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Research Article

Flood Disaster in Erbil City: Problems and Solutions

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Abstract: Several floods occurred in Erbil City in 2021 and 2022, which caused disaster in the city. 12 people died, thousands of houses and vehicles were destroyed, and numerous public projects such as electric stations and roads were damaged as well. Specifying reasons and providing suitable solutions are essential for minimizing damages. Thus, this research aimed to identify causes and offer scientific solutions for minimizing flood damage in the future. Several site visits for the locations of floods were carried out. Quantitative and qualitative data collection was conducted. Based on the catchment properties and maximum probable rainfall, the peak flood is 250, 200, 90, and 70 m^3/s for Roshnbiri Bridge, Roshnbiri-Daratu Culvert, Korean Drainage Valley, and Daratu Natural Valley, respectively. Heavy rainfall, partial or full clogging of some inlets, sewers, and culverts, obstructions in watersheds, altering the direction of normal flow, technical and design problems, and disposal of waste in watersheds are the main factors contributing to the flood. Cleaning watersheds, maintaining storm sewers, providing new diversion channels, proper design of storm sewers, culverts, and bridges, eliminating barriers on the usual streams, and studying the master plans of the new projects and cities are the main solutions for minimizing flood disasters in Erbil City.

***Keywords*:** edisaster, flood, Erbil City, Geographic Information System, management, problem, solutions

1. Introduction

Nowadays, flood-hazard events are very common in the whole world. The main reasons are climate change and reducing impervious areas due to the increasing population [1]. Over the last century, the population of the world has markedly increased and will continue to increase; this rapid growth and unplanned urbanization have stopped the flow of water and filled the waterway. In general, it is predicted that by 2030, most of the world's population (about 60%) will stay in cities, and nearly 8,000 km^2 of land will turn into built-up areas in one year [2]. Converting farmyards, vegetation covers, and bare ground into concrete and grading surfaces has a great effect on hydrological processes and flooding. Climate change leads to an increase in the amount and frequency of climatological, meteorological, and hydrological hazards. This may expose communities to flood events. New research conducted worldwide indicates that flooding is currently the deadliest disaster compared to other natural disasters such as earthquakes and typhoons. Urban areas are the most affected by flooding due to urbanization. According to the hydrological data available in Kurdistan, Erbil City is largely affected by flood damage. Other factors that cause urban or pluvial flooding are reducing green areas, increasing urbanization, and discarding construction waste into drainage lines [3]. Moreover, as Iraq is a

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developing country, there are no or limited strategies for flood management and no early warning for flood incidents. That causes losses of human life, animals, and vegetation; social impacts; harming infrastructure; broadening diseases; and large economic influences [4]. Flood risk plans and mapping play a big role in protecting and raising awareness of urban areas from floods and managing land use [5].

There are many studies available to understand how to control and manage flood risk. Al-Nassar and Kadhim [6] studied flash floods in Iraq by using European Centre for Medium-Range Weather Forecasts (ECMWF) data and collected data in different metrological stations in Iraq. They conducted three different scenarios for the flash flood in Iraq (longest rainfall storm duration, highest overall rainfall depth, and highest rainfall storm frequency per month), and these scenarios were made by taking advantage of statistical techniques and the Geographic Information System (GIS). Sandink and Binns [7] investigated urban flooding and techniques for mitigation. Mustafa et al. [8] worked on the flash floods in Erbil City by statistical analysis due to different high-intensity rainfall by using data from the Climate Forecast System Reanalysis (CFSR) of the National Centre for Environmental Prediction from 1980 to 1991 and the General Directorate of Meteorology and Seismology in the Kurdistan region of Iraq from 1992 to 2022. Hameed [9] explored work for evaluating runoff volume and how it can be affected due to urban evolution in the Erbil City basin using GIS for analyzing soil and land use to estimate the curve number for the basin from 1984 to 2014. Gupta and Dixit [10] stated the methodology of using GIS and remote sensing to evaluate Natural Resources Conservation Service-Curve Number (NRCS-CN) for the Assam region in India for separation surface roundoff from rainfall.

Flood damage maps are a powerful tool to mitigate flood hazards and manage flood damage. As Iraq is known as a poor and developing country, climatology data is unavailable and research in the water resources area is very limited. Also, using GIS and remote sensing techniques and software, particularly in this field, is limited. Hence, this research aims to understand the risk of flooding, how to manage flooding, explain the methods to reduce flooding, and clarify the causes and solutions of this phenomenon.

The history of flood hazards in Erbil City started with the development of the city. For example, some portions of Erbil City were inundated many times in the years 1963, 1975, 2013, 2014, and 2018. The most recent floods in 2021 and 2022 caused significant damage to many homes, vehicles, and farmland, and it was a deadly flood that claimed the lives of approximately 12 people.

2. Floods in Erbil City

Generally, the event of a flash flood has been very popular in recent years, which may happen due to increasing urban areas and climate change. In Erbil City, the flood significantly damaged people, houses, and vehicles, specifically in the last two years (2021 and 2022). Figure 1 clearly shows what the damage was. According to Xinhua [11], 12 victims were recorded, and the damage was estimated at 15 million dollars. Moreover, the flood affected more than 2,509 houses and 867 cars.

Due to the recent frequent rainfall in Erbil City, the decision-makers of the city decided to revise the crossing structures, such as bridges and culverts, and natural canals that faced flooding. For that reason, this work will help them to check the design of old structures and to prevent violations of natural canals by throwing construction debris into the waterways of those canals. This research explains the reasons and proposes solutions for the problems of flooding in Erbil City by providing variant explanations for different problems that lead to flooding.

