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Flood Hazards in Erbil City Kurdistan Region Iraq, 2021: A Case Study

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Abstract

Erbil city is constructed in a flat plain with moderate gradient increasing northwards, the plain is dissected by tens of ephemeral wadis. The maximum elevation in the high lands NE of Erbil city is 1062 m (a.s.l.), whereas the elevation of the center of Erbil city is 420 m (a.s.l.). The average gradient from the highest part to the center of the city is 2.15%, increasing towards northeast to reach 4.79%. The mean annual rainfall is 365 mm, while the average monthly rainfall is about 24.42 mm. The site of the city is mainly covered by alluvial fan sediments. Towards northeast, however, the exposures of the Bia Hassan Formation, which consists of alternation of conglomerate and claystone cover considerable areas (82 km^2) and form the high lands NE of Erbil city. The exposed rocks are thick claystone alternating with coarse conglomerate. Two very heavy torrential rain events have caused flash floods in Erbil city on 30th October and 17th December 2021. The rainfall intensities were 52 mm/day and 60 mm/day, respectively, causing destructive floods. The most affected areas were Zirin (north of Erbil) and Dara Too (northeast of Erbil), respectively, with very heavy property damages and tens of fatalities. The main reasons for the floods were the partially constructed embankments of the 150 m ring-road, and the urban development within large and wide drainage basins. Different climate data were used for the purpose of this article, with field checks.

Keywords

Flood, Climate Change, Rainfall, Fatalities, Erbil

1. Introduction

The whole of Iraq is suffering from climate change and global warming effects, which is scarcity of water in the form of decreasing rainfall and decline of rivers and streams' flow. The Kurdistan Region of Iraq is also affected and suffers from this scarcity; but, with a lesser degree as compared to the central, southern, and western parts of Iraq.

Iraq has hot, dry climate characterized by long, hot, dry summers and short, cool winters. The climate is influenced by Iraq's location between the subtropical aridity of the Arabian desert areas and the subtropical humidity of the Arabian Gulf. January is the coldest month, with temperatures ranging from 5˚C to 10˚C, and August is the hottest month with mean maximum temperatures rising to 30˚C and more [1]. About 70 percent of the average rainfall in the country occurs between November and March, while June, July and August are often rainless. Rainfall varies from season to season and from year to year. Precipitation is sometimes concentrated in local, but violent storms, causing erosion and flush flooding, especially in the winter months [2]. The average annual precipitation in Iraq varies from 120 mm in the west (Rutba town), 150 mm in the central part (Baghdad; the capital), 365 mm in the northwest (Mosul City), and reaches 745 mm in the northeast (Sulaymaniyah city) [1]. In Erbil city, however, the average annual precipitation is 365 mm with total of 82.2 days/year [3].

Erbil city has been built in a flat plain that increases in elevation northwards with irregular gradients, which range from (0.30 - 4.79)% (**Table 1** and **Figure 1**), but the average gradient however is 1.45%. The elevation of the highest point in the highland; northeast of Erbil city is 1062 m (a.s.l.) from which the wadis and streams outflow towards Erbil Plain. Some of these wadis cross Erbil city and disappear within the city (**Figure 2**) due to the constructions of residential sites and roads. Some of the wadis, which cross the city are controlled by concrete ditches (culverts); however, others are backfilled, and residential sites and complexes have been built, causing disappearance of the wadis' courses.

The topography of Erbil plain is summarized in **Table 1**. Mainly it is flat area with gentle undulations. The highest and lowest points along the plain are 1062 and 300 m (a.s.l.), respectively, whereas the height of the center of Erbil city is

Table 1. Topographic data of Erbil city and near surrounding。

Height Difference Between (m)							Distance Between (km)						Gradient (%)						
Highest point and 150 RR	150 and 120 RRs	120 and 100 RRs	100 RR and Citadel	Citadel and 100 RR	100 d 120 RR s	120 RR and lowest point	Highest point and 150 RR	150 and 120 RRs	120 and 100 RRs	100 RR and Citadel	Citadel and 100 RR	100 and 120 RR s	120 RR and lowest point	Highest point and 150 RR	150 and 120 RRs	120 and 100 RRs	100 RR and Citadel	Citadel and 100 RR	100 and 120 RR s	120 RR and lowest point
493	101	34	14	32	1.3	49	10.3	5.5	2.1	3.9	4.4	1.0	9.1	4.79	1.84	1.62	0.36	0.73	0.30	0.54

