Flash Flood Modeling on Wadi Reem in the western region, Kingdom of Saudi Arabia

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ABSTRACT

Most of Saudi Arabia can be considered a typically arid region where the annual average amount of rainfall varies between 50 and 100 mm. Asser Region in western Saudi Arabia is characterized by high rainfall intensity that leads to flash floods. Using digital elevation model (DEM) Watershed and its stream were delineated and morphological parameters calculated using Watershed Modeling System (WMS). Rainfall frequency analysis was performed for selected three rainfall gages using annual maximums of 24-h rainfall. As a result of the sparse hydrologic information, the relation between rainfall and runoff was calculated depending on the morphometric parameters, GIS techniques, Watershed Modeling System (WMS) and Hydrologic Engineering Center- Hydrologic Modeling System software (HEC HMS). In this work, the flood risks were studied and the results are considered the baseline data required to designate the required protection system against these risks. This study aims to assess the impact of flash floods in the Wadi Reem basin, which located in Assir Region, Saudi Arabia

Keywords: Flash flood, Wadi Reem, Saudi Arabia, Morphological parameters, WMS , HEC-HMS Modeling

INTRODUCTION

Flood impact is one of the most significant disasters in the world. Floods are due to natural factors such as heavy rainfall, high floods and high tides, etc., and human factors such as blocking of channels or aggravation of drainage channels, improper land use, and deforestation in headwater regions, among others.

Saudi Arabia has very limited water resources most of which are form groundwater reserves. Living under these conditions makes it necessary to conserve and develop each drop of water in these areas. In the western part of Saudi Arabia, the Hijaz Scarp Mountains receive comparatively the highest rainfall in the region, due to its high mountainous nature.

Water resources need to be carefully monitored and managed in order to achieve their sustainability and continue to be beneficial to the society. Watersheds are important units of which water and other natural resources can be strategically managed (Singh *et al*., 2017). Watersheds need to be carefully managed in order to use water resource wisely and optimally. Surface hydrological indications are one of the promising scientific tools for assessment and management of water resources (Ouyang *et al*., 2011; Viji *et al*., 2015).

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The western region of Saudi Arabia is characterized by low altitude-flat coastal plain bounded from the east with a chain of high rugged mountains of the Arabian Shield oriented North-Northwest to South-Southeast. Many of the major cities and villages along the coastal plain are situated along or at the mouth of these wadis. Due to the aridity of the area and lack of long-term strategic planning, most of the population tends to settle along wadi courses and sides. Flash floods along these wadis caused severe damages to lives and properties in the past (Subyani *et al*., 2009).

The main objective of this study is to estimate direct runoff for the study area watershed where the records of runoff are not available. Within the framework of this study, the following data and parameters should be obtained and determined:(1) The boundary of catchment, sub-catchment, and stream network of the watershed under the study area; (2) The rainfall data include values of precipitation; (3) The geographical characteristics and the geology of the study watershed; (4) The soil type properties and land use of the study watershed.

MATERIALS AND METHODS

Models used:
The Digital elevation model (DEM) was used to evaluate the efficiency of the investigated basin through its morphometric parameters of the drainage system.

Basic parameters such as area, perimeter, elevation, slope, width and length of watershed, stream order, stream number and stream length were measured directly from the DEM using Watershed Modeling System (WMS) softwear.

Rainfall frequency analysis was performed for selected three rainfall gages using annual maximums of 24-h rainfall.

Hydrologic Engineering Center- Hydrologic Modeling System software (HEC HMS) were used to calculate the runoff volume and peak runoff rate , depending on the morphometric parameters, GIS techniques, Watershed Modeling System (WMS) due to the sparse hydrologic information

RESULTS AND DISCUSSION

Location and description of the study area:
The Wadi Reem catchment area in this study is located in Asseer Region, Saudi Arabia, between latitudes 17°42'15.51"N to 18°16'20.05"N (North) and longitudes 41°59'35.68"E to 42°22'35.04"E (East) (Fig. 1). The study area basin is surrounded by high mountains from east and north. It includes various land use activities including residential, urban, and agricultural as well as road networks.

Altitude
Wadi Reem basin can be divided into three main topographic features; The Red Sea coastal plain (Tihamah), the Hills, and the Scarp of Hijaz Mountains. Tihamah area is a flatted land located in the East and North East of wadi Reem basin, and its width is about 33 km and the elevation of Tihamah varies from sea level to 300 m above sea level. The hills are area which sloping slightly at west of the Scarp Mountains and the elevation of the hills varies from 400 m to 1,139 m above sea level. The Hijaz Mountains belt is characterized by knife-edged ridges and deep canyons (Fig. 2).