Figure 1. Disaster during recent floods in Erbil City

3. Materials and methods

3.1 *Study area and data collection*

Erbil City was chosen as the study area, which is the capital of the Kurdistan Region. The Erbil area is located between (426842.3, 4019021.4) from the northeast and (402309.2, 3996615.9) from the southwest according to the Universal Transverse Mercator (UTM) coordinate system, and has an area of about 700 km^2 according to the latest satellite image. The population of this city is approximately 930,389, based on the last census held in 2015 [8]. Erbil has a flat area in the center, while the area is surrounded by mountains on the east that connect Iraq with Iran and on the northeast that link both Iraq and Turkey. Moreover, there is rural land to the south of the city [8]. The Kurdistan Region has a semi-arid climate. In Erbil City, the summer is long and warm, while the winter is cold and moist. During the summer season, from June to September, there is no or very little precipitation. However, the rain starts to fall from October until the last days of May. In addition, January is the wettest month of the year. The temperature of this city changes from 7 °C to 47 °C, with an average annual temperature of 21°. The average precipitation that falls each year is approximately 400 mm, which varies from 200 to 650 mm for dry and wet years, respectively [9]. Figure 2 illustrates the maps of Erbil City. In 2021 and 2022, floods occurred in different areas in Erbil City, such as Korean Village, Zereen City, Zilan Quarter, Roshnbiri Quarter, Daratu Sub-District, Bnaslawa area (Dashti Hawler), and Zhyan Quarter (see Figure 3). Rainfall data was collected from the General Directorate of Metrology and Earthquakes, Erbil, Kurdistan Region, Iraq. Site visits were carried out in the mentioned zones on 17 December 2021, 16 January 2022, 15 March 2022, 17 March 2022, 5 May 2022, and 10 July 2022. Data on soil type, topography, catchment area, culverts, channels, and watersheds were collected. Additionally, problems with flooding occurred, and appropriate solutions were assigned at the different sites. Watershed overland slope and length, area of the watershed, weighted curve number, etc. were calculated using the ArcGIS-ArcHydro Program.

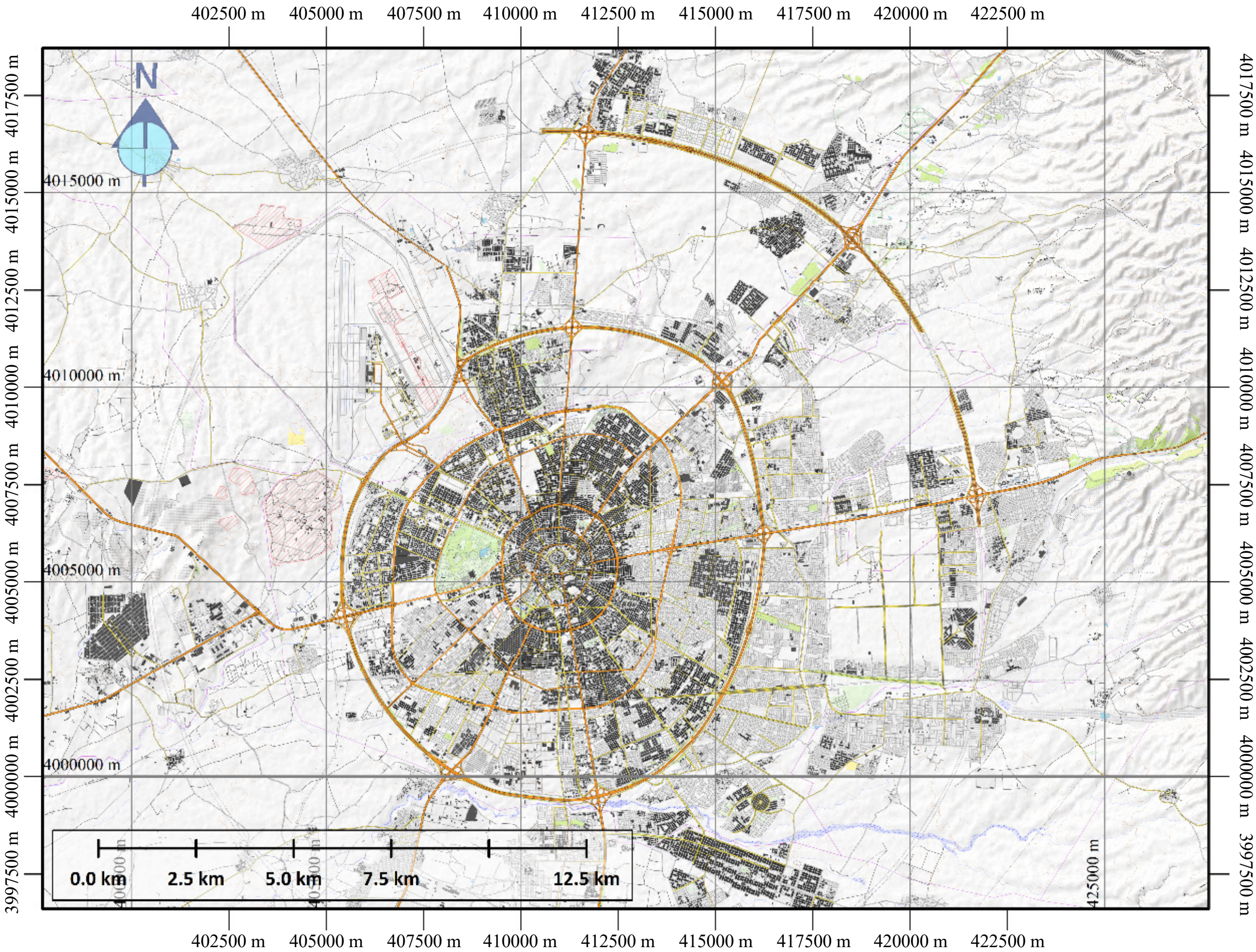


Figure 2. Map of Erbil City

Figure 3. Erbil City locations affected by floods in 2021 and 2022, including (a) Daratu Culvert, (b) Upstream Roshnbiri-Daratu Culvert, (c) Downstream Roshnbiri-Daratu Culvert, (d) Zerin City Drainage Trench, (e) Roshnbiri Bridge, and (f, g) Korean Village Drainage Trench