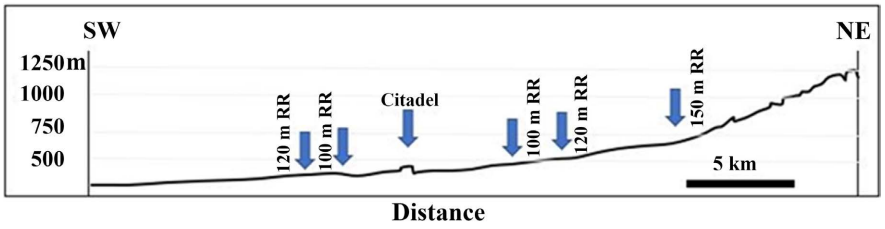

Figure 1. Topographic cross section showing different gradients (Note that RR on the graph denoted the Ring Road).

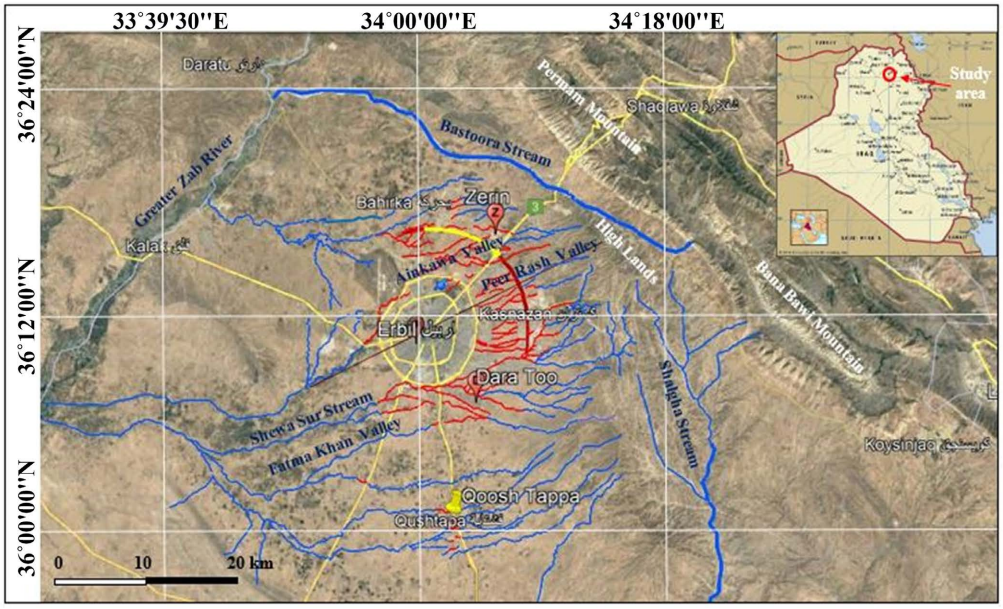

Figure 2. Satellite image showing Erbil city, the main wadis, streams, and location map. Note that majority of the wadis disappear in the city.

410 m (a.s.l.). The gradient of the plain decreases southwest wards from 4.79% in the northern part to 0.54% in the southern part of the plain "Table 1". Tens of ephemeral wadis dissect the plain flowing mainly SW wards "Figure 1".

Mustafa [4] conducted detailed evaluation and analysis of some extreme rainfall events that had happened in Erbil city during the last decade in terms of spatial and temporal rainfall distribution, intensity rate, and probability of exceedance. The study concluded that out of six episodes, which had happened, five of the analyzed events were classified as heavy rainfall. However, the durations of these heavy rainfall events were not more than two hours for each event. Four of them had maximum daily rainfall (for a 39-year dataset) and were rated as having a probability of exceedance of (1% - 10%). [5] studied the Rainfall Intensity–Duration–Frequency (IDF) relationships, which are critical for the safe design of flood protection structures, storm sewers, culverts, bridges, etc. The IDF curves and empirical IDF formulas for the city of Erbil were developed for the first time by employing the annual maximum rainfall data for a period of 39 years (1980-2018), which is the only available recorded data. The correlation between the rainfall intensities obtained from IDF curves and the empirical

formula presented a reliable match, with a coefficient of determination of (R2 = 1).

