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Flood Risk Analysis in Potential Points, Zerin City in Erbil as a Case Study

Anwer H. Dawood [*,1] and Dana K. Mawlood[1]

[1] Department of Civil Engineering, College of Engineering, Salahaddin University-Erbil, Kurdistan Region, Iraq

[*] **Correspondence**: anwer.dawood@su.edu.krd

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Abstract

The city of Erbil, the capital of the Kurdistan Region-Iraq, is exposed to frequent floods and cause human and material losses. The current research is analysis of floods as a case study on Zerin City, which was exposed to flood last session 2021-2022. The analysis is based on using different Hydrologic software and digital elevation models, soil data, rainfall data and land use data, were used in order to determine the boundary of catchment area, the area extension of flood plain, depth of flood, water velocity through hydrologic modeling. The results showed that there is a big similarity between the real flood and the modeled flood. Some of the natural water streamlines (valleys) have been filled and the remaining were unable to pass the excess flow generated by the storm. The agricultural lands were not ploughed due to the late rains in this season. Accordingly, increase in the curve number CN (the estimated CN was 79) have been used, the flood inundation, water depth, and velocity through the modeling rainfall storm of return period 50 years on the Zerin City has been done in modeling. The results are a scientific tool that can be used to assess the damages of the study area, and is useful for decision makers.

Keywords: Flood management; Hydrological models; Flood modeling; Erbil flood; Catchment area; Flood exposure

1. Introduction

Flood phenomena is one of the most widespread natural disasters in the world, which cause material and human losses, and affect the economies of countries, in recent years it has received great attention (Ding et al., 2020). There are many studies conducted in order to explore the relationship between hydrological models and advanced technology, Such as Geographic Information Systems and Remote Sensing (GIS &RS), (Al-Qurashi et al., 2008) .The rapid progress in computer software, GIS and RS has played a key role in the development of these hydrologic models (Wilson et al., 2000).Several models have been developed to simulate hydrological systems from precipitation to flow across waterways (Beven, 2012).The most famous study (Ogden et al., 2001)of which considered one of the most comprehensive studies in this field for providing a detailed description of hydrologic models and GIS applications for analyzing water dividing lines and hydrologic models.(Al-Abed et al., 2005) applied the Hydrological Engineering Center– Hydrological Model System (HEC-HMS) and GIS model in the Zarqa Basin in Jordan with another model to discover the advantages of using GIS-based hydrological models as a water management tool. This study showed that the HEC-HMS model provides more favorable results than the other model.

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Yener et al. (2007) chose the Yuvacik basin in Turkey as a study area to simulate runoff scenarios using Intensity DurartionFrequency curves in the modeling studies used by HEC-HMS model, they found that the can used in flood damage estimation and flood control. Reza (2007) used HEC-HMS model to simulate the response of the watershed to any changes caused by taking structural and non-structural flood control measures as well as hydrosynchronyanalysisto find best alternative for flood mitigation, the results shown that for floodcontrolmeasures should not apply in Kiga sub-basin.

Rathod et al. (2015) conducted a study in the basin of the Tapi River, India, in which the HEC-HMS model was used to simulate the flow processes in the usual rain and torrential processes in this region. The results of the study showed that the HEC-HMS has pinpointed areas characterized by flooding with precision. It was stated by Verma et al. (2010) to the suitability of the HEC-HMS model for flow simulation using the HEC-HMS modelin their study of the Petarani catchment in India. Dastorani et al. (2011) evaluated the HEC-HMS model in terms of its ability to predict floods and model runoff processes in the watershed of the Toruq region in Iran. Their study indicated the strengths of the HEC-HMS model in simulating the runoff after rainfall in the ungagged catchments. However, the main factors that affected the results were the Curve Number (CN) and the initial loss. Thus, these parameters must be properly estimated during the calibration process to ensure more accurate results.

The main advantages of HEC-HMS model, it has capabilities that can be applied to different sizes, shapes and characteristics of watersheds, and the model manages data according to its entry, organization, access, and presentation in the simplest ways (Beckers et al., 2009).

Abushandi (2011) modeled rainstorms in Jordan and used the models HEC-HMS. Soil Conservation Service-Curve Number(SCS –CN), GIS, in arid region, Jordan, Wadi Dhuliel. The model shows that the flow observed of flux data by HEC-HMS model are agree with calibrated flux results.