3.2 *Techniques of the work*

In this study, the researchers are focused on the locations of recently flooded areas in Erbil City and the evaluation of the natural valleys to carry this amount of water that flows through them by taking advantage of GIS and hydrological investigation. The unit hydrograph technique is considered an effective way to estimate the runoff hydrograph; the catchment areas and other watershed properties of the flooded sites are delineated based on the digital elevation model in the ArcGIS package. The Soil Conservation Services (SCS) synthetic unit hydrograph method is utilized to develop unit hydrographs based on curve number (CN), which is a direct function of soil hydrological group, land use, and land cover of the catchment areas. These techniques can be used for reducing and preventing floods in any desired study area, but the catchment properties, topography, land use, and land cover have to be found for that specific location. Figure 4 indicates the catchment area of the recent flooded positions (Roshnbiri Bridge, Roshnbiri-Daratu Culvert, Daratu Natural Valley, Korean Drainage Valley), with more details in Figures 5 to 8. The Roshnbiri Bridge catchment has the largest size and highest slope, which are 119.56 km^2 and 0.1462 m/m, respectively. The Korean Drainage Valley Catchment has the smallest area, and Roshnbiri-Daratu Culvert has the lowest slope. According to the size and other properties of the catchments, the passageways in the outlets of the catchments have not been designed for routing extreme rainfall, and some of the outlets clogged and slowed the waterway. The catchment parameters for each position are shown in Table 1. The data from the Erbil metrological station was utilized for all catchments in rainfall-runoff analysis because it's the only station in that city (Figure 4).

