Journal of Earth Sciences and Geotechnical Engineering, vol.7, no. 3, 2017, 115-140
ISSN: 1792-9040 (print version), 1792-9660 (online)
Scienpress Ltd, 2017

Characters and Types of Alluvial Fans in the Middle and Eastern Parts of Iraq

Varoujan K. Sissakian[1], Arsen O. Capigian[2], Nadhir Al-Ansari[3] and Sven Knutsson[3]

Abstract

Hundreds of alluvial fans are developed and still under development in the central and eastern parts of Iraq. The fans are of different sizes, types, shapes and stages, laid down by rivers, permanent streams and valleys. The composition of the sediments of the fans differs widely depending on the source of the sediments, the depositional area, size and type of the fan. Some of the alluvial fans have typical fan forms; others are hardly recognized, especially in the field; in nature; and more specifically when the fan areas are occupied as agricultural fields and/ or are very large with very gentle gradient that hinder their occurrences.

Majority of the studied alluvial fans in the studied area are not presented on geological maps. This is attributed to the fact that they are not presented on the base geological maps because they are unrecognizable in the field, mainly because they have lost their fan shapes. Others; however, are presented even on the geological map of Iraq at scale of 1:1000000.

In this study, the main alluvial fans are presented and described with the reason and form of their deposition. Accordingly, different types of alluvial fans are presented and described including their coverage areas, types, number of stages, shape and constituents. This is performed through interpretation of different types of satellite images, documented field data and the experience of the authors with their long careers and expertize in the field.

Keywords: Alluvial fans, Morphology, Tectonics, Perennial streams, Iraq

[1] Private Consultant, Erbil,and Kurdistan University, Iraq.
[2] Senior Chief Geologist, Baghdad, Iraq.
[3] Lulea University of Technology, Lulea, Sweden.

1 Introduction

Alluvial fans are very common geomorphological forms in the studied area, the central and western parts of Iraq (Fig.1). The developed alluvial fans are of different shapes, sizes, stages, lithological constituents and reasons of development. They are laid down by rivers, like the Tigris, Lesser Zab, Diyala and Adhaim, or by perennial streams like Khas'sa Soo, Tawooq Soo, Kifri Chai and even by dry valleys. All of them have laid down the carried weights of sediments to develop alluvial fans either after crossing a gorge and/ or narrow outlet or due to change in the gradient. Some of the developed alluvial fans are extremely large with length of about 190 Km and maximum width of 85 Km, like Al-Fatha Alluvial Fan [1,2]. Other fans are of few kilometres in length and even shorter. Those which have small coverage areas will not be dealt in this study.

The main aim of this study is to present those alluvial fans which are not studied and presented on the available geological maps. Moreover, to delineate their limits, types, shapes, sizes, and stages.

Figure 1: Google Earth image showing the location of the studied area

1.1 Previous Studies

Many studies have carried out dealing with the alluvial fans of the studied area, although not all of the fans are presented on the available geological maps. Among those studies are:

[3] and [4] reported on the alluvial fans in the eastern part of the studied area, along the Iraqi – Iranian borders. They presented the alluvial fans and differentiated four stages, which are well presented on the geological maps of the involved area.

[5] and [6,7] reported about Al-Fatha Alluvial Fan and many other fans; but they did not present the fan on geological maps.

[8] compiled the geomorphological Map of Iraq and presented many large alluvial fans in the studied area.

[1] and [2] compiled the Geological Map of Iraq and many other geological maps at scale of 1:250000 within the studied area. They presented many alluvial fans, which are located in the studied area on the geological maps.
[9] compiled the Quaternary Sediments Map of Iraq and presented many alluvial fans in the studied area.
[10] established a detailed classification of the alluvial fans in Iraq. They divided the alluvial fans into different main types and sub types

1.2 Materials Used

In order to achieve the main aim of this study the following materials were used:
- Topographic and geological maps of different scales of the studied area.
- Google Earth, FLASH Earth and DEM images.
- Field and subsurface data.
- RockWorks 15 program

Using the available topographical and geological maps of different scales with the help of FLASH Earth, Google Earth and DEM images, the parameters of the alluvial fans were measured.
Lithological data acquired from water wells are used to recognize alluvial fans, especially those which have lost their morphometric characters due to urbanization, cultivation and other man made activities. Roc Ware 15 program was used in drawing the cross sections.

