Flash-Flood Potential Assessment by Integrating the Remote Sensing Data and GIS with Reference to Adam Area, Western Saudi Arabia

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Abstract: Heavy rainstorms are common occurrences in the Western mountainous region of Saudi Arabia that results in hazardous floods damaging the infrastructure and development plans. Severe rainstorms and heavy showers cause instant flash floods that result in major damage of properties and loss of human lives. Therefore, it becomes crucial during the development planning that floods are accurately analyzed. For the calculation and spatial mapping of flood features, an integrated remote sensing and GIS methodology has been formed. This new methodology makes use of various landscape, metrological, geological, and land use datasets in a GIS environment by employing the technique of Curve Number (CN) of flood modeling for unrestricted dry catchments. The prediction of rainfall depths for 50 and 100-years are 73.6 and 82.3 mm respectively. 4.3679 and 8.0605 million cubic meters are the flood volumes for 50- and 100-year return periods. Moreover, the flood's statistical data like the depth and volume of runoff is added in GIS layers' attribute tables so that all results are collected in the same environment. The application of advanced methodology aids in providing exact estimations and digital results. Moreover, it is economical and can be re-operated in different circumstances as well.

Keywords: Flood modeling, Integrated remote sensing, GIS environment and Adam city.

I. INTRODUCTION

Flash floods are known to be one of the most destructive hydrological occurrences in dry areas. Flash floods rarely occur but they are most common in barren areas where they might cause uneven and severe measures by risking the lives of people and their properties. The structures that are at the highest risk of damage from flash floods include dams, bridges, culverts, wells, roads and highways built along and across wadi courses. According to (Subyani 1999) [1], flash floods are formed quickly after a short heavy rainfall and they flow over arid or almost dry watercourses. Moreover, it becomes hard to collect authentic data of such environments due to low populated areas situated at far distances that are not easy to reach. As the climate undergoes severe variations every year and the probability of rainfall also varies, this results in more complications during the designing of probabilistic rainfall-runoff models.

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Hence, the prediction of flood in wadi channels cannot be accurately ascertained without intricate methodologies for effective accomplishment (Yair and Lavee 1985)[2].

In terms of space and time, the rainfall varies greatly in semi-arid and arid areas. Generally, rainfall is not only unpredictable in Saudi Arabia but it also occurs rarely and irregularly, however, extreme rainfall is experienced during local storms. As compared to other areas, the amount of rainfall in the western part is reasonable and that is due to its topographical location and mountainous area. This area mostly experiences rainfall in the spring and winter seasons because of its side towards the African Mediterranean (Sen 1983)[3]. Various methods have been used to examine the flash floods in different ungagged parched wadis around the world. Researcher (Dawod et al. 2011) [4] stressed on the importance of GIS in quantifying and mapping Makkah's flood features. According to him, the key factors responsible for the complete flood volumes are catchment area; the basin stream length, and peak discharge.

The flash flood synthetic hydrographs in the Western Arabian Peninsula's dry areas was evaluated by (Sirdas et al. 2007) [5] through the integration of isohyetal map, kinematic wave and rational approaches.

According to (Rahman 2002) [6], a Monte Carlo simulation method was effective for determining the flood frequency curves. An assimilated model for flood management and identifying the areas prone to flood hazards and estimation of possible flood effects was created by (Todini 1999) [7]. An assimilated mathematical model for the simulation of flash flood and assessment of possible damage was proposed by (Dutta et al. 2003) [8].

Moreover, a new method was put forward by (Correia et al. 1998) [9] that combined hydrologic and hydraulic models with GIS to identify the areas impacted by floods in various flood situations, along with estimating the resulting loss. GIS was declared as an instrument in the evaluation of flood hazards by (Lanza and Siccardi 1995) [10]. When Jeddah city of Saudi Arabia was faced by an intense flood in November 2009, a study was conducted by (Mashael Al Saud 2010) [11] to examine the flood hazard.

The flood hazards in Tabuk city were evaluated by (Ayman et al. 2013) [12] through the integration of space technique (IKONOS) with GIS.

Multi-temporal satellite images and DEM with geological information were used by (El Bastawesy and Al Ghamdy 2013) [13] to pick the prime areas best for harvesting runoff for replenishing Al Saq groundwater aquifer.

A rainfall data was gathered from eight stations and investigated by (Subiani 1999) [1] by Gumbel's technique to determine the possible maximum precipitation and also used a runoff coefficient method to predict maximum flood possibility.