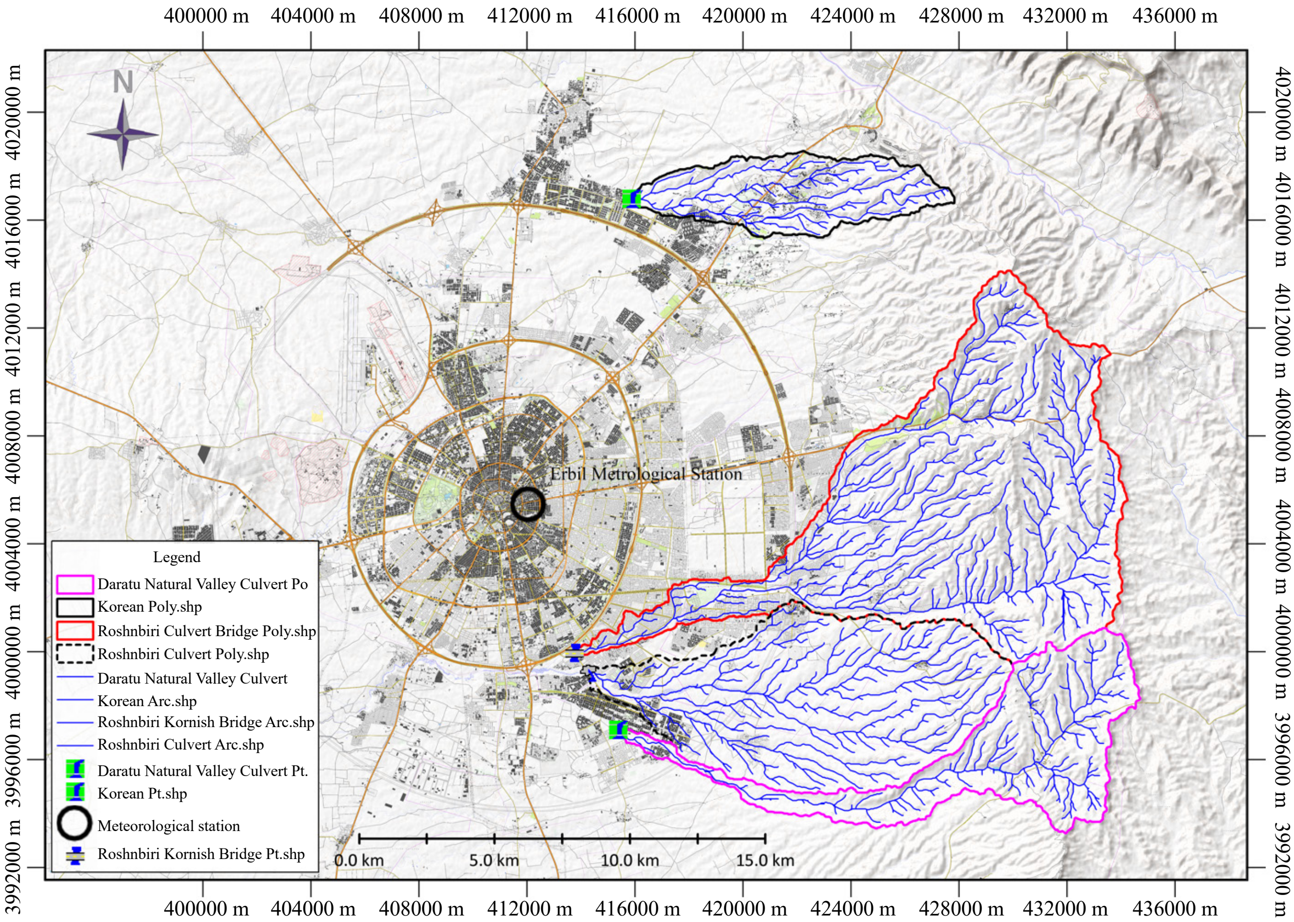


Figure 4. Catchment areas of flooding positions in Erbil City

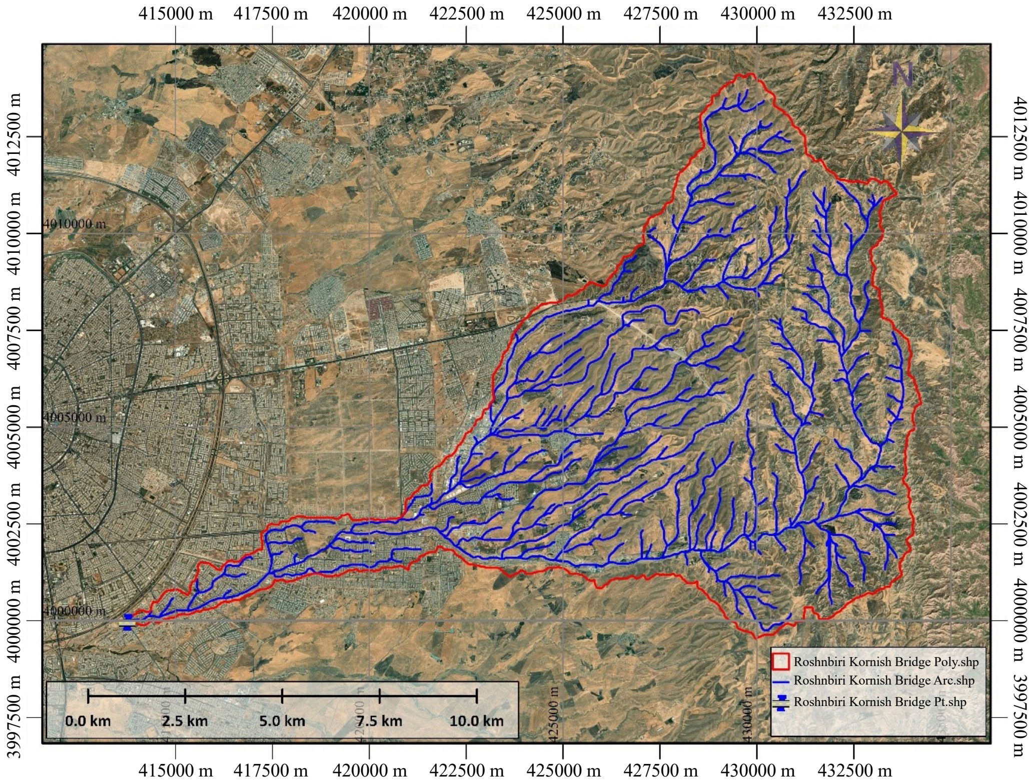


Figure 5. Roshnbiri Bridge Catchment Area

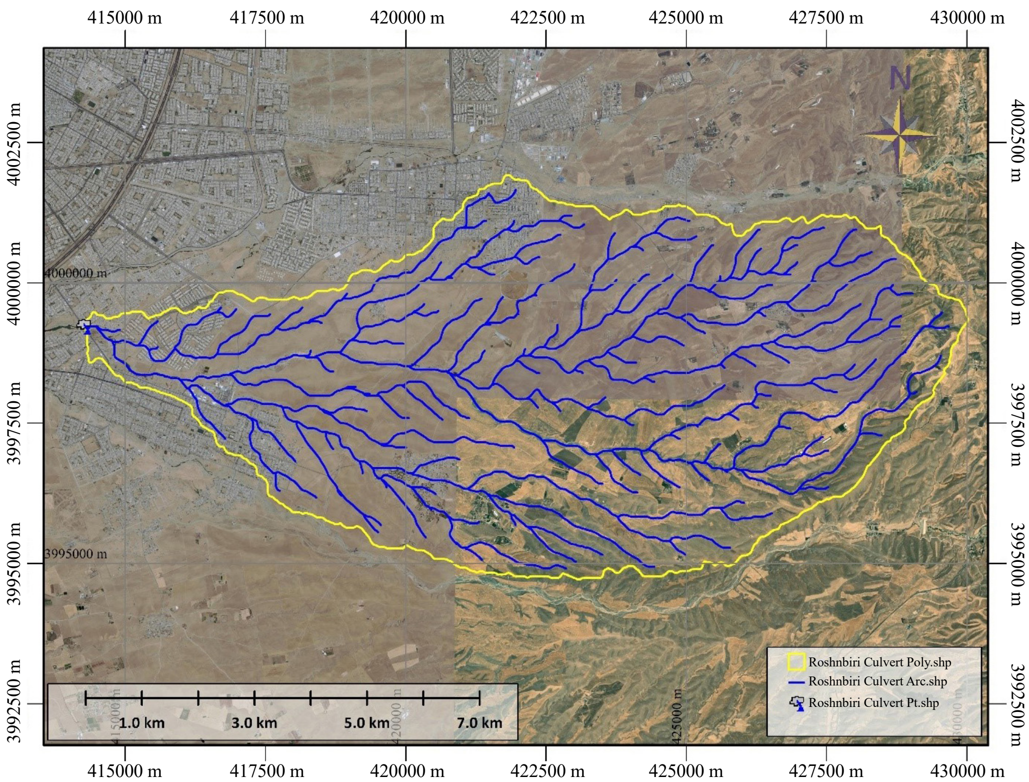


Figure 6. Roshnbiri-Daratu Culvert Catchment Area

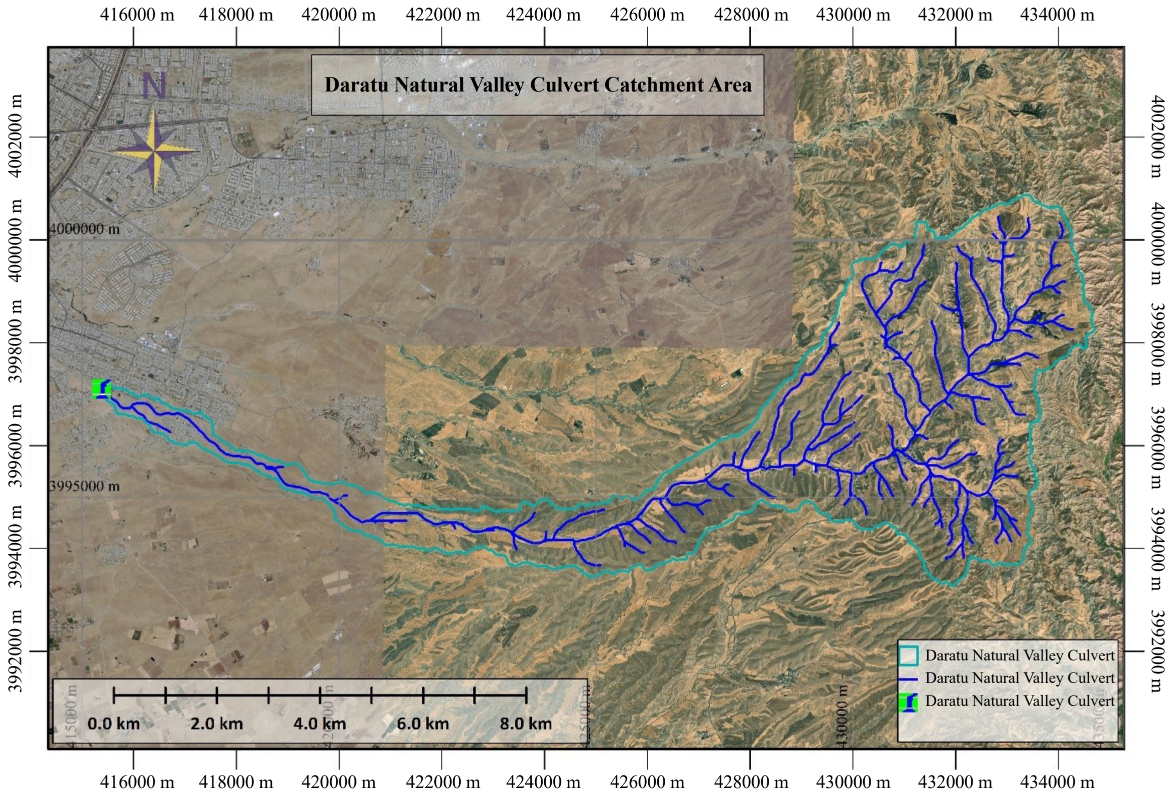


Figure 7. Daratu Natural Valley Catchment Area

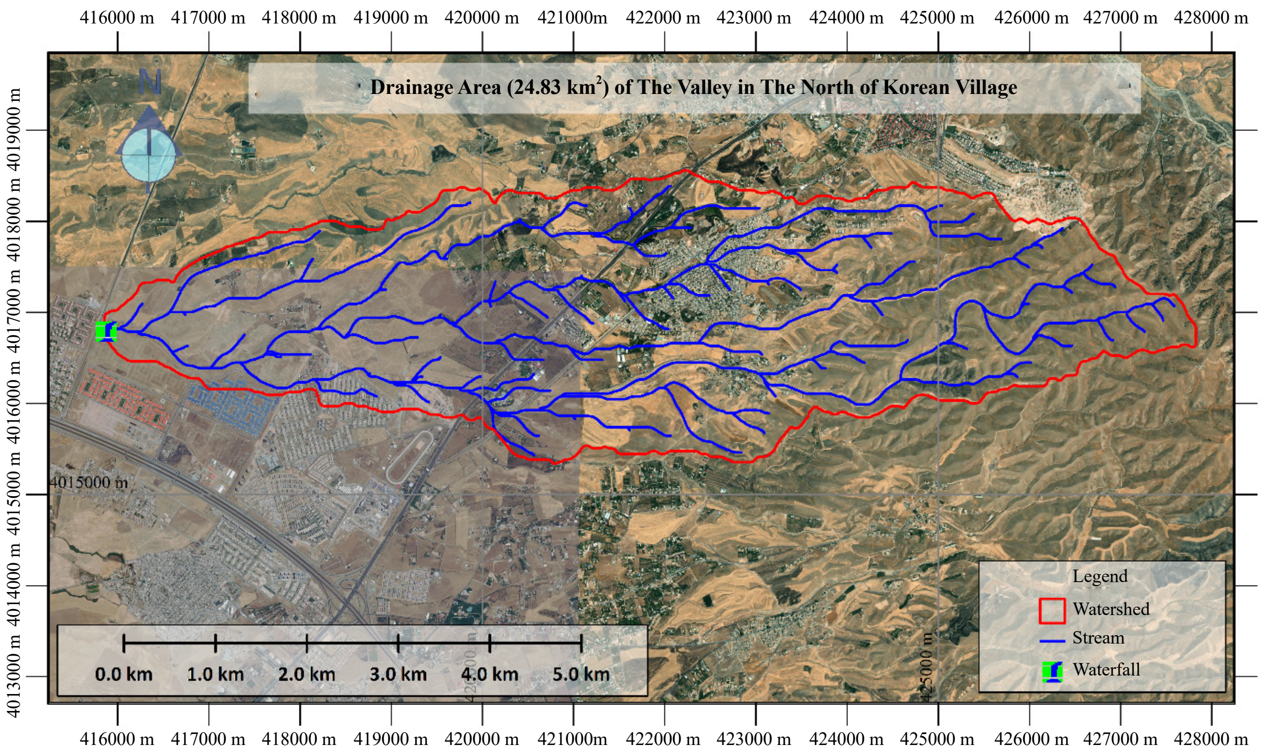


Figure 8. Korean Drainage Valley Catchment Area

Table 1. Catchment area parameters of the selected locations

Catchment parameters	Roshnbiri Bridge	Roshnbiri-Daratu Culvert	Daratu Natural Valley	Korean Drainage Valley
Area of watershed (km^2)	119.56	70.93	42.44	24.83
Watershed overland slope (m/m)	0.1462	0.0591	0.1335	0.1138
Watershed length along the main channel from the outlet to the upstream boundary (km)	32.706	19.886	25.59	14.93
Watershed slope along the main channel from the outlet to the upstream boundary (m/m)	0.0193	0.0179	0.0155	0.0351
Length from an outlet along the main channel to the opposite of the centroid (km)	17.952	10.415	17.46	7.2866
Maximum flow (watercourse) length (km)	31.857	19.361	25	14.3858
Maximum flow (watercourse) average slope (m/m)	0.0162	0.0165	0.0135	0.0309
Watershed perimeter (km)	85.723	51.829	69.52	34.8201
Weighted curve number	69.8	69	62.15	64.8

4. Results

4.1 *Rainfall data and analysis*

The daily rainfall data of Erbil City from 1992 to 2022, taken from the General Directorate of Meteorology and Seismology in the Kurdistan Region, is then used for the analysis of the floods (peak discharge) instead of monthly data because monthly data is averaged over the entire time and does not provide peaks that take place in a short period of storm time. Table 2 shows the maximum daily data.