2 Geological Setting

.

The studied alluvial fans are located within the central and eastern parts of Iraq only; therefore, the geological setting of the concerned area is briefed; hereinafter based on the best available data [1,2,11,12,13].

2.1. Geomorphology

The studied area is located within the Low Mountainous and Mesopotamian Provinces [2]. The main geomorphological units and forms in the studied area are:

- **Alluvial Fans:** Tens of large alluvial fans (Fig.2) and hundreds of small alluvial fans are developed in the studied area. The latter's usually form Bajada (Fig.3), whereas the formers cover large areas; more than tens of square kilometers. They are covered usually either by gypcrete or thin veneer of flood plain silty clayey soil.

- **Anticlinal Ridges:** These form continuous ridges (Fig.2) for few tens of kilometers and are the main outlets of the rivers and streams that have developed the studied alluvial fans.

- **Drainage Patterns:** The main drainage pattern in the studied area is the dendritic pattern, which is developed along the flanks of the ridges (Figs. 2,

3 and 4). Trellis drainage pattern (Fig.3) is developed within the anticlinal ridges indicating anticlinal ridges that consist of alternation of hard and soft rocks. Parallel drainage pattern (Fig.4) is developed in the main valleys and/ or streams; following the regional slopes.

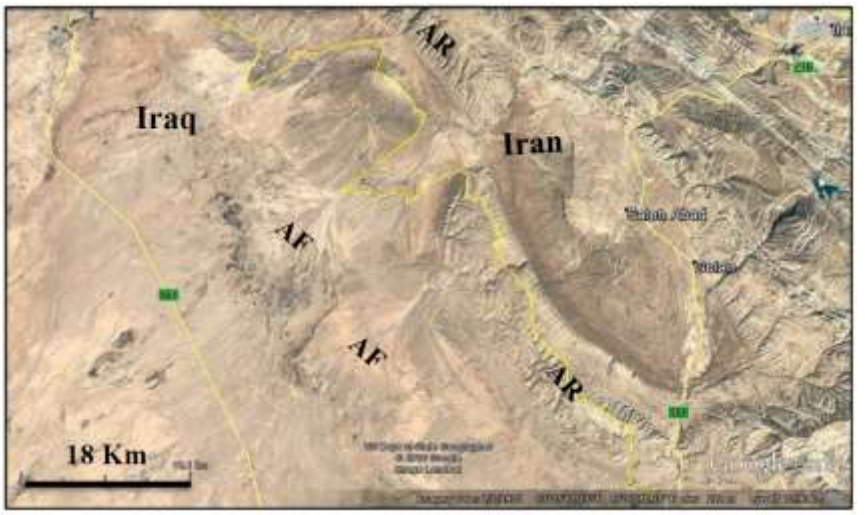

Figure 2: Google Earth image showing the developed alluvial fans (AF) along the Iraqi – Iranian borders. Note the continuous anticlinal ridges (AR) and the outlets from where the alluvial fans are developed.

Figure 3: Google Earth Imge showing Bajada along Himreen North anticline and dendritic drainage pattern

Figure 4: Google Earth image showing parallel draiange pattern (in the lower reaches) and dendritic pattern (in the upper reaches), north of Kalar town

2.2 Tectonics and Structural Geology

The studied area is located within the Low Folded Zone and Mesopotamian Zone, within the Outer Platform of the Arabian Plate [14]. The former zone is characterized by long antilcines and shallow and wide synclines. The anticlines form typical anticlinal ridges that are dissected usually by rivers, streams and valleys, all of them form alluvial fans with different sizes, stages, shapes and types in the areas where they cross the ridges.

The anticlines trend NW – SE (Figs. 3 and 4); in the eastern part of the studied area; however, they trend NNW – SSE (Fig. 2). Majority of the anticlines exhibit thrusting; the northeastern limbs are thrusted over the southwestern limbs, covering mainly the axis and the southwestern limb of the anticlines (Figs. 2 and 3).