The aim of this study was for discovering the reasons behind the flash floods that happened on 30 October and 17 December 2021 in Erbil city and why such heavy losses in lives and infrastructure had to happen.

The location of the current study is Erbil city and near surroundings in Kurdistan Region of Iraq "**Figure 1**". The northern and eastern parts of the city are more emphasized where the two concerned floods have caused severe losses.

2. Materials and Methods

To conduct the current study, the materials used were many published articles related to Erbil flooding events have been reviewed. Several official documents were checked to account for the heavy losses in infrastructure and lives. Field investigations were also carried out to the severely flooded areas to check some indications of these floods and document them by photograph.

3. Geological Setting

3.1. Tectonics and Structural Geology

The studied area is in the Low Folded Zone of the Outer Platform (Unstable Shelf), which belongs to the Zagros Fold, Thrust Belt and which is part of the Arabian Plate [6]. The zone is characterized by long and narrow anticlines, which are separated by wide and shallow synclines [7]. In the extreme northeaster part of the studied area, small part of the southwestern limb of the Pirmam anticline forms the Highlands. Whereas in the southwestern part of the studied area is influenced by Erbil anticlines [8]. Apart from the high relief, no structural affect has influenced the study area as the two mentioned floods are concerned.

3.2. Stratigraphy

The main part of the studied area is covered by polygenetic sediments, which consists mainly of alluvial fan sediments. In the northeastern part, the rocks of the Bai Hassan Formation are exposed (**Figure 3**). They consist of coarse conglomerate alternated by thick reddish-brown claystone with rare reddish-brown sandstone [9]. The claystone beds are the source of the muddy floods.

3.3. Geomorphology

Erbil city has been built on a flat plain that rises upwards by an average gradient of 1.45% (**Table 1** and **Figure 1**). The drainage channels run in almost parallel courses following the main gradient of the land which is in a southwest direction with acute meandering west of Erbil city (**Figure 2** and **Figure 3**). The main geomorphological unit is of alluvial origin represented by large and wide alluvial fans, which were very active during the Pleistocene and may have been even in early Holocene. Main parts of the Erbil Plain is covered by alluvial fan sediments