Table 2. Maximum daily discharge in years between 1992 and 2022

Year	Date	Maximum daily rainfall (mm)	Year	Date	Maximum daily rainfall (mm)
1992	21 November	79	2008	24 October	41
1993	7 April	57.9	2009	30 December	28.2
1994	11 March	41.7	2010	28 February	33.8
1995	4 February	75.7	2011	22 April	67
1996	8 December	23.9	2012	20 December	29.4
1997	15 January	35.8	2013	28 January	71.8
1998	11 January	36.8	2014	27 January	51
1999	15 December	28.3	2015	31 December	55.8
2000	6 January	46.4	2016	28 March	42.4
2001	8 March	48.3	2017	27 January	31.4
2002	20 December	59.2	2018	21 April	22
2003	15 December	41.4	2019	22 November	47.7
2004	12 January	40.6	2020	18 March	25.24
2005	4 March	34	2021	17 February	41.06
2006	3 February	103.9	2022	10 January	30.12
2007	3 February	38			

For the rainfall data, frequency analysis and the extreme value distribution (EVD) method were used to produce the maximum probable rainfall for different return periods [12]. The analysis of the rainfall frequency is shown in Table 3 and Figure 9. For designing a crossing structure and an open drainage system such as a drainage channel for transmitting and collecting excess stormwater, usually the maximum probable rainfall for a 50-year return period is utilized. The rainfall of the 50-year return period is used to calculate the peak discharge flow for that structure or channel, which is used for getting the dimensions of the structure [13]. Based on Table 3, the maximum probability of rainfall for 50 years is 93.04 mm, which has been used to find the peak discharge that is generated by runoff separated from that rainfall.

Table 3. EVD summary for different return periods

Return period (year)	Probability (%)	Median curve (mm)	Exceedance probability (mm)	0.05 confidence limit (mm)	0.95 confidence limit (mm)
2	50	42.11	42.72	48.31	37.75
5	20	58.35	58.97	67.42	51
10	10	69.42	69.51	81.35	58.48
20	5	80.28	79.47	95.58	64.63
50	2	94.7	93.04	115.99	71.24
100	1	105.77	104.65	132.95	75.33
200	0.5	117.05	116.76	151.08	78.82
500	0.2	132.29	134.86	177.67	82.6

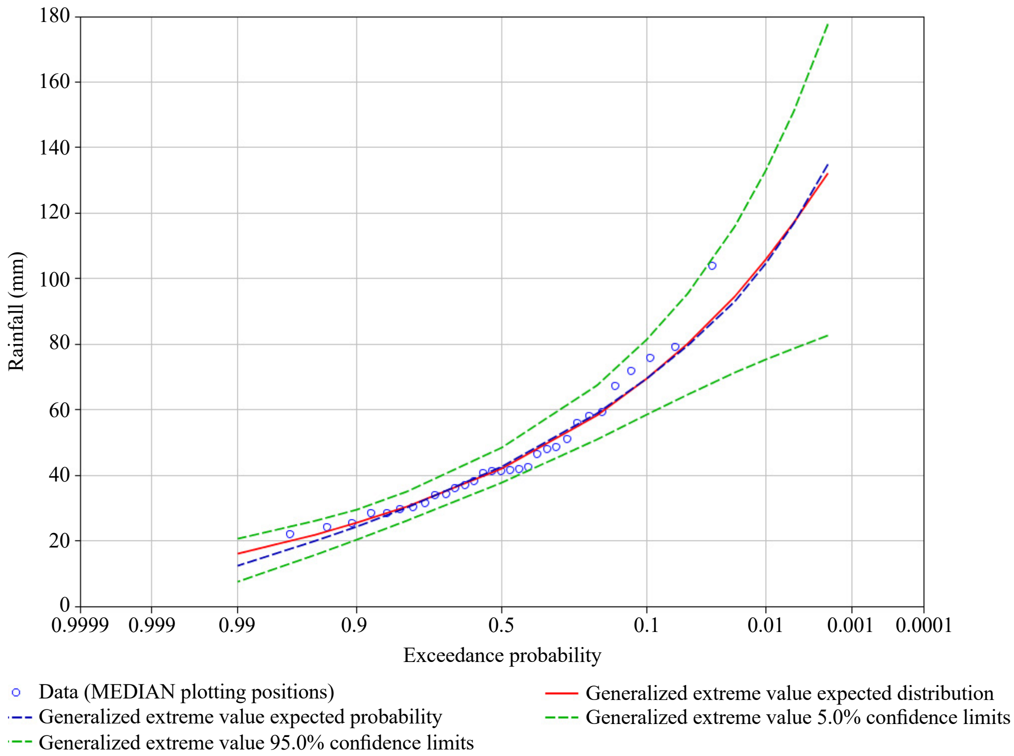


Figure 9. Maximum likelihood estimation (MLE) of rainfall by generalized EVD

SCS is the most widely used method and is considered a very practical way of calculating excess rainfall (runoff) depth. The SCS method relies on the CN parameter, which is a direct function of the land use, land cover, and hydrologic soil group of the catchment area. These parameters are spatially distributed over the area of the catchment, and the weighted average is calculated based on the provided tables of the United States Department of Agriculture (USDA)-SCS converted for the weighted CN [14, 15] (see Table 4).

$$S = \frac{25400}{CN} - 254 \tag{1}$$

$$Q = \frac{(P - 0.2\,S)^2}{P + 0.8\,S} \tag{2}$$

$$T_p = 0.6665\,T_c \tag{3}$$

$$Q_p = 2.08 \times \frac{A}{T_p} \tag{4}$$

$$T_b = 2.67\,T_p \tag{5}$$

$$T_c = (0.0195 \times Lo^{0.77} \times s^{-0.385}) \times 60 \tag{6}$$

where S is the potential maximum retention depending upon the soil-vegetation-land use (mm), Q is the maximum daily runoff (mm), P is the maximum daily rainfall (mm), T_p is the time to peak (hr), T_c is the time of concentration (hr), Q_p is the peak discharge rate at time T_p (m^3/s), A is the catchment area (km^2), T_b is the base time of the hydrograph (hr), Lo is the length of overland flow (m), and S_o is the average overland slope (m/m).