2.3. Stratigraphy

The exposed geological formations in the studied area are described very briefly; hereinafter.

- **Fatha Formation** (Middle Miocene): The Fatha Formation includes two members, Lower and Upper. Both of them consist of cyclic sediments; each typical cycle consists of green marl, limestone and gypsum. In the Upper Member; however, red claystone occur above the green marl and reddish brown sandstone occur in the uppermost cycles.

- **Injana Formation** (Upper Miocene): The Injana Formation consists of fining upwards cycles. Each cycle consists of reddish brown sandstone, siltstone and claystone, with many sedimentary structures.

- **Mukdadiya Formation** (Upper Miocene – Pliocene): The Mukdadiya Formation consists of fining upwards cycles. Each cycle consists of grey sandstone, siltstone and claystone, with many sedimentary structures. Some of the sandstone beds are pebbly.

- **Bai Hassan Formation** (Pliocene – Pleistocene): The Bai Hassan Formation consists of fining upwards cycles. Each cycle consists of conglomerate and reddish brown claystone, with rare sandstone. Many sedimentary structures occur in the beds.

3 Concept of the Study

In the studied area, majority of the alluvial fans were not recognized and mapped during the regional geological mapping of Iraq. This is attributed to: **1)** the sizes of the fans are very large; therefore, cannot be recognized in the field and **2)** cultivation and other human activities have hindered the details of the fans. However, some of the alluvial fans are well studied and presented on geological maps, among them are the alluvial fans in the eastern part of the studied area (Fig. 2) [3,11]. Another well studied alluvial fan is the Al-Fatha Alluvial Fan [5]; it is located in the eastern part of the studied area.

These two groups of fans presented as examples for well recognizable fans; the former example and non-recognizable alluvial fan; the second example.

In this study, those alluvial fans, which were not recognized and mapped are studied and recognized using satellite images and subsurface data. The subsurface data are acquired from hundreds of drilled water wells.

The rivers, streams and/ or dry valleys, where they cross barriers; like anticlines and/ or topographic highs; usually form alluvial fans on their outlets [15,16]. Therefore, all those outlets in the studied areas are checked thoroughly using available satellite images and confirmed using water well data; as the lithology is concerned. The most difficult part in this study; however, is the limits of the alluvial fans; since all the surface characters; especially the concave form are almost vanished. The drainage pattern; such as the main feeder channel and other diverted channels and/ or streams are used mainly to identify the alluvial fans. Digital Elevation Model (DEM) is used to recognize the shape and characters of the studied alluvial fans.

4 The Studied Alluvial Fans

The following large alluvial fans are recognized and mapped in the studied area. However, some well-studied fans are presented too for comparison reasons.

4.1. Mandili Alluvial Fans

Many alluvial fans are developed in Mandili vicinity. They are very clearly seen in satellite images (Figs. 2 and 5) and are well studied by [3,11,12,13], and differentiated into five stages. The stages can be seen and limited clearly; depending on the: **1)** tone, **2)** drainage density, **3)** drainage type, **4)** materials of the top cover and **5)** cultivation density (Fig. 5). They are multi stages, medium sized alluvial fans covered by gravels [17]. These five parameters are used to recognize the studied alluvial fans, which are not clear in satellite images.