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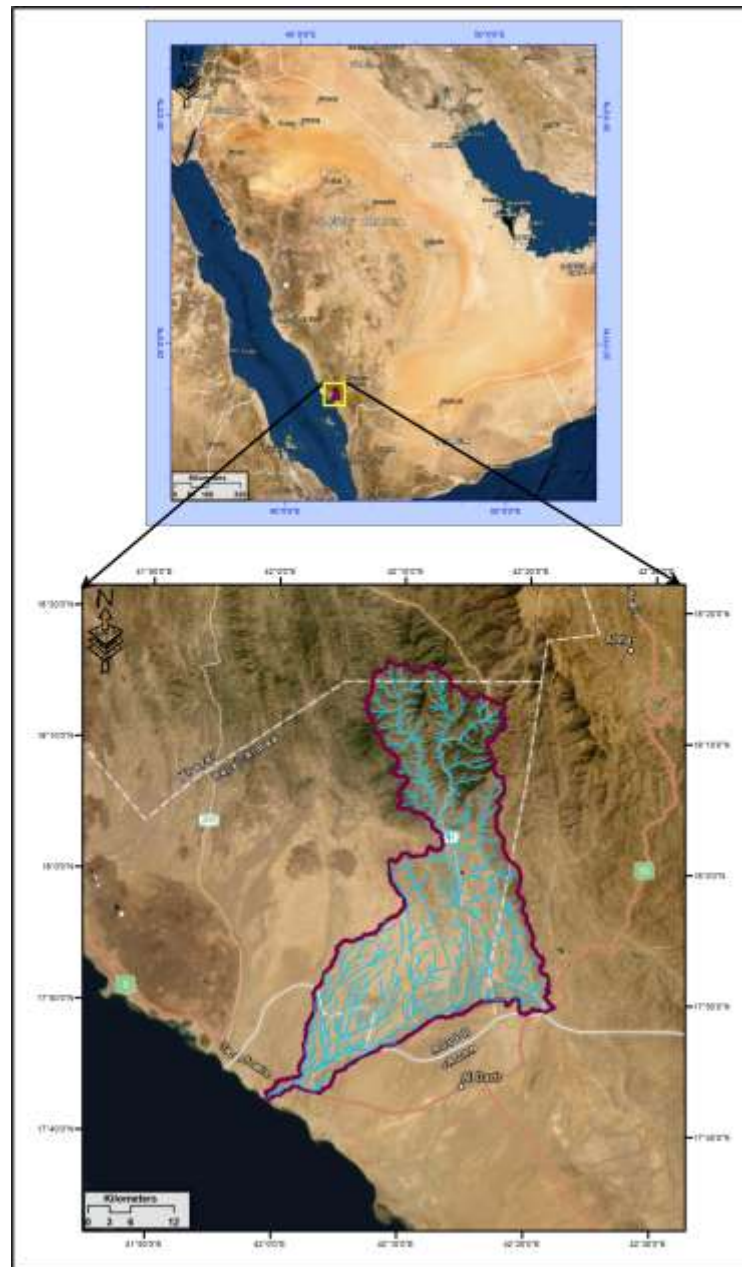
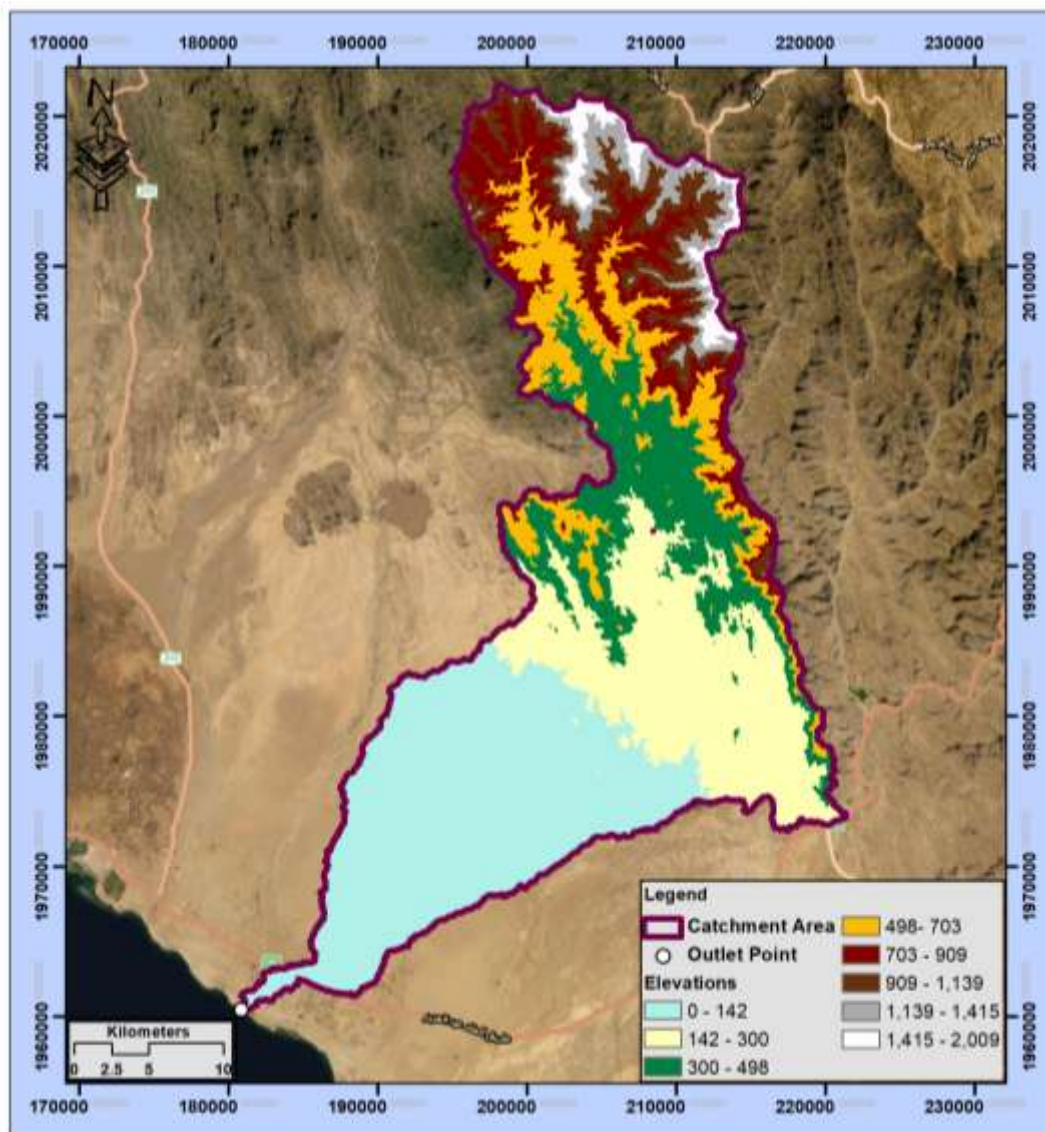**Fig. 1: Location Map of Wadi Reem basin.**

Fig. 2: Digital elevation map (DEM) of Wadi Reem basin.