Eleutério (2013) studied the concepts and principles of flood risk analysis by HEC-RAS model, as well as the sensitivity of damage predictions for various assessment modules. As a result, many tests were conducted based on two case studies of French cities. In Flood probability analysis, he examined the diversity of damage predictions as a result of several considerations in the datasets, and models employed. Mustafa et al. (2019) studied the event ofheavy rainfall in Erbil as a cause of flash flood in urban area. However, the durationof those heavy rainfall is less than two hours, they conclude, that the study can be aninitial step in hydrological modelling for studied area. Mustafa et al. (2020) presented a study on the applications of remote sensing in land cover change impacts on the surface runoff using hydrological model SCS-CN in Dhok catchment area,the study indicates that the surface runoff volume increased from 12% in 1990 to 36% in 2016, and the vegetation area decreased from 47 to 14% in this period. Abdelshafy et al. (2020) studied the delineation of catchment area boundary using WMS and Flash Flood Modeling by HEC-RAS on Wadi Reem in the western region, Kingdom of Saudi Arabia. Flood phenomena correlated with the characteristics of the catchment area as well as the climatic elements, analysis of precipitation and catchment area are necessary to understand and realize Floodphenomena and to identify the variables affecting in the Risk points. To analyze the flood disaster, Several recent models have been developed to simulate hydrological systems by using Hyfran plus, WMS and HEC-RAS from precipitation to its flow through waterways (Dawood et al., 2021)

The case study is Zerin area in the northeast of Erbil, which exposed to a sudden flood 30 October 2021 and cause material losses. It is extremely important to prepare plans and measures to reduce the risk of flooding to the in a low-level vulnerable area, the occurrence of sudden floods in potential points in Erbil is an important indicator for studying this issue, Flood Risk analysis is one of the useful technique to determine the areas that have been inundated in these floods within residential areas.

This study is hydrologic modeling using a set of digital data and software, such as the Digital Elevation Model, land use data, Harmonized World soil Data base (HWSD), Hydrological Engineering Center– Hydrological Model System (HEC-HMS) software, Curve Number (CN) and HEC-RAS Hydrological Engineering Center- River Analysis System.

The aims of research are the determination of the flood hydrograph and inundated area including flood depth and flood area, resulted from such flood in the urban area of Zerin using hydrological model and verification with the actual flood that accrued and Submitting the current study to the decision makers to take the necessary action to reduce flood risk in such urban area.

2. Study Area

Location of Erbil City is in the north of Iraq and center of Kurdistan region, in the foot plain of highlands. The city is subjected to floods during heavy rainy days. The case study Zerin District that is located in the northeast of Erbil City. Zerin City important and vital site in terms of urban development; it is extremely important to prepare plans and measures to reduce the risk of flooding to the city in a vulnerable area.

The climate of the study area is classified as arid and semi-arid region, In recent years due to huge development and urban expanding of the city, the new residential area were constructed at north and east of Erbil. Accordingly, the covered areas by concrete and asphalt are increased, and agricultural area are decreased, risk of flood increased and studying techniques in simulation and management of flood to convert the flood disaster to one of the best water resources (water harvesting), becomes one of the priorities of researchers. The location of the study area is shown in Fig. 1.

The boundary of catchment study area determined by Watershed modeling system WMS and site visits by authors through the flood and after the flood, only the west part of Zerin City subjected to flood ,there was small sub catchment in the southeast of study area consist of 2 streams, but this 2 streams are completely filled in the city and connected with the main stream in the upstream of the city.

The photos of the last flood with the caused hazards, which had happened in study area (Zerin City) on 30 October 2021 are shown in Fig. 2.