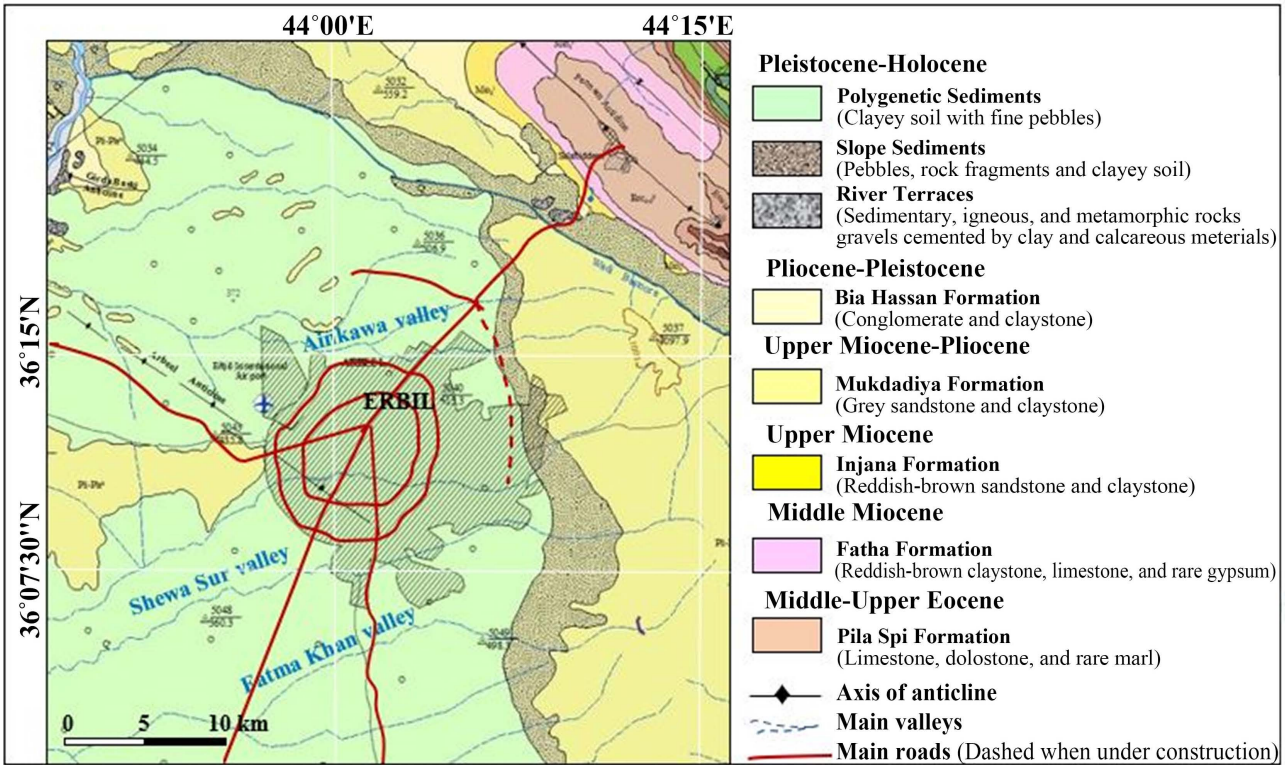

Figure 3. Geological Map of the studied area and near surrounding (Modified from [8]).

which consist of thick clayey soil with lenses of fine conglomerate. These sediments are derived mainly from the outcrops of the Bai Hassan Formation which are exposed in the area northeast of the city (**Figure 3**). Another unit is the slope sediments which form a belt north and east of Erbil city along the foothills. The sediments consist of loose gravel and soil; however, locally are weakly cemented. The main wadis are filled of sediments, which consist of loose gravels; north and east of Erbil city, however, the gravels are replaced by sand and clay at the extreme middle and western parts of the wadis.

4. Results

4.1. Flash Floods

Heavy rains have hit Erbil city and surroundings' area as well as major part of the Kurdistan Region of Iraq after one of the driest years in decades. On 30th November and 17th December 2021, heavy rainfalls swept the country's northern Kurdish region. The heavy rains overnight caused a flash flood in Erbil that has started at 4 am. The incident caused widespread damage to homes, infrastructure, vehicles (**Figure 4**), and inflicted life losses. Muddy water swept (**Figure 4(c)** & **Figure 4(d)**) into homes in Erbil's northern and eastern parts, especially the districts of Dara Too, Qush Tappa, Shamamk, Zhyan, Roshinbiri, and Bahrka. The flash flood occurred in the early hours of the morning, forcing the residents out of their houses (**Figure 4** & **Figure 5**), the streets changed to water streams (**Figure 4(a)** & **Figure 4(h)** since the residential areas were constructed

Figure 4. Erbil floods, 17 December 2021. (a) Flooded street; (b) Damaged vehicles blocking a street; (c) Remains of muddy flood water; (d) Blocked Street with mud; (e) and (f) Flooded streets; (g) A man referring to the height of the flood water in his house; (h) Inundated cars and height of the flood water in a street in Dara Too district.