Basins Delineation and Morphometric analysis

     The efficiency of any basin can be evaluated through its morphometric parameters of the drainage system. Basic parameters such as area, perimeter, elevation, slope, width and length of watershed, stream order, stream number and stream length could be measured directly from the DEM using WMS SOFTWEAR. The main morphometric parameters of Wadi Reem basin are shown in Figure (3) and Table (1).

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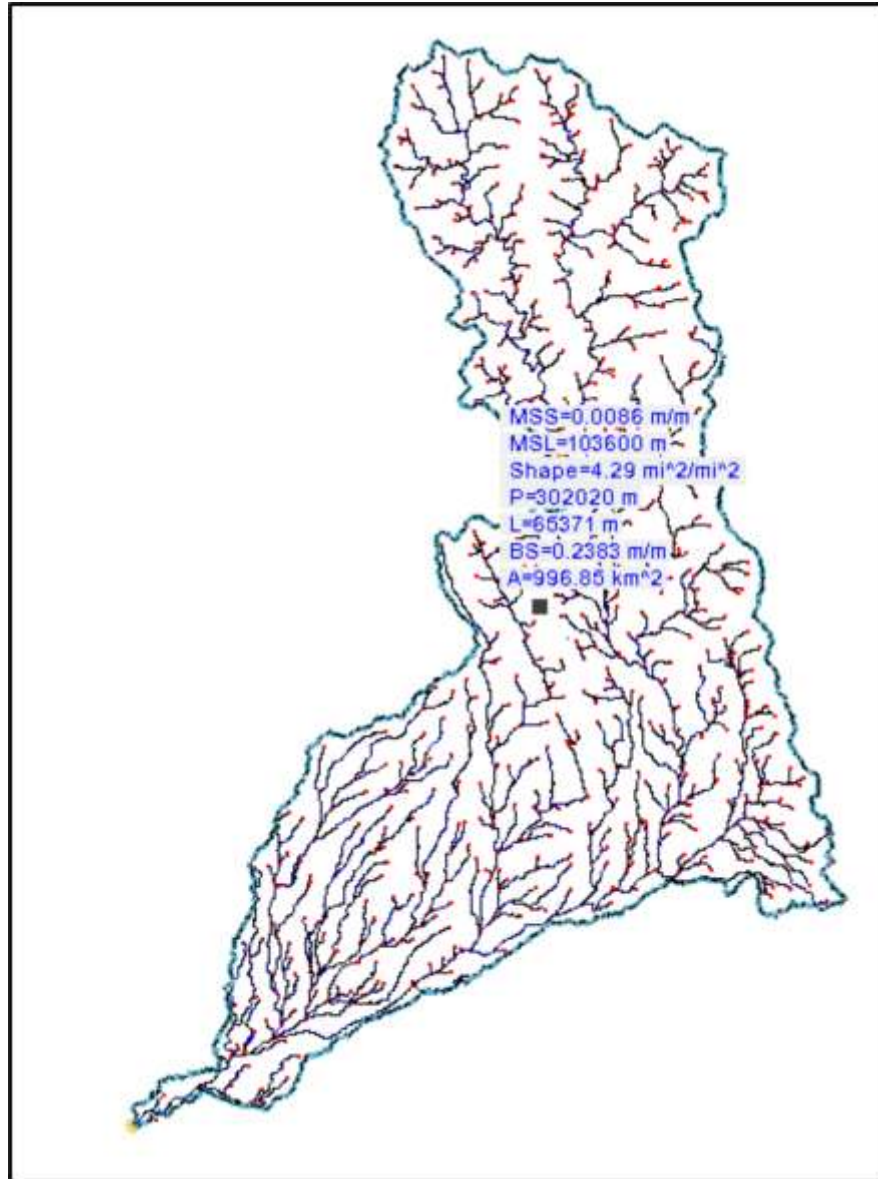
Fig. 3: Wadi Reem basin Delineation and its morphological characteristics measured directly from DEM using WMS SOFTWEAR.

**Table 1: The morphometric parameters of Wadi Reem basin.**

Basin Area (km^2)	Basin overland Slope (BS) m/m	Maximum Stream Length (MSL) km	Basin Perimeter (P) m
996.85	0.238	103.600	302020

Geology and Land use

Interpretation of the geological maps (GM-70C and GM-75C) (1:250,000-scale) acquired from the Saudi Geological Survey database for the study area revealed the rock types in The

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Wadi Reem area and is shown in Figure (4a).