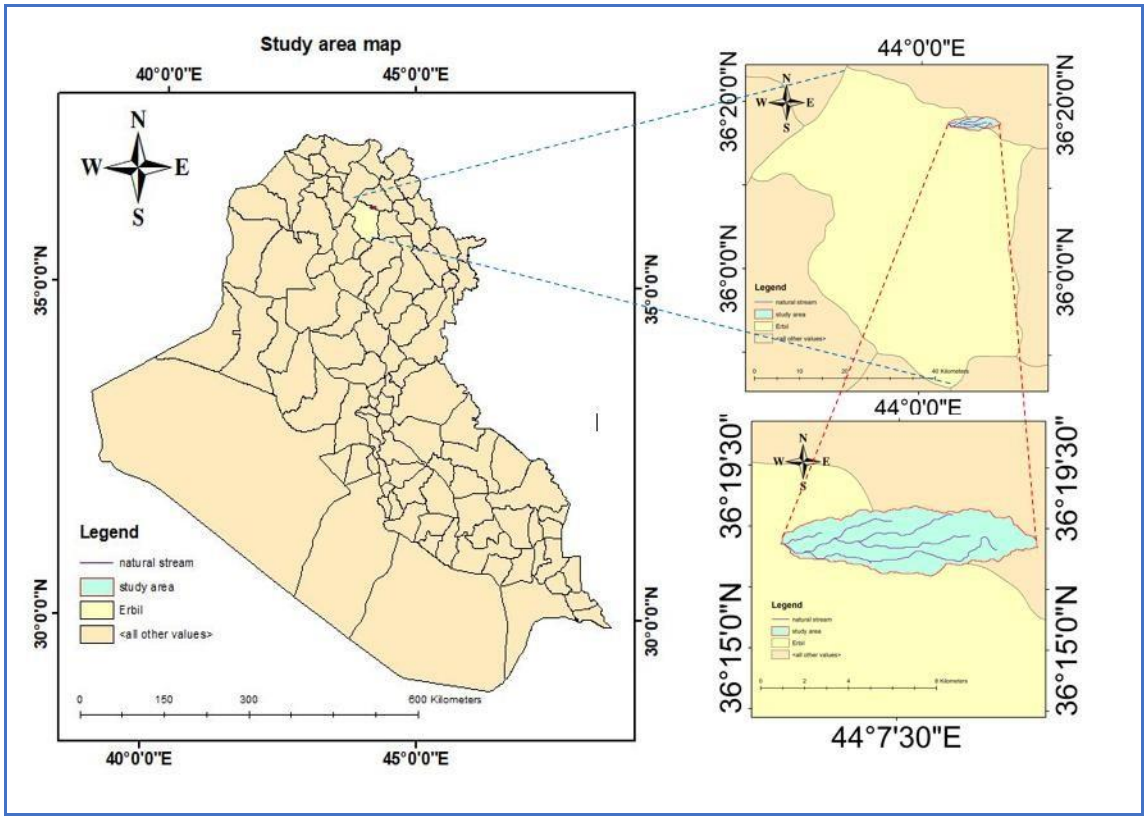


Fig. 1. Location map of study area



Fig. 2. Impact of flood hazards in Zerin District (30 October 2021)

Rainfall data collected fromErbilmeteriology station. Rainfall data is the first requriment in hydrologic modeling and accuracy of hydrologic modeling depends largely on the quality of this data (Gunduz and Aral, 2003). Rainfall is the main source of run-off in waterways and a source of danger for the formation of floods in most cases, especially in rainstorms. Table 1 shows the total of the maximum daily rainfall in Erbil station (1980-2021) (Kurdistan Regional, 2021).

Table 1. Maximum daily rainfall data in station of Erbil station.

Year	max daily rainfall mm	year	max daily rainfall mm	year	max daily rainfall mm	year	max daily rainfall mm
1980	57.6	1991	62.4	2002	32.3	2013	71.8
1981	40.9	1992	15.7	2003	59.2	2014	51
1982	38.1	1993	79	2004	41.4	2015	37.6
1983	32.9	1994	41.7	2005	34	2016	55.8
1984	42.7	1995	75.7	2006	103.9	2017	36.4
1985	72.7	1996	22.3	2007	38	2018	51.1
1986	73.6	1997	35.8	2008	37.8	2019	59.5
1987	31.8	1998	36.8	2009	41	2020	36.8
1988	37.2	1999	25.8	2010	33.8	2021	16
1989	48.4	2000	46.4	2011	67		
1990	35.8	2001	48.3	2012	21		

3. Materials and Methods

The methodology used for doing the flood risk analysis consists of the analysis of rainfall data for estimating the design rainfall depths, using Hyfran software, and then water shed delineation using WMS watershed modelling system and soil classification by using Harmonized World Soil Database (HWSD) for estimating SCS-CN. The next step are using HEC-HMS for determination flood hydrograph and Peak flow at return period, and the final step are Using the hydrograph in HEC-RAS

model to estimate the inundation area of flood and depths of water in each point of flood plain (Abdulrazzak et al., 2019; El Shinnawy et al., 2019; Dawood et al., 2021).

4. Results and Discussion

4.1. Rainfall Analysis

For estimating the design depth of rainfall for return period (2 – 100) year, the rainfall data through length of record 42 year must be extend by suitability of statistical distributions and find the most suitable distribution. The software used is Hyfran plus and the extended data illustrated the Table 2.

Table 2. Statistical distribution of max. daily rainfall depth for Erbil station at a different returning period

Predicted Design Storm Resulted from Hyfran						
Distribution	Exp.	GEV	Gumbel	Lognormal	inverse Gamma	Graphical
Return Period Yr						
2	36.4	43.1	42.9	42.4	41.2	40.45
5	64.7	59.4	59.8	59.8	59.8	59.31
10	86.2	69.9	71	71.7	74.1	73.58
25	114	82.7	85.1	86.8	94.4	92.45
50	136	92.1	95.6	98.3	111	106.72
100	157	101	106	110	130	120.99

The criteria use in selection the best distribution check by statistical tests is mentioned in Table 3(Chi-Square Goodness of Fit Test Calculator (2020) (Zach, 2020). The root mean square error (RMSE), V. Index of Agreement Calculator (2022), WHAT: Web-based Hydrograph Analysis Tool (2022) (Dawood et al., 2021).