Table 4. Hydrologic parameters of the catchment areas of the selected sites

Hydrologic parameters	Roshnbiri Bridge	Roshnbiri-Daratu Culvert	Daratu Natural Valley	Korean Drainage Valley
P (mm)	94.7	94.7	94.7	94.7
S (mm)	108.86	114.12	154.69	137.98
Q (mm)	29.26	27.78	18.61	21.96
T_p (hr)	2.96	2.08	2.67	1.29
T_c (hr)	4.45	3.12	4.01	1.93
Q_p (m^3/s)	245.4	197.0	61.5	86.8
A (km^2)	119.56	70.93	42.44	24.48
T_b (hr)	7.92	5.56	7.13	3.44
Lo (m)	32706.5	19886.0	25590.0	14930.0
S_o (m/m)	0.0193	0.0179	0.0155	0.0351

The flood hydrograph that was generated based on the SCS method for all sites is shown in Figure 10. Each hydrograph is taken from a triangular synthetic SCS unit hydrograph and then adjusted according to the dimensionless coordinates of the unit hydrograph and the size of the runoff the flood hydrograph achieved. Each of the hydrographs is a function of the size of the catchment area, rainfall, and physical situation of the catchments. Figure 10 shows the maximum flood discharge is about 250 m^3/s for the Roshnbiri Bridge, which has a catchment area of 119.56 km^2. For the Roshnbiri-Daratu Culvert, the runoff discharge is approximately 200 m^3/s for 70.93 km^2. Moreover, it's about 70 m^3/s and 90 m^3/s for the Daratu Natural Valley and the Korean Drainage Valley, with catchment areas of 42.22 km^2 and

24.83 km^2, respectively.

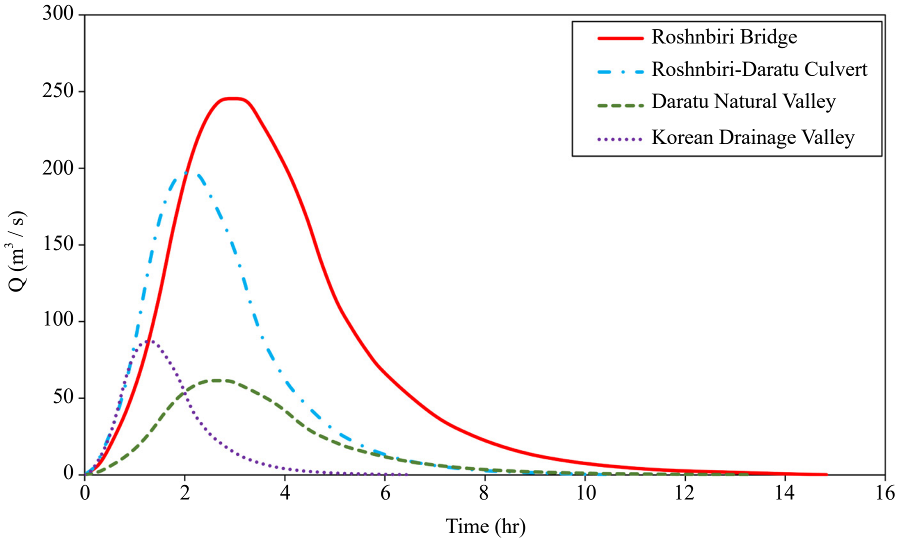
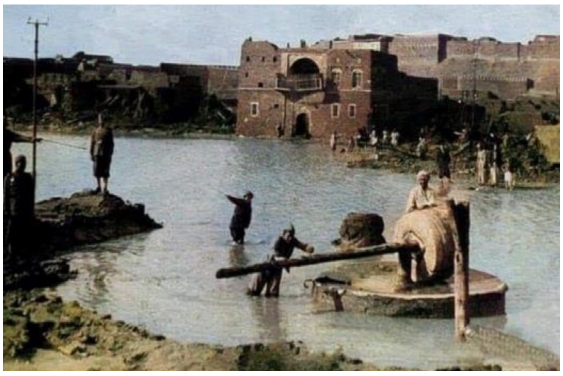


Figure 10. Generated flood hydrograph of the selected sites

4.2 *History of flood in Erbil City*

In Erbil, there are two types of floods: those brought on by clogged inlets and manholes and inadequate maintenance, and those brought on by the drainage system's incapacity to manage rainfall in specific regions. The former is because of the intense rainstorms that originate in the mountains outside of Erbil and travel to the city's heart and nearby communities. As shown in Figures 11 to 13, some were minimal yet still caused significant damage to the city. The most notable is the flood of Basti Gardish in 1984, located above Daratu, which claimed a woman's life. 12 people also perished in the flood of 2021. Figure 2 depicts recent floods in Erbil and illustrates how water rushes from one side and five sides to the city's center due to its geographic location. The first flood on October 30, 2021, affected the hamlet of Korean Village, Gardjutiar, and Golden City; the second, on December 17, 2021, affected the Daratu, Qushtapa, Zeelan, and Roshnbiri areas. The third was a flood on January 13, 2022, on Shaqlawa Road in Erbil, as shown in Figure 11. According to data and meteorological rainfall, there was 69 mm of rainfall per day and 50 mm of flood-causing precipitation per hour on October 30, 2021. On October 30, 2021, 19 mm of rain fell from the heights of Mala Omar to Zereen City and the Korean Village, and an additional 19 mm fell from those same heights to the two districts of Daratu and Qushtapa. However, it is thought that the amount produced on December 17, 2021, in accordance with the weather (20 mm/day), was 40 mm/hr in the center of Erbil, as opposed to the predicted meteorological statistics and data (59 mm per day). The estimated flood cause is 15 mm/hr.