Based on field observation and the supervised classification of Setinal-2 satellite image results showed that there are seven types of land use/land cover in the studied basins, namely: Mixed forest or shrubland, Mixed cropland vegetation and shrubs, Cropland and Pasture, Farmlands, Mixed Urban or Built-up Land, Rocky areas and Desert areas as shown in Figure (4b).
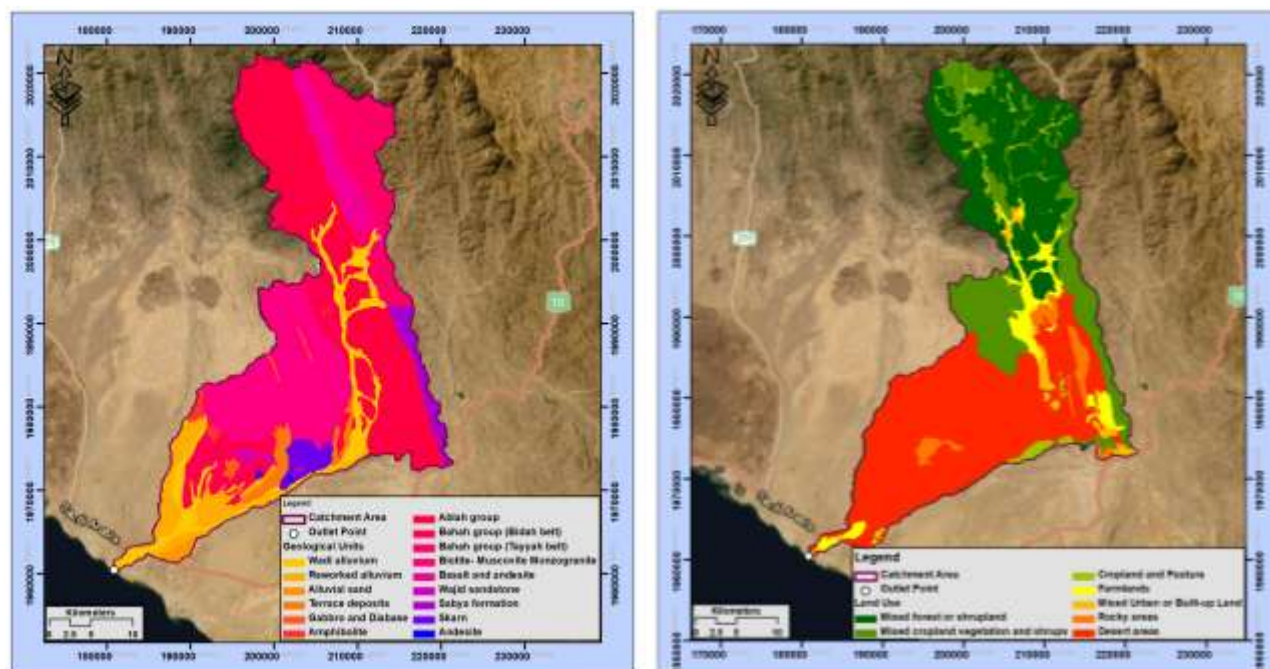
(a)   (b)

Fig. 4: (a) Geological map of the Wadi Reem basin Watershed, (b) Land uses map of the Wadi Reem basin Watershed.

Hydrologic soil maps and Curve Number

The SCS model categorizes soil types into four groups which are A, B, C and D, in accordance with their infiltration rate (Sindhu *et al*., 2013). A **Hydrologic Soil Group** (HSG) map was carefully produced based on the different types of soils in the watershed whereby each soil type was attributed to the hydrological soil group it belongs to. Classification of HSG in accordance with the SCS-CN standards is shown in Figure (5.a).

CN is the curve number, a dimensionless number that range from 0-100, which is drawn from a table provided by the SCS handbook of Hydrology depending on the HSG, land use /land cover, and Antecedent moisture condition, AMC (Songara *et al*., 2015; Satheeshkumar *et al*., 2017; Amutha and Porchelvan, 2009). The calculated curve numbers for Wadi Reem basin was 72.72 as shown in Figure (5b).

(a)   (b)

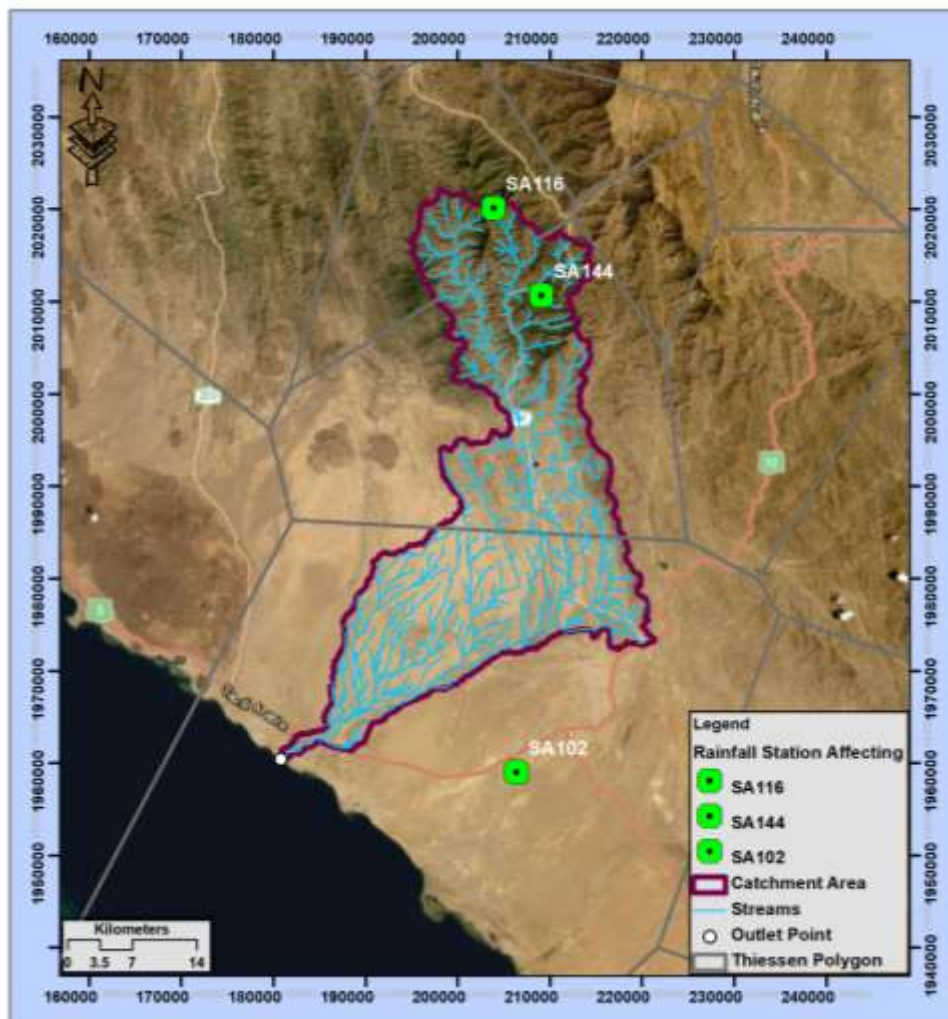**Flash Flood Modeling on Wadi Reem in the western region, Kingdom of Saudi Arabia**
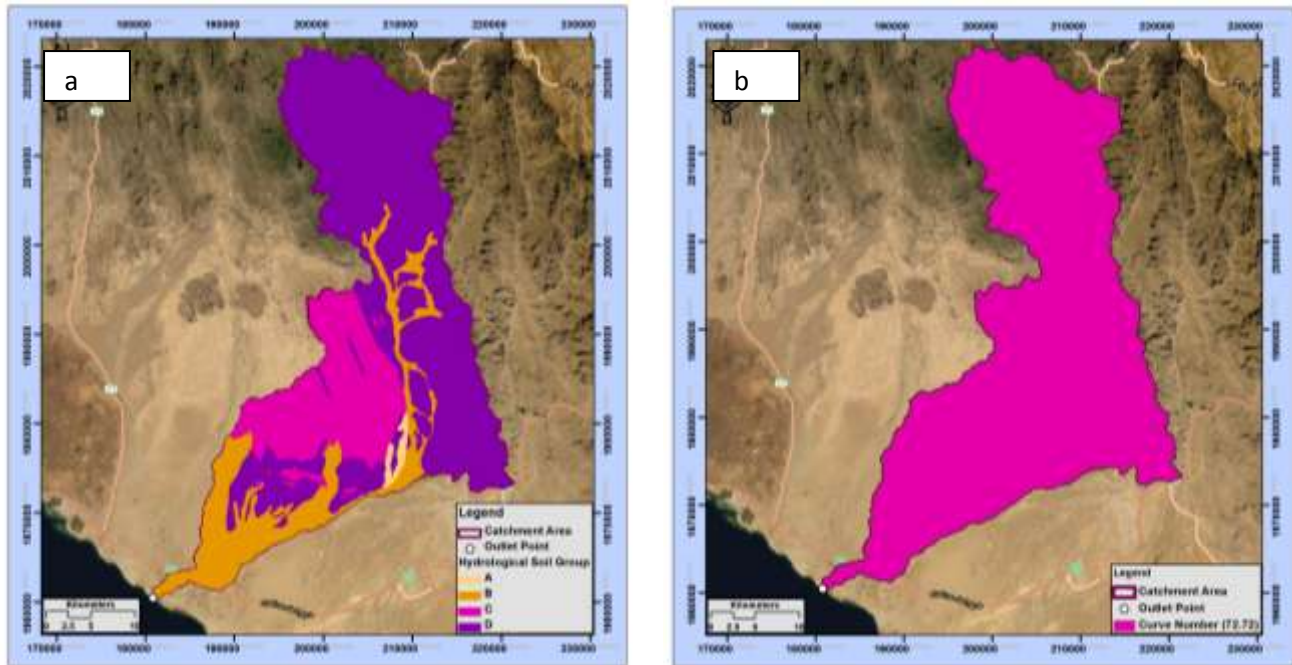
Fig. 5: (a) Hydrological soil group of Wadi Reem basin Watershed, (b) Curve Number of Wadi Reem basin Watershed.