Table 3. Goodness of fit tests results

Test	**Exp.**	**GEV**	**Gumbel**	**Lognormal**	**inverse Gamma**	**Criteria**	**Optimum value**	**best dist.**
CHI Test	21.30	7.20	4.20	2.30	0.85	Choose min value	0.850	inverse Gamma
RMSE	21.70	11.00	8.30	6.20	4.10	Choose min value	4.100	inverse Gamma
IOA	0.90	0.94	0.97	0.98	0.99	Choose max value	0.990	inverse Gamma
Nash	0.30	0.84	0.90	0.94	0.97	Choose max value	0.970	inverse Gamma

Itis obvious from the tests that the best statistical distribution represent the data is inverse Gamma distribution as shown in Fig. 3.

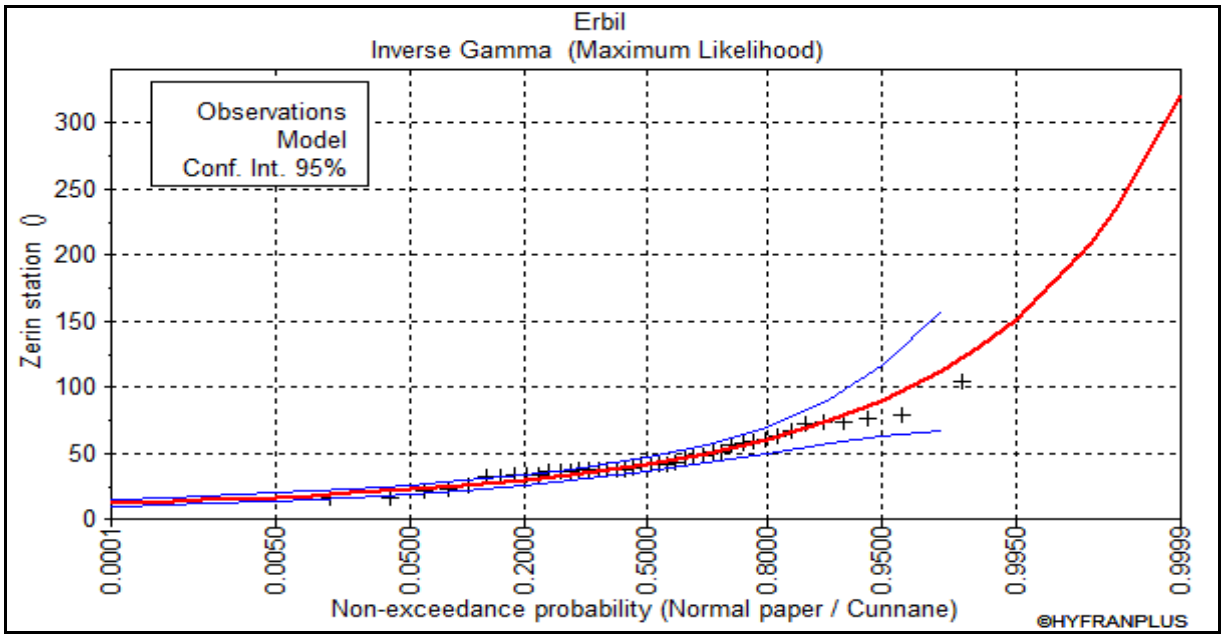


Fig. 3. Inverse Gamma probability distribution for case study Zerin City.

For selectin the design depth and return period (data of inverse gamma distriburion in Table 2) of rainfall storm used in modeling, United States Department of Agriculture, Soil conservation service, developed synthetic storm hyetograph by analysis the time sequence of precipitation for the maximum daily rainfall data. This method describe the behavior of storm through at sub-daily time increment started from zero and increase slowly and then steeply to reached the peak at middle of duration and then decreased from peak to zero (Chow et al., 1988)

Through the rainfall storm that happed in 30 Oct. 2021 in the study area, the record depth of rainfall was 52 mm through 1 hour (Kurdistan Regional, 2021), so the best selection of rainfall depth for modeling is 111 mm at 50 year return period according to the behavior of storm hyetograph.

4.2. Water Shed Delineation

Characteristics of the catchment area in Zerin done by DEM 30X30 digital elevation model with support of Global mapper and WMS software utilized to delineate the watershed boundary. Whereas to identify the topographic features, DEM from USGS (Al Kalbani and Abdul Rahman, 2022). The boundary and drainage lines are illustrated in Fig. 4 and Table 4.