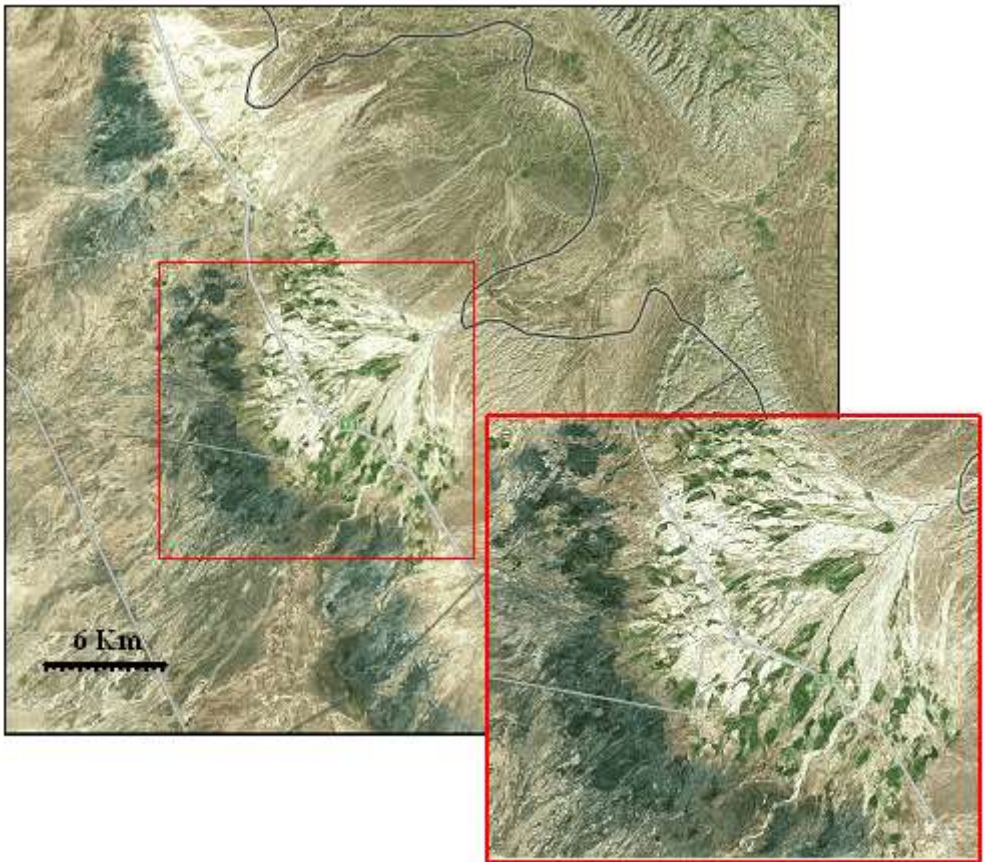

Figure 5: Here Maps image showing complex of Mandali Alluvial Fans.
Note the clearly visible limits between the developed multi stages, especailly in the enlarged caption.

4.2. Al-Fatha Alluvial Fan

It is the largest alluvial fan in Iraq (Fig. 6) represented on many geological maps of different scales (Sissakian, 2000 Barwari et al., 2003 and Sissakian and Fouad, 2012). Although the morphological characters of the alluvial fan are

vanished (Fig. 6), but the studied subsurface sections indicated the fan with its lithological details [5,6]. It is one stage large fan covered with gypcrete [17].

Figure 6: Google Earth image of Al-Fatha Alluvial Fan, note that all characteristics of the fan are vanished

4.3. Kirkuk Alluvial Fan

Kirkuk Alluvial Fan is one of the large fans (Fig.7) that is not recognized and presented on geological maps. [18]; however, studied the activity of the fan but she did not delineate the borders and characters of the fan.

The shape of Kirkuk Alluvial Fan is very clear in the DEM image (Fig. 7 C) and topographic map (Fig. 7 D), its length is 11 Km; whereas the maximum width is 9.8 Km. The concave fan shape is very clear; indicating that the coarse materials are the main constituents of the fan. Since the shape of the fans is related to grain size, fans built of coarse gravels have concave fan shape [19]. The materials of the fan are gravels, covered by gypcrete and thin soil cover, the thickness of the fan materials ranges from (5 – 12) m, as it is found in near surrounding water wells. The top soil cover ranges from (2.5 – 3) m. The height of the apex and apron of the fan is 366 m and 288 m, respectively.

In reviewing Figure (7 A), it is very clear that the characters of the alluvial fan are vanished due to urbanization of Kirkuk city and cultivation. However, in Figure (7 B) a faint cone shape can be seen indicating the presence of the fan and many other fans located south of Kirkuk Alluvial Fan. The type of the drainage pattern and system indicate the presence of feeder channels, some of them are abandoned. In Figure (7 C) the alluvial fan is very clear and is already limited; showing a typical fan shape.