Rainfall station data

It was found that Wadi Reem is affected by three meteorological stations, according to the Thiessen polygons as shown in Figure (6). Theses rainfall station data as the following; Rajal Almaa (SA116), Alhabil (SA144) and Aldarb (SA102), The records also revealed that these stations cover a period of 44 years, 46 years and 39 years, respectively. These stations are operated by the Ministry of Water and Electricity (MOWE).

The depth of the rain was determined in various return periods (5, 10, 25, 50, and 100 years) using the Hyfran-Plus (Hyfran, 1998) and various statistical distributions, such as normal, log-normal, Gamma, Gumbel, and log-Pearson type III, used to verify the results. It was concluded that the method (Normal) is the most suitable for Rajal Almaa (SA116), the method (Gamma) is the most suitable for Alhabil (SA144) and method (Log-Pearson type 3) is the most suitable for Aldarb (SA102) (Fig. 7) and (Table 2).

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Fig. 6: Meteorological stations located in Wadi Reem Watershed.

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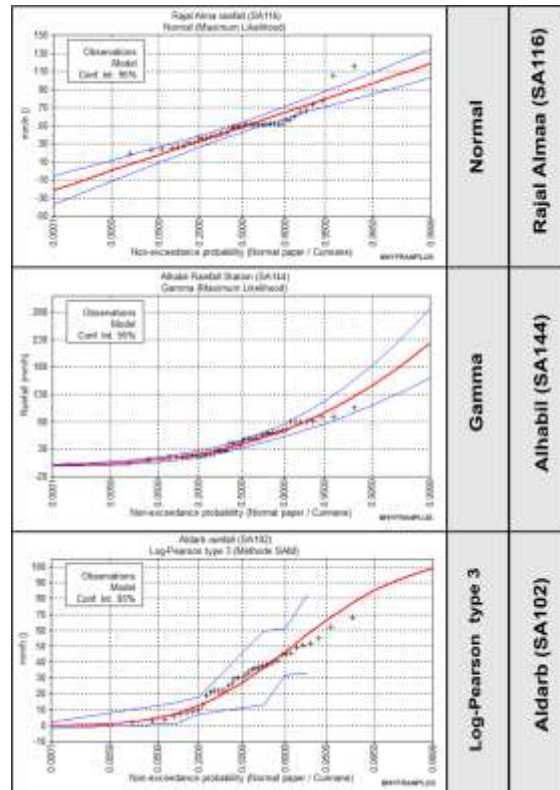
Fig. (7): Probability distribution curve of Rajal Almaa (SA116), Alhabil (SA144) and Aldarb (SA102) using Normal, Gamma and Log-Pearson type 3 distributions.

Table (2): The results at different return periods of extreme rainfall events.