On the other hand, floods also occurred in Erbil City in 1963, 1975, 2013, 28 January 2014, and 2018 (Figures 11 to 13). But, the recent floods in 2021 and 2022 caused damage to houses, infrastructure, and agricultural lands, and the death of 12 people.



(a) (b)

(c) (d)

Figure 11. Previous floods in Erbil City that happened in (a) Tairawa Street, 1975, (b) Cinema Hamrin Street, 1936, (c) Saidawa Bridge, 2018, and (d) Daratu, 2013 [16]

Figure 12. Kornish protection canal in Zeelan Quarter, Erbil City, as captured on January 28, 2014

Figure 13. Kornish protection canal in Roshnbiri Quarter, Erbil City, as captured on December 7, 2018

5. Discussion

Erbil, the biggest city and capital of the Kurdistan Region of Iraq, has experienced rapid growth in terms of the enlargement of the city's built area and population increment, and these have put a huge load on the drainage system of the city. In recent years, several floods have taken place in the city. According to the recently conducted study [8], Erbil City Center land use and land cover have altered markedly, while these alterations have a major influence on the increasing flash floods. For example, between 1984 and 2014, farming and vegetation decreased from 64% to 32% and 31% to 3%, respectively. Meanwhile, impermeable surfaces and barren soil increased from 5% to 35% and 1% to 31%, respectively. In a study by Mustafa et al. [17], the old, underestimated, and unmaintained drainage system of Erbil was stated. The risk in areas that are placed on both sides of the natural drainage channels that are built on culverts, bridges, or any other crossing structures downstream becomes higher; in the case of clogged structures, the water level will rise upstream of them.

Here, we are going to emphasize most of the problems that lead to floods in the city and suggest proper solutions for the problems, which are discussed in the following sections.

5.1 *Problems*

During several site visits to the locations of floods in Erbil City and data collection, the following weaknesses were observed:

a. Partial or full clogging of some storm sewers, inlets, manholes, bridge bays, and culverts.
b. Diversion and narrowing of normal streams.
c. Disposal of construction and demolition materials into the surface runoff streams
d. Changing the type of land surface from natural land to impervious layers, especially in the city center.
e. Construction of projects out of the exciting protection channel built in the 1980s.
f. Construction of houses and other structures on the natural streams.

g. The size of sewers, culverts, and bridges may not be sufficient to pass the amount of runoff discharge that increased due to altering land use and land cover.
h. Construction of temporary access roads on the streams.
i. Drought years and leaving the agricultural lands by the farmers caused an increase in surface runoff.
j. Increasingly intense rainfall storms occur in a short period of time due to climate change.
k. Although the city of Erbil has developed, the stormwater collectors are the same as before, but bigger and newer collectors are required.

5.2 *Solutions*

Many solutions can be applied to reduce the damage of floods, such as increasing green areas, building channels and drains to ensure that water runs into the river without causing any risk, cleaning the drainage lines, inlets, manholes, culverts, and channels before rainy seasons, preventing the narrowing of channels by constructing illegal buildings, and removing temporary access roads on the Kornish protection canal and other watersheds. The expansion of the projects should be in the south and west of Erbil City, not in the north and east zones. The Roshnbiri Bridge must clean all the bays from sedimentation deposits and construction disposal. The Roshnbiri-Daratu Culvert consists of six barrels, and each barrel has a dimension of 3 m by 2 m. This size is not suitable to pass flood water, and it is recommended to add four extra barrels for the culvert to pass the water, providing a new diversion or protection channel outside the new 150-meter ring road. Using pervious concrete for the yards and walkways instead of normal concrete and evaluating and redesigning some storm sewers, bridges, and culverts are also recommended. The construction of several retention and detention ponds upstream of watersheds, the cleaning of streams from sediment transports, and the disposal of construction, demolition, and solid waste can also help. It is also suggested to plant trees on hills to reduce runoff, develop rainwater harvesting in small quantities, such as house roof water collection, and reuse it for irrigating gardens. In larger quantities, the construction of ponds and small dams around the city to mitigate floods and reduce peak hydrographs is advised. Building an artificial cannel to collect the stormwater and transfer them to the Greater Zab River is also endorsed. Construction of multi-story buildings instead of horizontal expansion of the city and providing public transport instead of using private cars, which leads to a decreasing number of roads and impervious surfaces, should be advocated. The construction of a green belt for Erbil City according to the master plan, thereby using these lands according to the master plan and avoiding a change of the land, especially altering from green areas to residential or commercial zones, can positively impact this issue. Finally, plowing natural lands and using natural fertilizer instead of synthetic fertilizer are other solutions for decreasing surface runoff.

6. Conclusion

Heavy rainfall, incomplete or full blockage of some inlets, sewers, and culverts, barriers on water sheds, changing direction of natural flow, technical and design difficulties, and disposal of wastes to watersheds are chief parameters for the floods in Erbil City. Cleaning watersheds, maintenance of storm sewers, construction of another protection channel around 150 m of street, appropriate design of storm sewers, culverts, and bridges, removing obstructions on the natural streams, re-evaluation of the master plan for the new projects, construction of multi-story buildings, providing public transport, construction of a green belt for Erbil City using lands according to the master plan, and water harvesting from roofs are key resolutions for minimizing flood disasters in Erbil City. GIS techniques have been used to delineate catchments and other hydrologic parameters for all recent flooding positions. EVD is applied for estimating the maximum probable rainfall for different return periods. Moreover, the SCS method is utilized for breaking up runoff from rainfall and generating flood hydrographs for each flooding location.

Conflict of interest

All authors declare no conflicts of interest in this paper.

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