This study is conducted to collect all relevant information, including spatial and non-spatial and put it in a GIS system so that a geospatial database can be created to evaluate the flood risk maps in Adam city in the Western Saudi Kingdom. This will aid in the alleviation of the risky flood hazard. Moreover, flood-vulnerable zonation maps can also be designed by these methods, as they would detect the residential and industrial areas that are threatened by these perils.

II. STUDY AREA AND FLASH FLOODS IN ADAM AREA

On the south side of Makkah region, there is Wadi Adam, which is at a distance of almost150 km from Makkah City with an area of about 253.34 km2. Its geographic location is between 41o 03' to 40o 39' E and 20o 16' to 20o 39' N. It is a mountainous area and it mostly contains igneous rocks with various surface structures such as cracks, joints, and faults. The most commonly found rocks are basalt and granite in the catchment area.

There is a more commercial and residential area as compared to the free region. Several residential blocks, roads and infrastructure schemes can be seen. Adam general hospital is present in the catchment area.

There are regular incidents of flash floods resulting from rainfall storms in the summer season. It has a value between 10 to 140 mm per event.

The air temperature in Adam is between 16 and 45 Co and humidity varies between 75% in January to about 30% in June. By examining the frequency of flood series, it is possible to calculate the return period of the flash flood. That period gives an average number of years in which the flood of similar or higher magnitude might occur. The return Tr can be calculated by different methods, including the Welbull method:

Weibull formula

$$Tr(X > xm) = \frac{m}{N+1} \quad (1)$$

In this method, n equals the number of events, while m signifies the rank of the event (flood item) when flood magnitudes are placed in a descending manner.

The return period of 1969's flood has been recorded to be 49 years.

This type of data aids in the flood assessment studies by predicting that: 1) the next occurrence of the flood is expected by the year 2018, and 2) the specific value of return period for flood management projects is supposed to be equal or more than 49 years. The present research study uses the estimated rainfall intensity for a 50-years return period, which is 200 mm/h.

Most plotting position formulas like Weibull do not require sample size or length of the record. Another formula that does not require sample size was stated by (Gringorten 1963) [14]:

In Gringorten

$$P(X > xm) = (m - a) / (N + 1 - 2a) \quad (2)$$

Where P stands for extreme incident's occurrence probability, and (a) Gumbel parameter equals 0.44 depending on (n), (m) is the rank, (n) is the number of years of record.

Therefore, Gringorten formula was effective in evaluating an extreme incident's probability of occurrence by rating Adam meteorology station (AD 001) maximum daily (24 hours) rainfall data in descending order.

Figure 1 shows the sorted rainfall depth data that was drawn against Tr.

Table- I Prediction of rainfall depths by Gringoten Formula for selected return periods, based on 24-hr duration data.

NO	Return Period	Intensity mm
1	For Tr = 2 Years	33.0
2	For Tr = 5 Years	44.5
3	For Tr = 10 Years	53.3
4	For Tr = 15 Years	58.4
5	For Tr = 20 Years	62.0
6	For Tr = 25 Years	64.8
7	For Tr = 50 Years	73.6
8	For Tr = 100 Years	82.3
9	For Tr = 500 Years	102.6
10	For Tr = 1000 Years	111.3

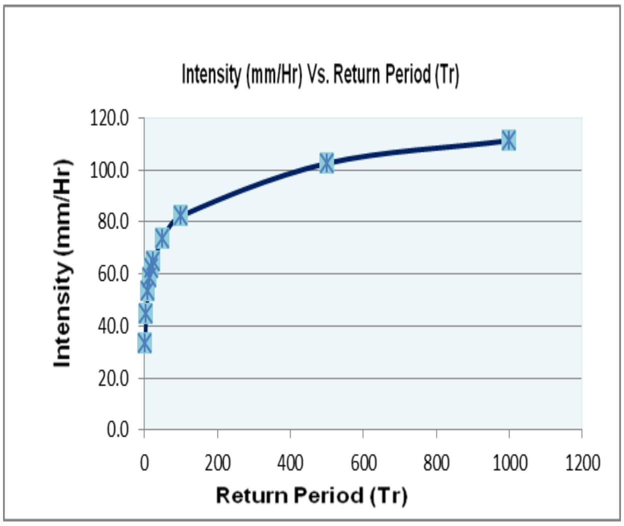

Fig. 1. Rainfall analysis

III. SOURCES AND ADAPTATION METHODS

There are numerous stages involved in the GIS-based flood assessment approach.