The series of daily rainfall	Statistical distribution	5 years	10 years	25 years	50 years	100 years
Rajal Almaa (SA116)	Normal	64.2	72.5	81.3	87	92.2
Alhabil (SA144)	Gamma	64.3	81.2	102	117	132
Aldarb (SA102)	Log-Pearson type 3	46.5	57.5	68.6	75.2	80.6

Hydrologic Modeling

In this part, HEC-HMS model is used to simulate rainfall-runoff process in Wadi Reem basin, to compute runoff volume and peak runoff rate.

Hydrological modeling is important for watershed management as hydrology is the driving force behind many processes occurring in the watershed and the accurate prediction of runoff responses to rainfall still remaining (McColl and Aggett, 2007). HEC-HMS is widely used as a rainfall runoff modeling tool, and it uses separate sub models to represent each component of the runoff process, including models that compute rainfall losses, runoff generation, base flow, and channel routing (Du *et al*., 2012). Results of 100-year return period hydrograph are illustrated in Figure (8). It was obvious that the hydrograph peak discharge is about 740.14 m^3/s and volume is about 38193590 million cubic meters for Wadi Reem basin.

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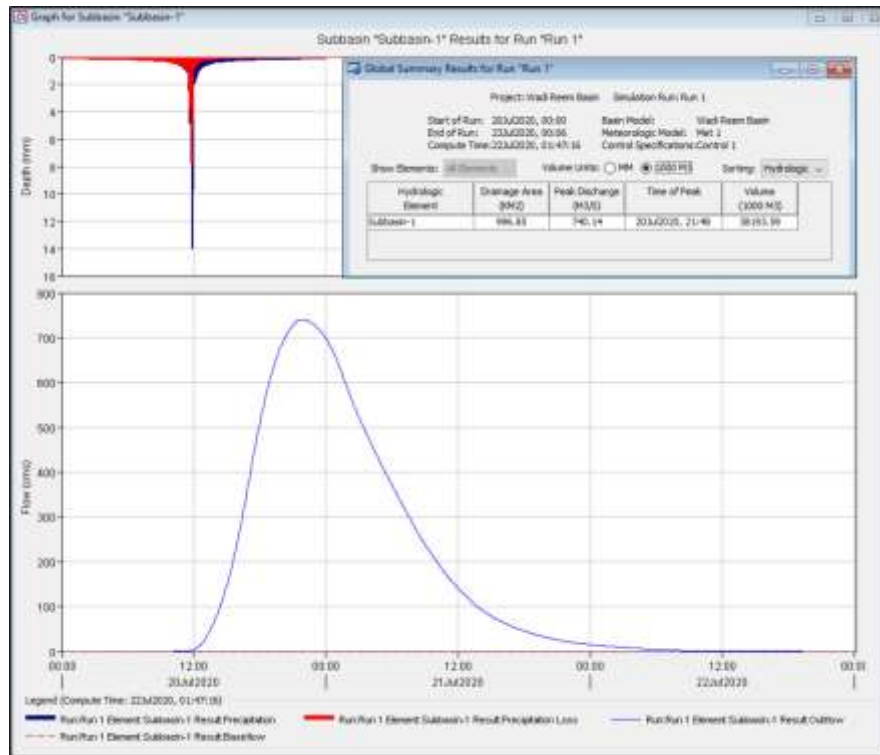
Figure (8): Outlet Hydrograph created by HEC-HMS for 100-year Return period

Floodplain Map

The most important parameters for the HEC-RAS hydraulic model are geometric and flow data. The geometric data have been developed by drawing the stream of Wadi Reem system schematically with flow direction. This was done by using the button of river reach of the HEC-RAS, the methods explain in details in software manual (U.S. Army Corp of Engineers, 2010).

A total of 15 cross sections were taken along the downstream of Wadi Reem as seen in Figure (9). The great numbers of cross-sections were chosen for more details of flood maps. Reducing the number of cross-sections result in poorer inundation maps (Aaron and Venkatesh, 2009). An example of the water surface elevation is given in cross section of Figure (10). After the geometric data was defined and saved, data of discharge was entered for calculation process and finalizing the model creation. Floodplain map has been developed for Wadi Reem stream area using RAS Mapper as shown in Figure (11).

The simulations were performed to define the highest water levels related to the spread of floods in 100 years periods, and their speed and other characteristics. The map shown in Figure (11) presents the heights of the flood; it is to notice that the maximum height is 5.42 m.

The very high flood risk areas are shown in Figure (12) in blue color. In these areas, the level of water can reach the height of 5.42 m and these areas have suffered a lot from flooding as a large number of houses were built in the bed of the Wadi.

The high risk areas are shown in green color (Figure 12). These regions are closer to the wadi bed. They are dangerous during floods as the water level can reach to 3.61 m. They mainly occupy the congested areas near the roads.