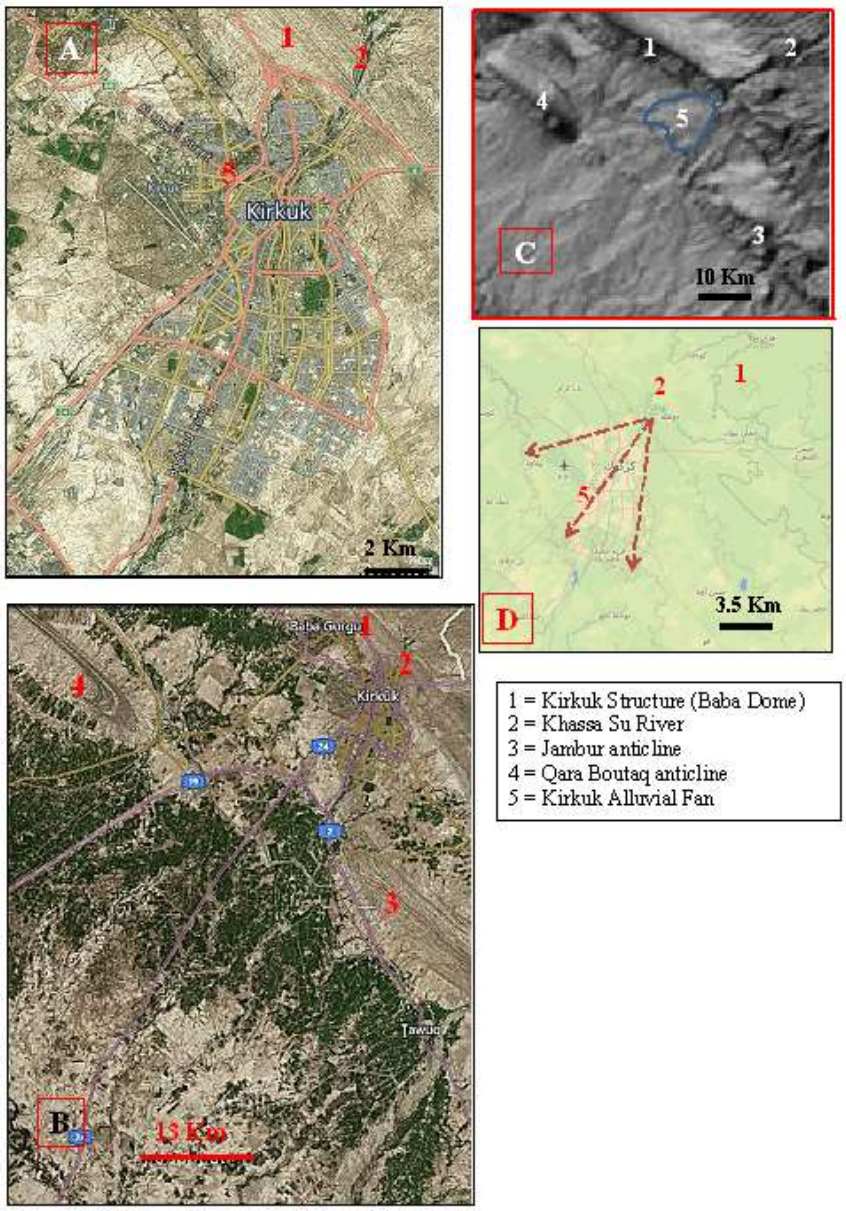

Figure 7: **A)** HERE map showing Kirkuk Alluvial Fan. Note all fan characters are vanished. **B)** HERE map showing Kirkuk Alluvial Fan with near surroundings including many other alluvial fans. Note all fan characters are vanished, but still some valleys and streams indicate the presence of the fan

C) DEM, showing Kirkuk Alluvial Fan with near surroundings. Note the shape of the fan is very clearly seen.

D) Topographic map of Kirkuk Alluvial Fan and near surrounding

4.4. Tawouq (Daqooq) Alluvial Fan

Tawouq Alluvial Fan is one of the large fans (Fig. 8) that is not recognized and presented on geological maps. The shape of Tawouq Alluvial Fan is very clear in the DEM image (Fig. 8 B) and topographic map (Fig. 8 C), its length is 30.4 Km; whereas the maximum width is 10.8 Km. The concave shape of the fan is very clear; with typical longitudinal fan form indicating that the fine materials are the main constituents of the fan. Since the shape of the fans is related to grain size, fans built of fine gravels and sand has longitudinal shape [19]. The materials of the fan are fine gravels and sand, covered by gypcrete and thin soil cover, the thickness of the fan materials ranges from (5 – 12) m, as it is found in near surrounding water wells. The top soil cover ranges from (2.5 – 3) m. The height of the apex and apron of the fan is 265 m and 171 m, respectively.