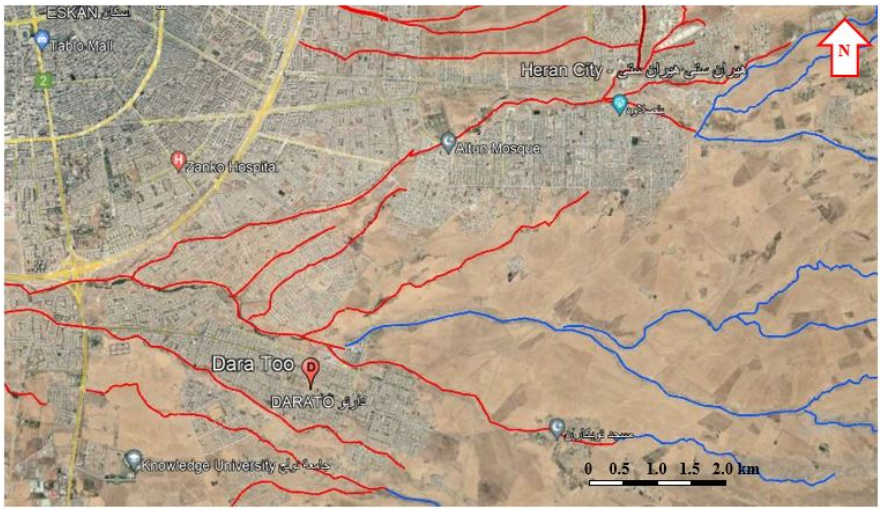

Figure 5. Satellite image showing the residential built-up sites within drainage basins.

on wadis which drain the area, and even some of the wadis that cross the city which were heavily flooded (**Figure 4(a)**, **Figure 4(e)** & **Figure 4(f)**). According to the Kurdish region government on 17 December 14 people were reported dead and 55 people injured by the floods, and more than 7000 people were affected by these floods, moreover, 1250 families had suffered heavy materials damages, and the swept vehicles blocked the flooded main roads (**Figure 4(b)** & **Figure 4(c)**). Three women from the same family drowned in Dara Too district (**Figure 2**) when their home was covered by about two meters of the torrent (**Figure 4(g)**) [10].

According to the Regional Directorate General of Meteorology and Seismology, (59 - 60) mm rain have fallen in Erbil overnight [11]. In the similar event of 30 October 2022, hundreds of houses were damaged when the region received its first strong rainfall of the year. In the previous years, several neighborhoods of Erbil have faced severe damages due to floods [12].

4.2. Reasons of Flash Floods

Heavy rainfall resulting from weather disturbances and high temperatures is a good indication for climate change [13] [14]. Other reasons for flash floods are: 1) Inadequate design of drainage channels and structures (**Figure 4(a)** & **Figure 4(f)**), 2) Inadequate maintenance of drainage facilities, blockage by debris brought by flood waters, 3) Construction of settlements in flood plains (**Figure 4** and **Figure 5**), 4) Removal or partial removal of existing earthfill barriers (**Figure 6**), and **Figure 5**) Blockage of the wadis inside Erbil city and in the surrounding residential sites where houses and roads were constructed (**Figure 7**). It can be said that the main reasons for what had happened in Erbil city during 30 October and 17 November 2022 are combination of all these factors.

5. Discussion

The exposed rocks in the northern and northeastern parts of Erbil city area belong to the Bia Hassan Formation (**Figure 2**) forming the highlands from where the wadis flow toward the city and the recently constructed residential sites (**Figure 2**, **Figure 5** and **Figure 7**). The claystone beds are the main constituent of the uppermost part of the Bai Hassan Formation (**Figure 8**) where the wadis

Figure 6. The remains of a previously built Earth fill dyke to protect the northwestern part of Erbil city, (a) the removed part; (b) northwest continuation of the earth fill dam.