The flowchart of that scheme is outlined in Figure 2. The first step involves the gaining of many shapefiles defining the geomorphology of the study area by using global mapper software watershed modeling system(WMS) software.

The shapefiles involve the main basins and sub-basins of all major catchments, drainage networks and the longest stream path in each catchment.

The second stage relates to the flood assessment method formed by using HEC-HMS and HEC-RAS software.

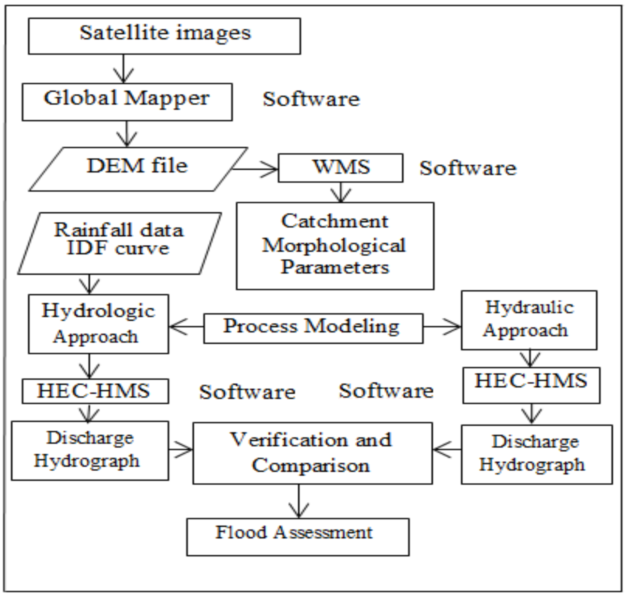

Fig. 2 The developed GIS-based flood assessment methodology.

A. Digital Elevation Model Generation

Numerous datasets were gathered for the purpose of Adam's flood examination. DEM (Digital Elevation Model) and Global Mapper Software have been used to form a 3D-Ground surface for the study area. In order to download the DEM file required for the study area, ASTER GDEM Worldwide Elevation Data (1 arc-second resolution) was used. Digital Elevation Model (DEM) is the major dataset that is collected relating to the study area. In other datasets, digital geological, soil, and study area's land use maps are also involved.

Innovative methods like "Waterdrop" were used to thoroughly assess the surface characteristics like depressions, hills, and Wadis for the purpose of identifying the basins outlets' locations.

DEM model and contour lines map shown in Figure 3 point to the mountainous features of the study area, which is apparent from the close placement of contour lines, (Figure 4), and the contributing sub-basins can be seen linked to the mainstream by almost right angles. These surface characteristics aid in giving a clear view of the nature of flash floods occurring in these streams.