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The moderate risk areas are in red colour as shown in (Figure 12), where the height of water can reach to 1.81 m. These areas can become at moderate risk in the event of heavy rains, especially near the bed and along the wadi; this is certainly due to the narrowing of the wadi bed, or to the artificial banks or houses.
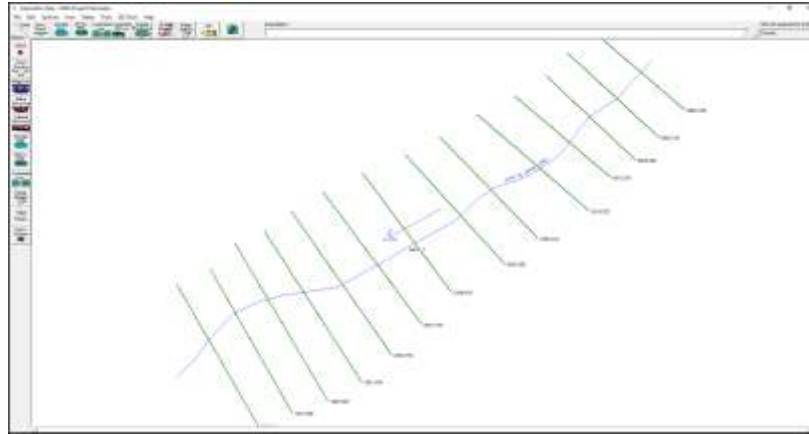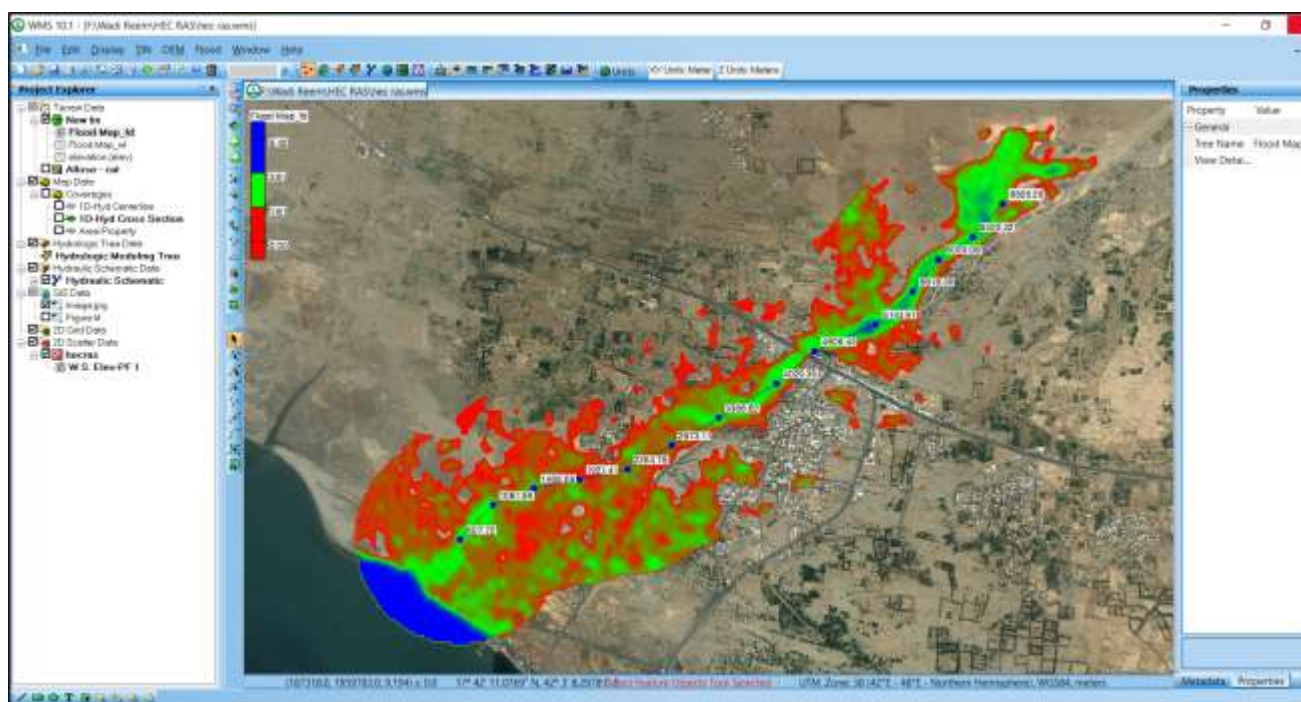

Figure (9): Locations of cross-sections in the HEC-RAS model.
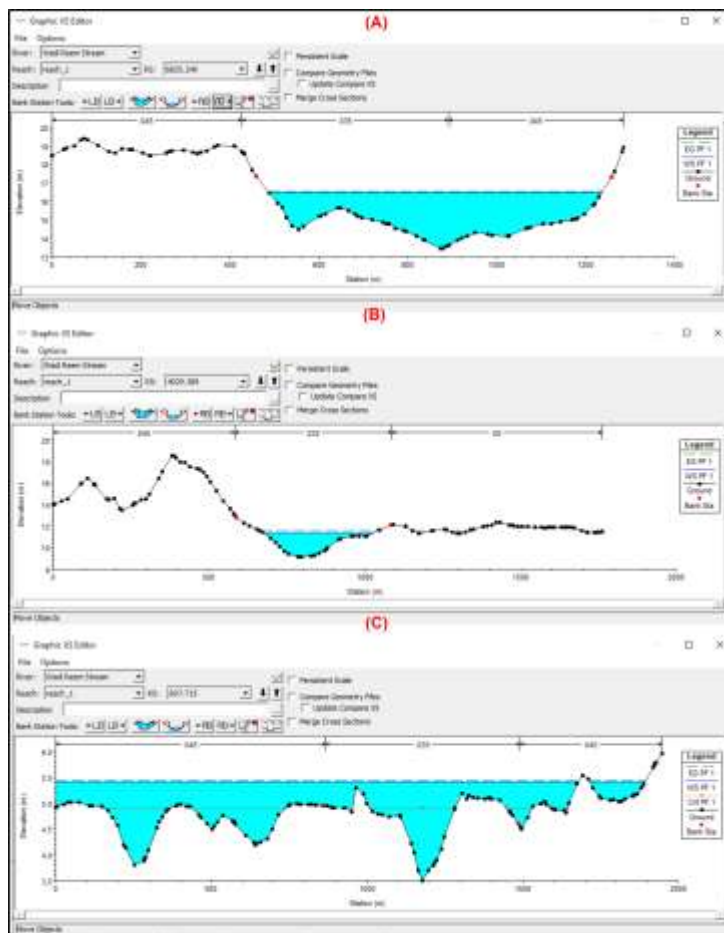
Figure (10): Sample of cross sections; (A) cross section No 6825.249 ;(B) cross section No 4029.389 (C) cross section No 607.715

