 2009 for both stations as they are no longer operational.

### 2.3 The Hydrological Model Output

A sequential procedure was followed in order to determine the rainfall runoff volume and peak discharges which were then used to test the applicability of constructing the relevant hydraulic protection system to regulate the flood water flow. Two different rainfall scenarios were run. In the first scenario, the actual maximum daily rainfall of 105 mm obtained from Bih rainfall station was used, whereas for the second scenario maximum daily rainfall of 200 mm was used as the maximum rainfall based on the PMF. In both case scenarios, the hydrologic model showed similar rainfall pattern response. Moreover, the rainfall flow pattern started from the upstream of the wadi to a collective root/area, which as shown, results in flushing the area surrounding the wadi with water.

### 2.3.1 The proposed hydraulic protection system

Based on the results of the hydrologic simulations (Fig. 2), the proposed hydraulic protection system consists of constructing a dam and a water corridor to control the water flow and is demonstrated in Fig. 3.
The embankment dam, SHAM100, will act as a large retention reservoir located close to the mouth of wadi Haqeeq. Downstream from the dam, the water corridor or channel, 100-23, is foreseen to convey the discharge of the spillway from extreme events to the sea. The channel follows a straight alignment downstream and it is acknowledged that it passes from a strip of existing dwellings almost to its entire routing. It is to be noted that this is the most optimum route from a hydraulic perspective, however, it would need a formal review by the authorities for the future development plans of the area. Nonetheless, as the entire downstream area surrounding the wadi path up until the sea is currently inhabited and filled with residential houses and buildings, no other option is found suitable other than designating the most optimum corridor as a new zone to regulate the water flow towards the sea during extreme events.

As far as the impact of the proposed hydraulic protection system (Fig. 3) is concerned, it is to be noted that for the 105 mm rainfall event (Bih station), the hydrologic model showed a peak discharge of 224.8 m$^3$/s with volume being 691.9 (1000m$^3$). After designing the hydraulic structure, the peak discharge was reduced to 3.8 m$^3$/s with a volume of 422.1 (1000m$^3$). As for the 200 mm rainfall event, the hydrologic model showed a peak discharge was 465.6 m$^3$/s with discharge volume of 2024.7 (1000 m$^3$). However, with the hydraulic structure, the peak discharge was reduced to 5.3 m$^3$/s with a volume to 662 (1000 m$^3$). Additionally, the storage of the reservoirs is estimated to reach 664,800 m$^3$ for a daily rainfall of 105 mm and 1,924,600 m$^3$ for 200 mm daily rainfall.

3 CONCLUSIONS

This research shows that hydrologic models are quite useful in simulating precipitation runoffs and calculating flood magnitudes. With proper hydrologic modelling, flash floods can be managed to a great extent and damage to the infrastructure can be minimized. Based on the results of the hydrologic simulations, a dam SHAM100 and a protection channel 100-23 were proposed to resolve the flooding issue in the Shamal area of Ras-Al-Kahimah leading to the conclusion that the
hydrologic modelling techniques should definitely be part of urban planning and design of infrastructure drainage systems for areas that are prone to heavy rainfall and floods.

Fig. 3. Proposed hydraulic protection system.

References