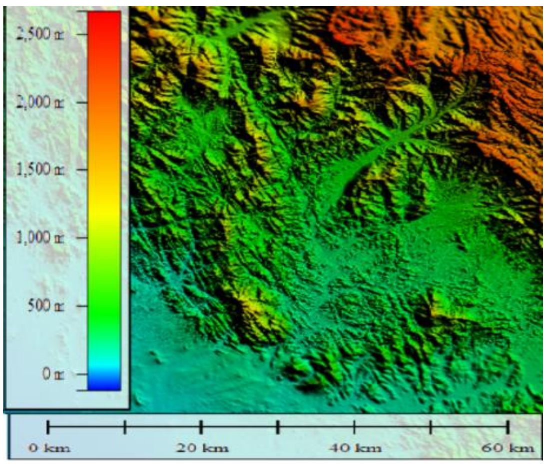

Fig. 3. DEM Model for Adam Area extracted from GlobalMapper®

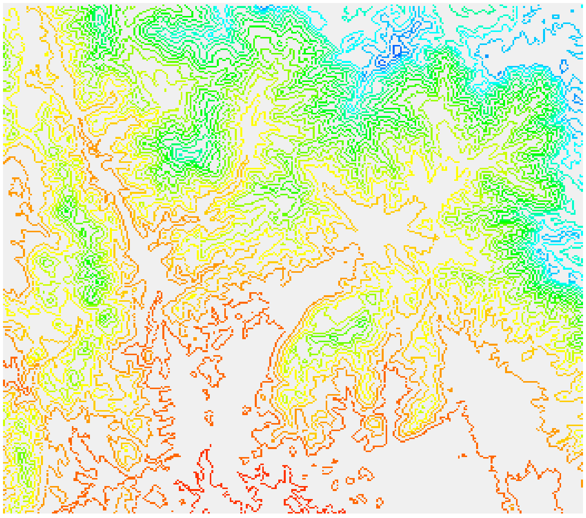

Fig. 4. Contour lines created by WMS

B. Watershed and Stream Modeling

Watershed Modeling System (WMS) Program was used to conduct the watershed and its sub-basins delineation procedure. Global Mapper formed the DEM surface, which was imported into WMS and small depression openings were packed. The built-in TOPAZ Flow watershed and its sub-basins data module were utilized to create the Flow path network. The basins were delineated after their outlet locations were input into WMS. Figure 5 demonstrates the identification of morphometric features. Also, the data file for HEC-HMS hydrologic model for Rainfall-runoff simulation was compiled with the aid of WMS.

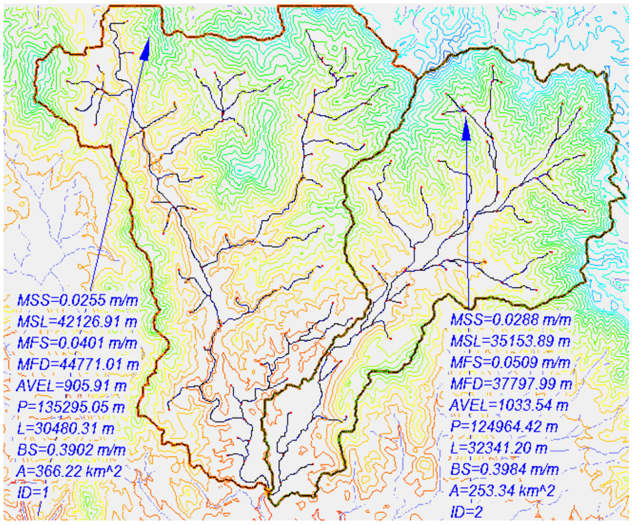

Fig.5. Basins Delineation and their morphological characteristics with the aid of WMS

C. Adam Geomorphologic and Morphometric Characteristics

The morphometric parameters of the drainage system are efficient in assessing the competence of any basin. Table 2 shows the key relevant main morph-metric parameters. According to the morphometric parameters, there is a total of 619.56 km2 catchment area.

Two sub-basins are of elongated shape aiding in transmission losses that are in huge quantities.

The average distance between basin elevations from the most upstream edge to the outlet is 35153.89 m to 42126.9 m, which shows the overall slope of 0.3902 m/m to 0.3984 m/m for sub-basins 1 and sub-basin 2 respectively.
The average slope of the main channel ranges between 0.0255 to 0.0288 m/m and it is higher than other slopes of main channels present in the area of sedimentary rocks (0.01 m/m). The main channel's high slope is made up of igneous rocks that promote high-speed flash floods.
Catchment's mainstream is of the fourth-order that shows the igneous rocks to have hard characteristics, which are dominant in the geological composition of the catchment. With regard to the whole morphometric features of the watershed, it aids in the promotion of high-speed flash floods with high infiltration rates.

Table- II The morphometric parameters of the selected basins in the study area.

Acronym	Description	Sub-Basin1	Sub-Basin2
A	Basin Area	366.22km^	253.34km^2
BS	Basin (overland) slope	0.3902m/m	0.3984m/m
L	Basin length.	30480.3m	32341.2m
P	Basin Perimeter	135295m	124964.42m
AVEL	Mean basin elevation	905.9m	1033.54m
MFD	Maximum flow distance	44771m	37797.99m
MFS	Maximum flow slope	0.0401m/m	0.0509m/m
MSL	Maximum stream length	42126.9m	35153.89m
MSS	Maximum stream slope	0.0255m/m	0.0288m/m

D. Hydrologic Modeling

US Army Hydrologic Engineering Center formed a program HEC-HMS, in which the project area sub-basins were exported.
The purpose of this program is to form a Hydrologic Model and simulate the Rainfall-Runoff process. In order to establish the basin curve number, CN, and rainfall losses, a number of features including soil type and land use of basin were gathered.
The term curve number refers to functions of various factors, such as hydrologic soil groups, cover type, treatment (i.e. management practice), hydrologic condition, antecedent runoff condition, and impervious area in the catchment. Hence, theoretically, the curve number may range between 0 and 100 and is practically found between 40 and 98.
If the soil of the study area is supposedly present within-group (A), natural desert landscaping then the CN would be selected at 63.
After adding the rainfall depths probabilities for 50 and 100-year return periods in the HEC-HMS model, the result findings were collected as outlet hydrographs.
Additionally, for both return periods, the peak flows were marked at the catchment outlet point visible in Figure 6.