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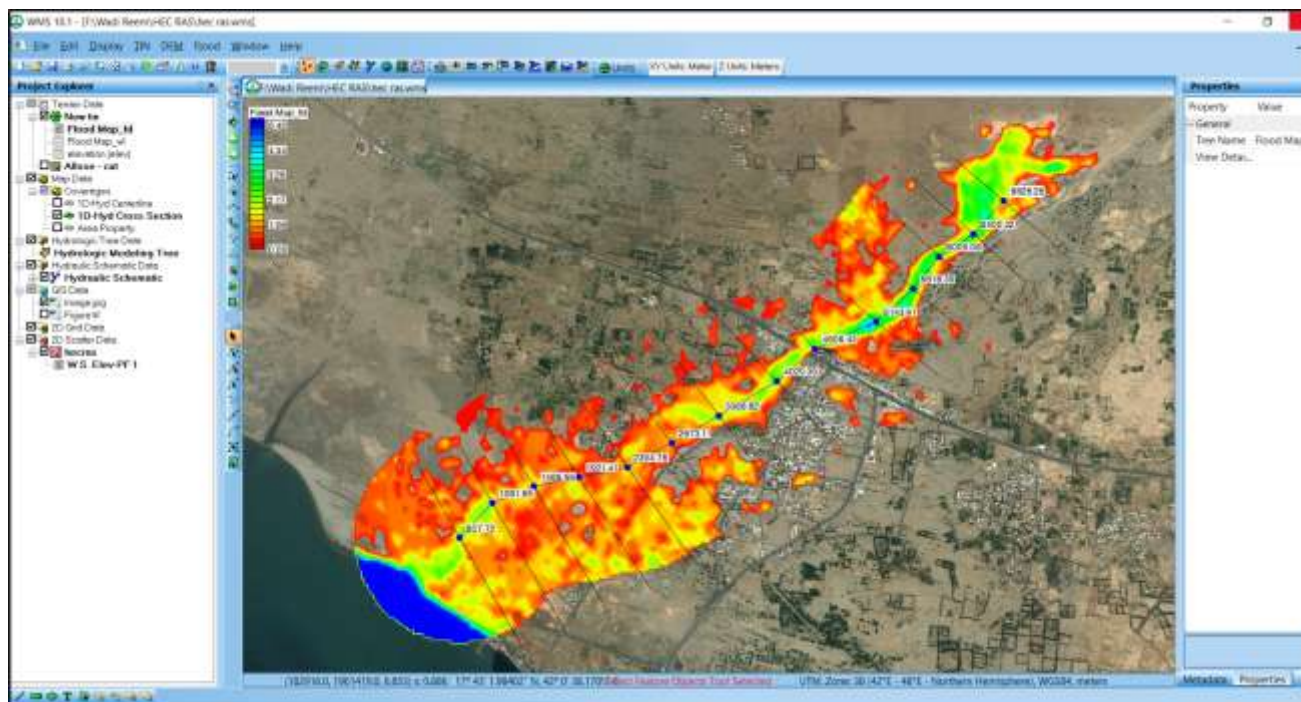
Figure (11): Flood waters depth and flooded areas simulated by HEC-RAS model for 100-year flood event in Wadi Reem Stream.

Figure (12): Flood waters Hazard areas simulated by HEC-RAS model for 100-year flood event in Wadi Reem Stream.

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Conclusion

     The study concludes the following; the watershed and its stream delineation process were carried out with the aid of Watershed Modeling System (WMS) software. Analysis of morphometric parameters indicated that the morphometric characteristics of the watershed contribute in high speed floods; the rate of runoff depth depends on the Curve number values which are decided based on the soil and land use cover types. The results obtained also show that runoff potential differs with land use/cover and soil characteristics. In the present study, the CN values found to be 72.72; Hydrologic modeling was carried out by HEC-HMS program that simulated rainfall-runoff process using curve number model. Flood hydrographs have been created at the outlet of catchment area. Floodplain delineation process has been investigated by HEC-RAS program; these results showed that the hundred-year flood could invade critical areas such as urban zone, agricultural zone, the national road. They reveal the necessity of integrating system generated information in the decision making process in order to make informed choices. The authority can apply the structural and non-structural proposed measures for a better economic and social development of the Wadi Reem basin outlet.

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نمذجة مياه السيول على وادى ريم بالمنطقة الغربية ، المملكة العربية السعودية

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المستخلص

تم فى هذا البحث دراسة استخراج حوض وادى ريم ومسارات الاودية بالمنطقة الغربية من المملكة العربية السعودية وذلك من خلال استخدام برنامج نظام نمذجة المياه   (WMS) . وقد أشار تحليل المعلومات المورفومترية الى ان الخصائص المورفومترية لمستجمعات المياه تساهم فى الفيضانات ، وان معدل عمق الجريان السطحى يعتمد على قيم رقم المنحنى التى يتم تحديدها بناء على أنواع غطاء التربة وأستخدام الاراضى. تظهر النتائج التى تم الحصول عليها أيضا ان امكانية الجريان السطحى تختلف مع استخدام الاراض وخصائص التربة. كما تم تحديد قيمة رقم المنحنى   (CN) لتكون 72.72. تم تنفيذ النمذجة الهيدرولوجية بواسطة برنامج   HEC-HMS الذى يحاكى عملية جريان الامطار باستخدام نموذج رقم المنحنى. وقد تم انشاء هيدروغراف الفيضانات فى منفذ منطقة مستجمعات المياه. وتم التحقق فى عملية ترسيم السهول الفيضية بواسطة برنامج HEC-RAS ، وأوضحت النتائج ان الفيضان البالغ مائة عام يمكن ان يصل الى مناطق حرجة مثل المنطقة الحضرية والمنطقة الزراعية والمناطق السكنية والطرق. ويوصى الباحثون بضرورة استفادة صانعى القرار من نتائج هذه الدراسة من اجل تطبيق بعض الاجراءات لتحسين التنمية الاقتصادية والاجتماعية لمنفذ حوض وادى ريم بالمنطقة الغربية من المملكة العربية السعودية.