Table 4. Main Parameters of the Zerin catchment area

Basin Name	Area (km^2)	Basin Length (m)	Basin Slope (m/m)	Mean Basin Elevation (m)
Zerin	24.54	14145	0.08	535

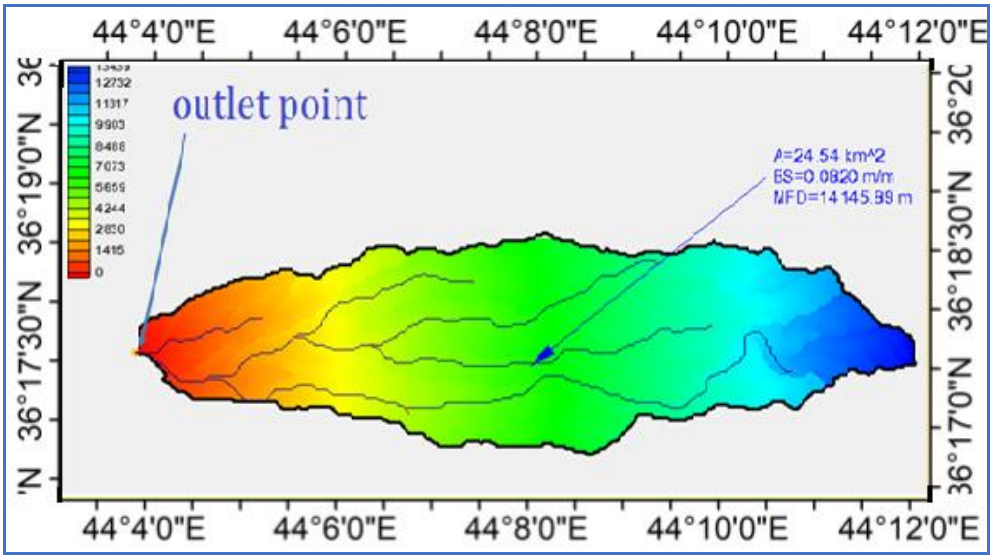


Fig. 4. Digital elevation model DEM for Zerin catchment area delineate by WMS

The catchment area is equal to 24.5 km^2 as shown map Fig. 4. The area in general has some hilly topography; also, there is flat land in the center there is a main valley with direction East-West, Many small valleys occur in the study area in different places toward the main valley.

4.3. Land Cover and Land Use Data

The streams of Zerin catchment area are ungauged i.e. no runoff data records. Usually Soil Conservation Services Curve Number (SCS-CN) used for estimating runoff. The the daily recorded rainfall data for Erbil station are used (Kurdistan Regional Government, 2021). The SCS procedure most frequently used by hydrology scientest nationwide to calculate surface runoff for raimfall storm in catchement area. Soil groups, as defined by SCS are: A, B, C, and D. The soil in Zerin catchment area analyzed with Harmonized World Soil Database HWSD Viewer (Nachtergaele et al., 2012), as shown in Fig. 5.

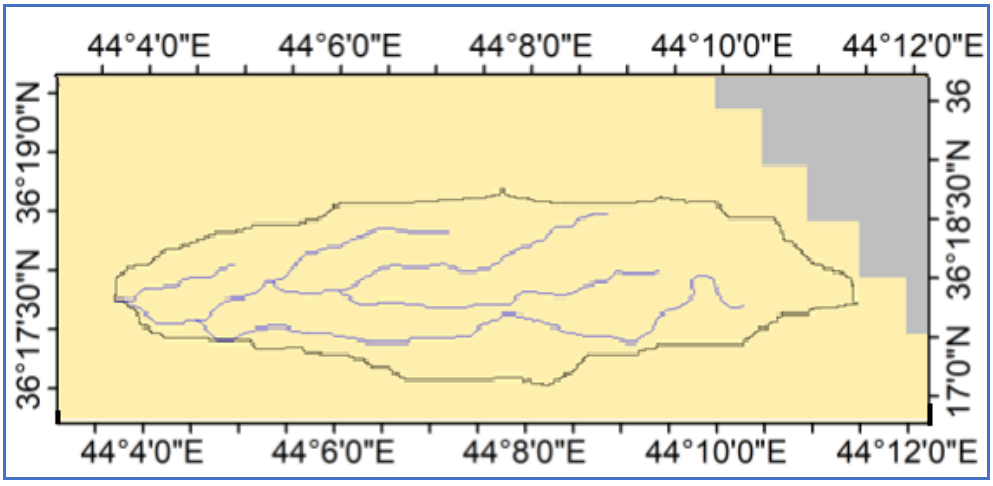


Fig. 5. SoilGroup in catchment area by HWSD

The analysis show that the catchment area consist clay loam soil, low infiltration, high Runoff curve number, i.e the soil in catchment area is D type Soil. Having little infiltration rate (less than 0.13 cm/hr). Agriculture area: About 25% of the catchment area used in wheat and barley cultivation, but in the last rain season 2021-2022 and because of delay rainfall the farmers not plough the area. Accordingly, infiltration was decreased, and the curve number was increased, and the area was changed

to Sagebrush with grass understory. Brush weed-grass mixture with brush land, about 60 % of the catchment area. Urban area represents 15% of the catchment area. The best description for the study area Developing urban areas (Paved parking lots, roofs, driveways, etc.)estimation curve number for class D is 79 (Table 5) (Sc., 1986).