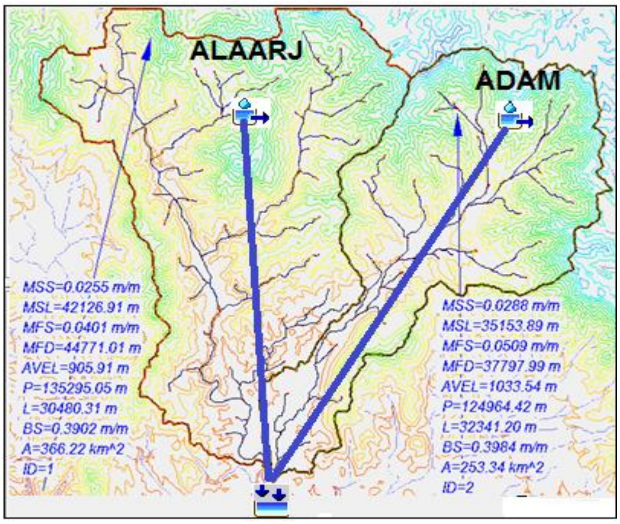

Fig. 6. **Schematic simulation of the catchment area representing Outlet Point and catchment area sub-basins**

E. Delineation of Floodplain

One of the goals of this research study was to ascertain a workable development for the study area and in accordance to the ground surveying calculations; a hydraulic model was developed for wadi Adam in sub-basin (1) through HEC-RAS program created by the US Army Hydrologic Engineering Center, to mimic wadi's water surface profile.
The model aided in determining the water surface elevations, flow velocities, and flow depths at several cross-sections along the wadi. As illustrated in (Figure 6), RAS Mapper has been used to create a floodplain map for Adam region.

IV. RESULTS

A. Adam Geomorphologic and Morphometric Characteristics

The morphometric data of the drainage networks are efficient in assessing the competence of any basin. Table 2 shows the key relevant main morphometric data.
According to the morphometric parameters, there is a total of 619.56 km² catchment area.
There are two sub-basins that are of elongated shape aiding in transmission losses that are in huge quantities. The average distance between basin elevations from the upstream to the downstream is 35153.89 m to 42126.9 m, which shows the overall slope of 0.3902 m/m to 0.3984 for (sub-basin 1) and (sub-basin 2), respectively.
The slope of the mainstream of the catchment area ranges between 0.0255 to 0.0288 and it is higher than other slopes of main channels present in the area of sedimentary rocks (0.01 m/m).
The main channel's high slope is made up of igneous rocks that promote high-speed flash floods.
Catchment's mainstream is of the fourth-order that shows the igneous rocks to have hard characteristics, which are dominant in the geological composition of the catchment. With regard to the whole morphometric features of the catchment area, it aids in the promotion of high infiltration with high-speed floods.

Table- III The morphometric data of the selected sub-basins in the Adam area.

Acronym	Description	Sub-Basin1	Sub-Basin2
A	Basin Area	366.22km²	253.34km²
BS	Basin	0.3902m/m	0.3984m/m
L	Basin length.	30480.3m	32341.2m
P	Basin	135295m	124964.42
AVEL	Mean basin	905.9m	1033.54m
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The datasets present regarding the Adam area have been used to run the GIS-based methodology. The first stage provides numerous maps and assessments of several morphometric data. Two key catchments are identified in Adam that range from 253.34 to 366.22 square kilometers and their main streams have lengths ranging from 30.48 to 32.341 kilometers. Fig. 6 And Table 2 shows the measurements of some morphometric data of the tow catchments.