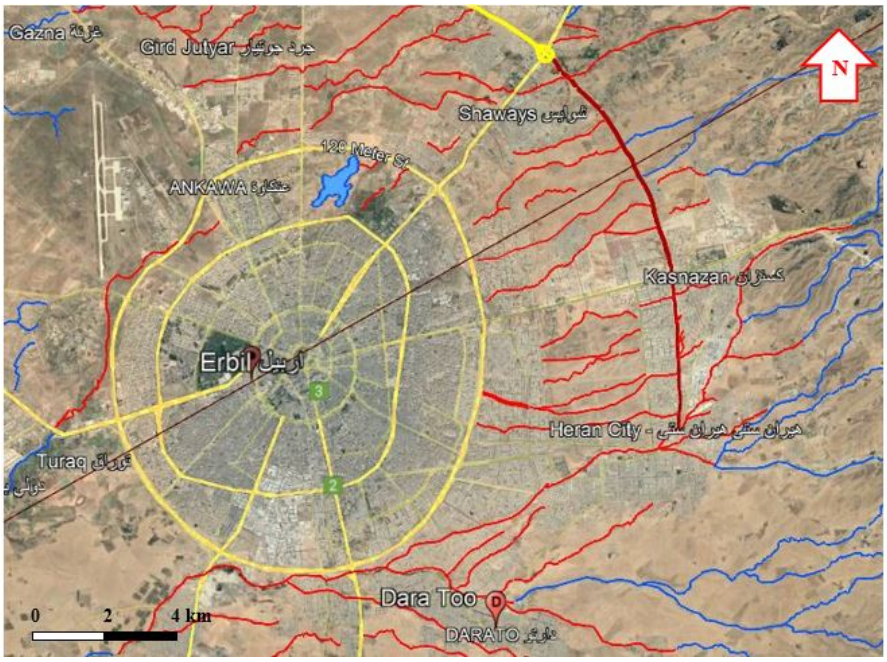

Figure 7. Satellite image showing large number of wadis which outflows into Erbil city area and some of the residential sites. Wadis in red are those parts inside residential sites. The thick brown color is the 150 Ring-road (Under construction).

Figure 8. Thick claystone beds of the Bai Hassan Formation, which is exposed in the Highlands northeast of Erbil city, (a) General view, (b) Enlarged view.

are well developed. During the heavy rain showers, the claystone beds are easily weathered and eroded, they were the main reason for the muddy water during both mentioned flash flood events (**Figure 4(c)** and **Figure 4(d)**). The rainwater during the flash floods has attacked the residential sites such as Zeren and Dara Too covering all their streets and roads (**Figure 4(a)** and **Figure 4(h)**) as most of these roads were originally wadis (**Figure 9(a)**), which were backfilled and/or passed through undersized concrete culverts which were installed to drain the rainwater. In consequence to this rainwater storm discharge flooded the residential areas in both cases and the constructed culverts were unable to pass the floods.

The recently constructed residential sites, especially north and northeast of Erbil city (**Figure 5** and **Figure 7**) are built nearby the courses of wide and shallow wadis without any protective embankments. Locally, even in the courses of

Figure 9. Filed photographs, (a) A concrete ditch below a paved road, previously was a valley, (b) The gravelly nature of the land north and northeast of Erbil city, (c) Flooded part of 150 Ring-road, which was a good source of the mud during the flash floods, (d) General view of the 150 Ring Road, note height difference between the road level and surrounding land.

these wadis (**Figure 5**). As the gradient of the wadis is high (**Table 1**) and since they flow directly towards the residential sites; therefore, majority of the houses in these sits were inundated by the flood rainwater causing heavy damages to houses, homes, cars (**Figure 4**) and even inflicting life losses.

The 150 Ring-road, which is under construction (**Figure 7** and **Figure 9(d)**) has played a big role in both mentioned flood events. Locally, it served as an easy passage to the flood water due to the low height of its embankment in most of its length and in other parts forming obstacles to the flood rainwater due to the backfilling of the crossing wadis, and due to the huge amounts of construction materials laid haphazardly along the road.

The stockpiles of clay fill materials and the excavation of borrow areas of these material along portions of this road made the flood water muddier and increased more the destructive power of the floods "**Figure 4(c)** and **Figure 4(d)**" causing heavy damage especially inside the affected houses.

The partial and/or total removal of some of the existing previously constructed protective dikes, "**Figure 6**" and the backfilling of and/or blockage of some existing drainage channels (**Figure 9(a)**), which were constructed during the last century to control the rainwater (northeast of Erbil city) have played a significant role in increasing the destructive power of the rainwater during the flush floods that had happened on 30 October and 17 December 2021. Therefore, it is very important to assess the management of water resources [15].

6. Conclusion

Two destructive flush floods have occurred in Erbil city on 30 October and 17 December 2021. In both events, huge damages have occurred to houses, cars,

and roads, beside loss of lives. The main reasons for the damages are the construction of residential sites inside the courses of the existing wadis, blockage of wadis by construction of roads on their courses, partial or total removal of existing protective earth fill dikes, and backfilling of existing artificial drainage channels previously dug to control the rainwater flow towards Erbil city. Moreover, the 150 Ring Road has played significant role in increasing the severity of both flash floods.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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