Table 5. Estimation SCS-CN for case study catchment area (Sc, 1986).

Land cover and land use feature	CN	Area km^2	CN*A	Av. CN
Urban area	98	3.3	323.4	79
Brush—brush-weed-grass mixture with brush good	73	15	1095	
Sagebrush with grass understory poor	85	6.24	530.4	
Sum		24.54	1948.8	

4.4. Runoff Calculation by HEC-HMS

The HEC-HMS model is one of the commonly used hydrologic models, and it was developed by the Center for Hydrological Engineering of the US Army Corps of Engineers, in order to simulate the hydrological processes of rain and runoff in drainage basins, this model is applicable to arid and semi-arid region, and has a great ability to calculate many hydrological parameters at user-defined reference intervals based on the historical record of rainfall data. the most important of these hydrological parameters are: calculating flood hydrograph, estimating losses, and quantity infiltration into the soil, the amount of surface run-off, the time of reaching the peak flow, and others. The accuracy of the model results depends on the accuracy and quality of the data used, the design depth of rainfall, a morphological study of the drainage network, ground cover, Curve Number, Soil Classification, Manning coefficient. Determination flood hydrograph and Peak flow at return period 50 years, CN Curve number (Scharffenberg, 2013), The drainage network was carried out based on the digital elevation model (DEM) with resolution 30×30 m. Where the network consists of three drainage lines (valley) that converge near Zerin after the disappearance of their features on the ground due to filling for urban expansion. Stream numbers of 1, 2 and 3 were given in Fig. (6). The drainage network done by HEC-HMS program.

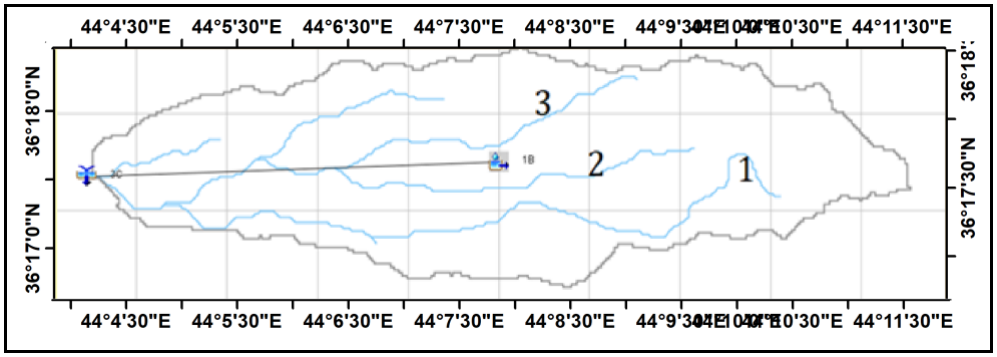


Fig. 6. Drainage network by HEC-HMS for catchment area

The required data for simulation by HEC-HMS lag time 149 minute, the time between the highest rainfall and the peak discharge. The National Resources Conservation Service's (NRCS) equationis most typically used to compute lag time, which is based on the physical characteristics of a specific watershed. This formula is shown in Equation 1 (Folmar et al., 2007).

$$Lag\ Time = \left(\frac{L^{0.8}(\frac{1000}{CN-9})^{0.7}}{1900 * Y^{0.5}} \right) \quad (1)$$

Where: L: hydraulic length (m), Y: Average catchment slope (%), CN: Curve Number CN =79

The results from Calibrated Simulation Model hydrograph in catchment area peak flow equal to 148 m3/s shown in Fig. (7), The Drawing make by MS Excel.