B. HEC-HMS results

The above described HEC-HMS data was used in the construction of the model's basin and meteorological module, as displayed in Fig. 6. The HEC-HMS hydrograph at the catchment outlet outside Adam city for different return periods is displayed in Fig. 7. The summary of the peak discharges and runoff volumes for the 50- and 100-year return periods are displayed in Table 3. Fig.7(A) shows the finding of 50-year return period hydrograph, in which the hydrograph volume is almost 7 million cubic meters and has a peak discharge of about 241.9 m³/s for sub-basin 2. Furthermore, the peak discharge values are seen to range from 58.3 m³/s for basin 1 to 241.9 m³/s for basin 2. In addition, the depths of runoff for the tow basins range from 12.25 mm to 21.91 mm. The flood volume varies between 823.99 x10³ m³ (for sub-basin 1) and 3541.7 x10³ m³ (for sub-basin 2) and has a total of 4.3679 million m³ over Adam city. Fig.7(B) shows the hydrograph results of the 100-year return period. According to the findings, sub-basin 1 has a 4500,000 m³ of hydrograph volume and a peak volumetric rate of approximately 382 m³/s. When the volume is converted to runoff depth over the catchment area, it results in 0.1225 cm out of 0.82 cm of rainfall storm with a coefficient of runoff equals 28%.

It is possible to observe in Fig.7 that the difference in the generation of the runoff between the urban part close to the outlet and the remaining catchment, has a great influence on the hydrograph's shape. The majority of the runoffs for small events, in terms of when the catchment's runoff ratio in the barren part is small, comes from the urban part. The catchment contributing barren part to the hydrograph for larger events becomes remarkable, but leads to a delayed peak, thereby creating the hydrograph bimodal. With the event rainfall increasing, the delayed peak will begin dominating the hydrograph and completely concealing the first peak for events that are larger, compared to the 100-year event Fig.7 (B).

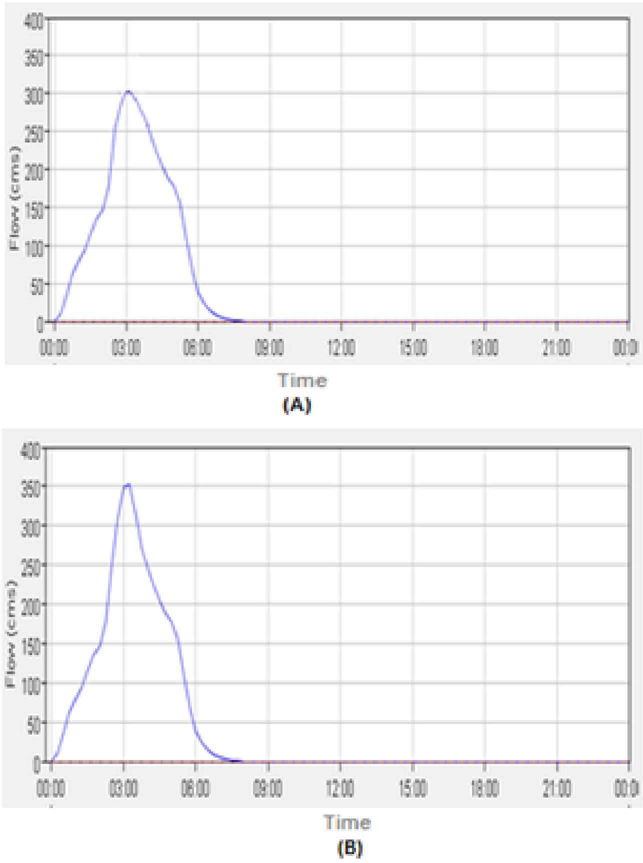

Fig.7. Discharge Hydrograph at outlet created by HEC-HMS for (a)50- yr and (b)100-yr Return period.

Table- V Flood Hydrograph Analysis, (50 and 100 yrs. Return Period).

Return period (years)	Location	Area km²	Peak(Q (m³/s)	Volume Depth (mm)	Volumem³ x10³	Inundated area (km2)
50	Sub-basin 1	366.2	58.3	2.25	823.99	11.2
50	Sub-basin 2	253.3	241.9	13.98	3541.7	11.6
50	Outlet	619.5	300.2	7.05	4367.9	10.8
100	Sub-basin 1	366.2	10.1	12.25	4486.2	12.01
100	Sub-basin 2	253.3	382	21.91	5550.7	11.9
100	Outlet	619.5	468	13.01	8060.5	12.5

In accordance with the field observations made of upstream regions and monitoring the measurements for the basin (1), a dam cannot be constructed based on the present flash flood volume. This is because the region is extremely dry and water would keep evaporating. With regard to the delineation of the flood plain, several nearby regions would be affected by the 100 return period storm. In order to ensure sustainable development, it is critical to replace the properties of people, improve the infrastructure systems and evacuation of flood plain areas from any permanent activities.