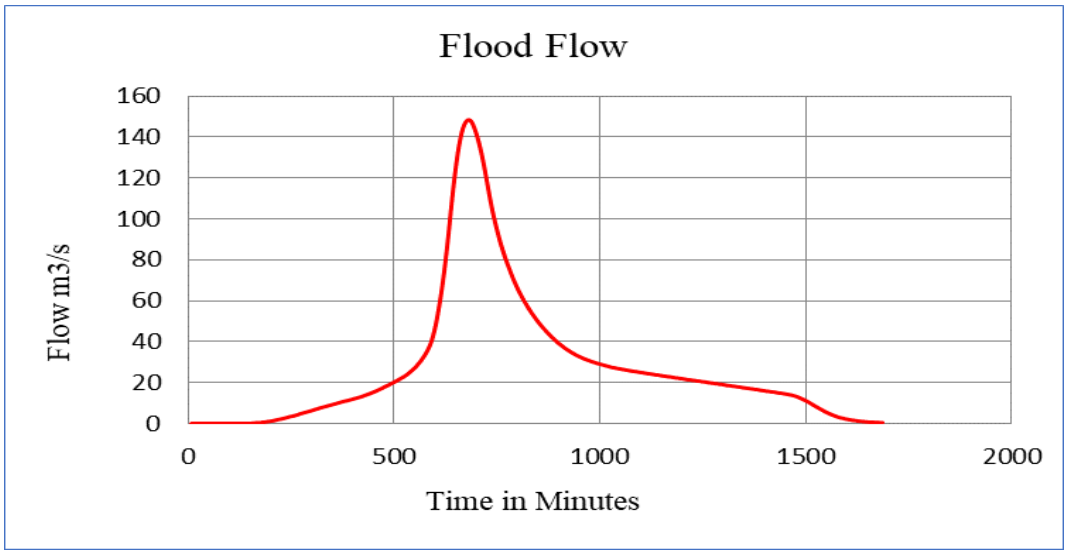


Fig. 7. Results of Simulation hydrograph Model for return period 50 Year by HEC-HMS Model

The flood hydrograph shows the peak flow 148 at Time 11:24 hour from starting of the storm, and the flow between Times 11 and 12 are 124 to 110 m^3/s, the estimated average volume 132*3600=475200 m^3 approximately at peak time (this resutlts from synthtic hydrograph by HEC-HMS for design depth 111 mm). This volume will distribute over the flood plain in study area. These results are used later in flood hydraulic model.

4.5. Flood Inundation by HEC-RAS

This section deals with Modeling HEC-RAS Hydrological engineering center-River analysis system, for flood inundation. HEC-RAS program water flow analysis system developed at the Engineering Center for Hydraulics. It is an engineering software performs hydraulic calculations for stable and unstable flow, and it is considered an upgraded version of the HEC-2. This program is based on saint venant equations of water flow (Kinyanjui et al., 2011). After obtaining the data within the HEC-HMS model, the flow hydrograph and specification of catchement will processed by HEC-RAS program. The flood area was divided into a network of small mesh with dimensions of 10×10 meters to facilitate modeling, the inundation map, depth and flow velocity as shown in Figs. 8, 9 and 10. The Center of flood plain coordinates locate Latitude 36°17'18.19"N, Longitude 44° 5'17.99"E and Elevation 532 m above mean sea level.

At flood modelling 50-year return period, the flood inundation as shown in Fig. 9. More spreading of water is observed in the urban area. The average water depth is 2.5m.

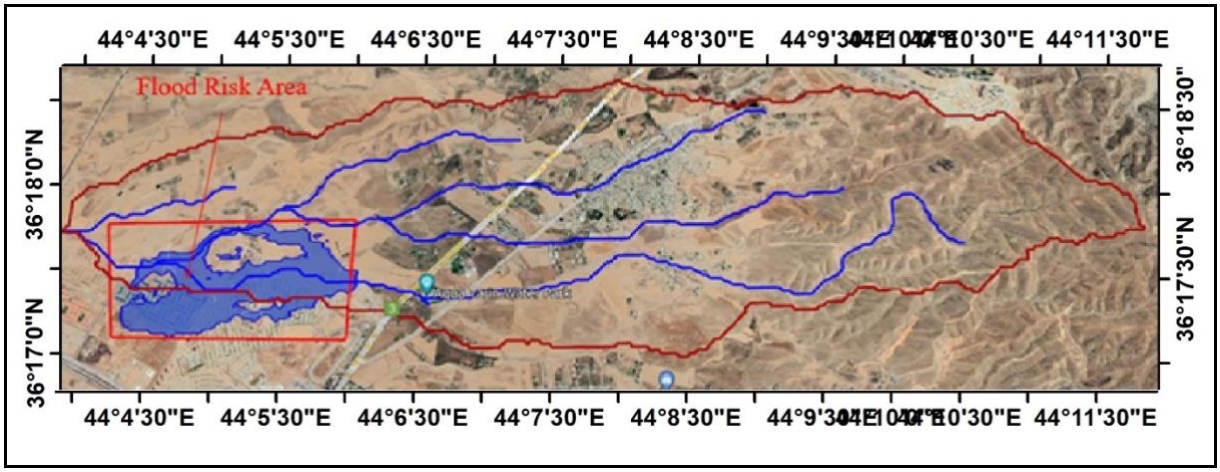


Fig. 8. Flood Inundation at the end of Catchment area

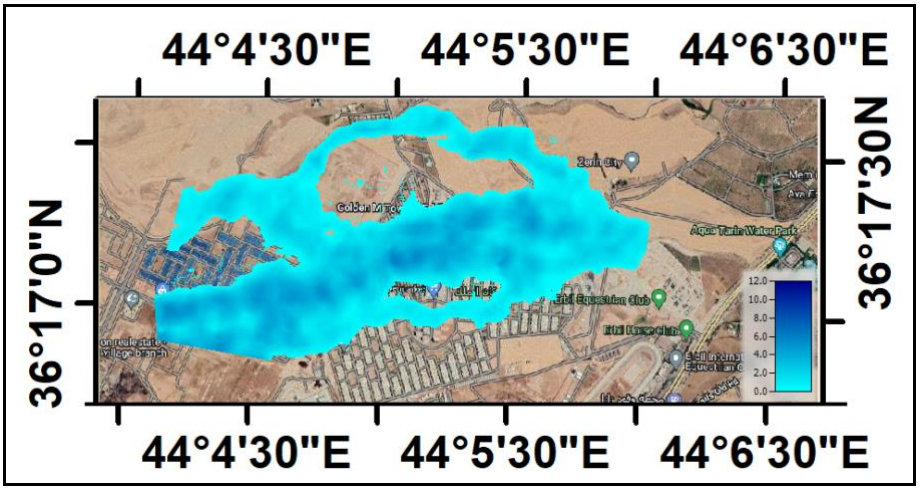


Fig. 9. Flood depth and flood extent map for the peak discharge

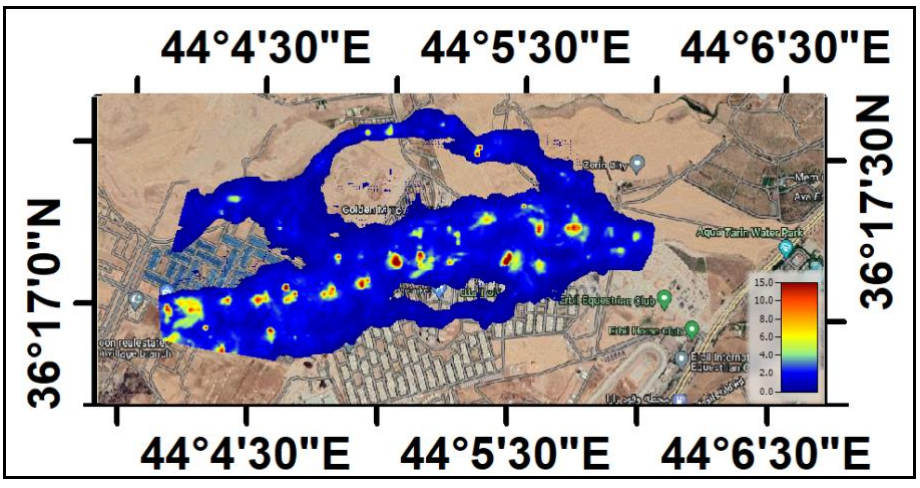


Fig. 10. Flood Flow velocity in the flood plain

5.Conclusions

The proposed flood risk analysis approach in an urbanized area was conducted in the study area of Zerin City, using maximum daily rainfall of the Erbil meteorology station, and return period 50 year, the

synthetic hydrograph using HEC-HMS considered for modeling with peak flow of 148.3 m^3/s, and the flood inundation area was determined using HEC-RAS as shown in Fig. 9. Boundary of inundation area and depth, and Fig. 10 shows velocity of flow through the flooded area, regarding to area of inundation and depth the results show that there is a similarity between the observed flood happened 30 October 2021, and the modeled flood. It is obvious from the results of flood of return period of 50 years effects will be observed for the human and materials, for return period of 100 years the effect will be disaster. The result indicates that study area is a risky and possess high priority areas for decision makers, which needs immediate actions like constructing a dam (small or medium scale) in the north and east of study area as a flood mitigation measures.

The agriculture lands were not ploughed due to the late rains in this season. This reason led to an increase in CN, some of the natural water streamlines in catchment area have been completely filled and the remaining streamlines are unable to pass the expenses generated flow by the storm. Through the morphological analysis of the catchment area, it was found that the north, east and south of study area were exposed to flooding. The vegetation area were decreased and the impermeable area like concrete and asphalt are increased and affects not only on flooding, but also destroyed the environment, ecosystem, raises temperatures.

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