C. HEC-RAS Water Surface Computation

Definitions of channel and geometry of floodplain and roughness values of Manning are required by the Hydraulic model (HEC-RAS). WMS and HEC-GeoRAS were used in the preparation of HEC-RAS input data in this study. A series of interconnected reaches are represented by the structure of the network of the channel in HEC-RAS. The extractions of channel centerlines and the flood plains were made from the DEM. The reaches' densities, akin to the sub-catchment arrangement, were much higher in the catchment's urbanized part. Only two-dimensional data were utilized by HEC-RAS for computing the hydraulic. For display purposes, nonetheless, three-dimensional data extracted from the DEM were utilized. Imputation of the materials and land use data into HEC-RAS was also performed in order to provide a description of roughness variability. Exportation of the layout of the channel network and the details of the cross-section were transformed into HEC-RAS from WMS. The most time-consuming task in the model development was the schematic construction then network. The operation of the HEC-RAS model was undertaken with increasing details of networks of the channel until the observed effect on the subsequent inundation maps was considered marginal. The depths conforming to the maximum discharge which HEC-HMS computed at the distinct cross-sections and accomplished interpolations along the reaches were computed by HEC-RAS. Figure 8 illustrates the highest water surface elevations at the watershed outlet for several return periods.

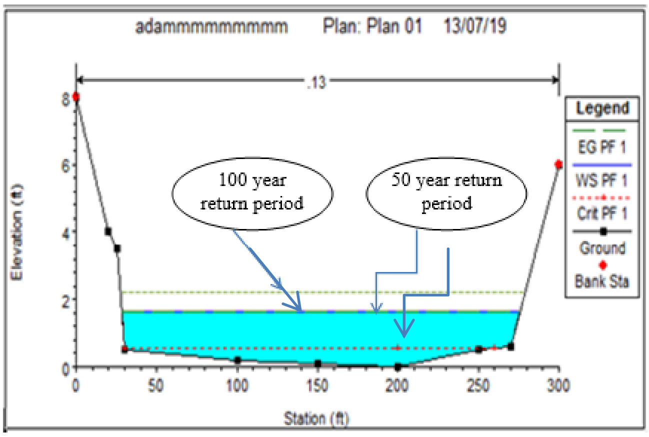

Fig.8. HEC-RAS output showing wadi's typical cross-section at Alsahwah, Adam.

The inputting of the peak flows for every sub-catchment that HEC-HMS simulated into HEC-RAS and the importing and reading of HEC-RAS model generated solutions by WMS were undertaken for the flood hazard map development. The repetition of the procedure was made for all return periods. Every time, reading of a new scatter point file containing the water depths stemming from the HEC-RAS simulation was made into WMS in the form of two-dimensional scatter points connection for the delineation of the flood inundation. There was interpolation of these scatter points containing the water surface elevation's 60-m spacing along the key channel centerline, where extractions of cross-sections were made in the urban area in order to attain a more precise delineation of a floodplain. The representation of the inundated areas in the developed flood hazard map was in the form of flood polygons as illustrated in Fig. 9, for the 50-year design storm. Six classifications – high risk1, high risk2, medium risk, and low risk1, low risk2, as well as no risk - are included in the map, based on observation Fig. 9. The visual comparison is an indication of the municipality map agreeing well with the significance delineated for the 100-year storm. There is an intersection of the inundated area with various major and minor roads in the city, signifying the risk involved in driving through these roads when there are flood incidents. Media images from current flooding in Adam City (Nov. 2016) displayed flooded streets and operations of high water rescue. Schools were closed for several days due to flooding. Table 3 displays the Adam inundated area's estimates for tow frequencies. The 11.2, 11.6, 10.8, 12.01, 11.9 and 12.5 km2 sizes for the inundated area are respectively for the Sub-basin 1(for 50 return period), Sub-basin 2(for 50 return period), outlet (for 50 return period), Sub-basin 2(for 100 return period), Sub-basin 2(for 100 return period) and outlet(for 100 return period) respectively . The size of Adam City is 619.56 km2 with results indicating that the city percentages of 7.1% and 12.08 %, respectively were expected to be overwhelmed by the 50 and 100 year return periods. The results also reveal an increase in the return period when no significant increase in the inundated area is taking place. Because of Adam City's location and the watershed topography, the city is expected to experience flooding even for incidents having small return periods.

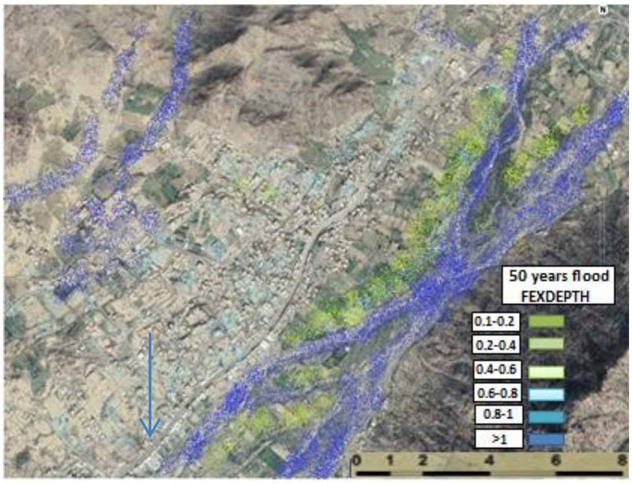

Fig. 9. Flood hazard maps developed by WSM.

V. CONCLUSIONS

The frequency of rainfall for Wadi Adam in the Kingdom of Saudi Arabia, as well as the examination of flood dangers in Adam City with the location close to the catchment outlet, were studied in this paper.

Reanalysis of gridded rainfall was utilized in the frequency storm development as a result of discontinuity of rain ungagged data and the huge catchment size.

The reanalysis of data average and modification homogeneity versus observations coming from a rain ungagged with the location at the Adam City was examined. Pre-processing of the terrain and rainfall data and generation of input files for hydrologic and hydraulic models made use of a GIS-based modeling interface. The popularly known SCS CN method was the basis for the estimation of the runoff.

The catchment was divided into sub-catchments for the improvement of runoff estimation having smaller sub-catchment in the urban part of the catchment. The runoff hydrograph conforming to different design storms was stimulated by the hydrologic/hydraulic model and assisted by the delineation of the subsequent maps of flood accumulation. The outlined maps of inundation are in agreement with the municipality developed a hazard map. City officials can utilize this information as the reason for the rough estimates of the indicative infrastructure/houses/buildings losses consistent with the design storms, through the superimposition of up-to-date detailed land use maps on the zones of the delineated flood. The current urbanization levels and design storms were utilized in undertaking the present study on the basis of the fairly short rain record. In spite of the fact that the rainfall record for this region failed to reveal any increasing trend, it is still possible to make future changes. The change in urbanization even under the existing dry climate, however, has the ability to significantly increasing the runoff, stemming from all storms. The fact of urbanization substantially increasing runoff in comparable catchments and such increase being more pronounced for small rainfall events. The fact of hydrograph being bimodal is one other problem linked to small incidents for this catchment, which happens to be a delayed peak from the barren part of the catchment not possibly expected by residents, but capable of increasing the flood risk. The possibility of localized storms over the large catchment, without the ability of being felt by residents until the arrival of the flood in the city exists.

Watershed Modeling System (WMS) and Global Mapper software were used to conduct the Adam area basins delineation procedure. According to the study of morphometric parameters, the watershed's morphometric features supported the rapid floods. HEC-HMS program conducted the hydrologic modeling that replicated the rainfall-runoff process through the curve number model. Both the outlet of the catchment area and catchment outlet have flood hydrographs. HEC-RAS program has been effective in examining the floodplain delineation process. A GIS dependent methodology is formed by this research, in order to map and quantify the flood examination procedures. The methodology is formed to utilize various datasets in a GIS environment. According to the results, the major factors responsible for the complete flood volumes in Adam city study area include the basin stream length, the peak discharge, and the catchment area. This methodology is beneficial as it is accurate, cheap, produces digital outputs and can be re-run for other situations, such as the design return period. These results can be useful in the governmental planning in Adam city, and that method can be used in other cities of Saudi Arabia as well. It is possible to utilize the same methodology of this study for the development of flood zones corresponding to different return flood periods. The focus of the study is on design storms presumed to have uniformity. There is the possibility of real storms creating much more dangerous situations, considering the fact of the catchment size and the wadis meeting in the city. The use of real storms and the use of different urbanization scenarios capable of fully incorporating the rainfall's spatiotemporal variability and provision of runoff predictions at high resolutions are recommended for an in-depth study of flood hazards.

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