In reviewing Figure (8 A), it is very clear that the characters of the alluvial fan are vanished due to cultivation. The type of the drainage pattern and system indicate the presence of feeder channels, some of them are abandoned. In Figure (8 B) the alluvial fan is very clear and is already limited; showing a typical longitudinal fan shape.

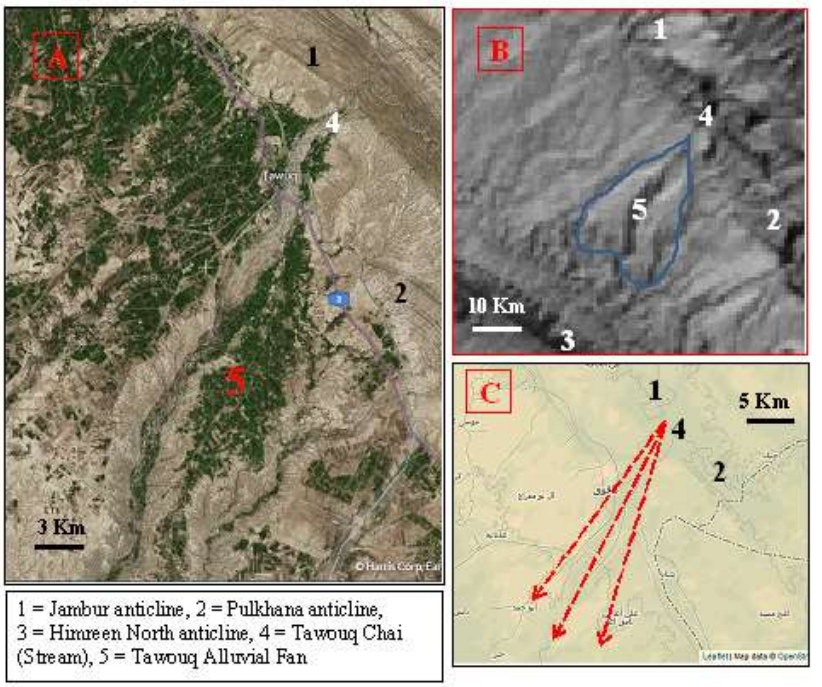

Figure 8: Tawouq Alluvial Fan. **A)** HERE map image, note the charcaters are vanished and the fan is hardly visible, the feeder channel is clear. **B)** DEM image, the longitudinal shape of the fan is clear, **C)** Topographic map.

4.5. Tuz Khurmatou Alluvial Fan

Tuz Khuramtou Alluvial Fan is one of the large fans (Fig. 9) that is not recognized and presented on geological maps. The shape of Tuz Khuramatou

Alluvial Fan is very clear in the DEM image (Fig. 9 B) and topographic map (Fig. 9 C), its length is 16.25 Km; whereas the maximum width is 11.70 Km. The concave shape of the fan is very clear; with typical longitudinal fan form indicating that the fine materials are the main constituents of the fan. Since the shape of the fans is related to grain size, fans built of fine gravels and sand has longitudinal shape [19]. The materials of the fan are fine gravels and sand, covered by gypcrete and thin soil cover, the thickness of the fan materials ranges from (5 – 12) m, as it is found in near surrounding water wells. The top soil cover ranges from (2.5 – 3) m. The height of the apex and apron of the fan is 234 m and 172 m, respectively.

In reviewing Figure (9 A), it is very clear that the characters of the alluvial fan are almost vanished due to cultivation; however, some faint indication still can show the presence of the alluvial fan. The type of the drainage pattern and system indicate the presence of feeder channels, some of them are abandoned. In Figure (9 B) the alluvial fan is very clear and is already limited; showing a typical longitudinal fan shape.

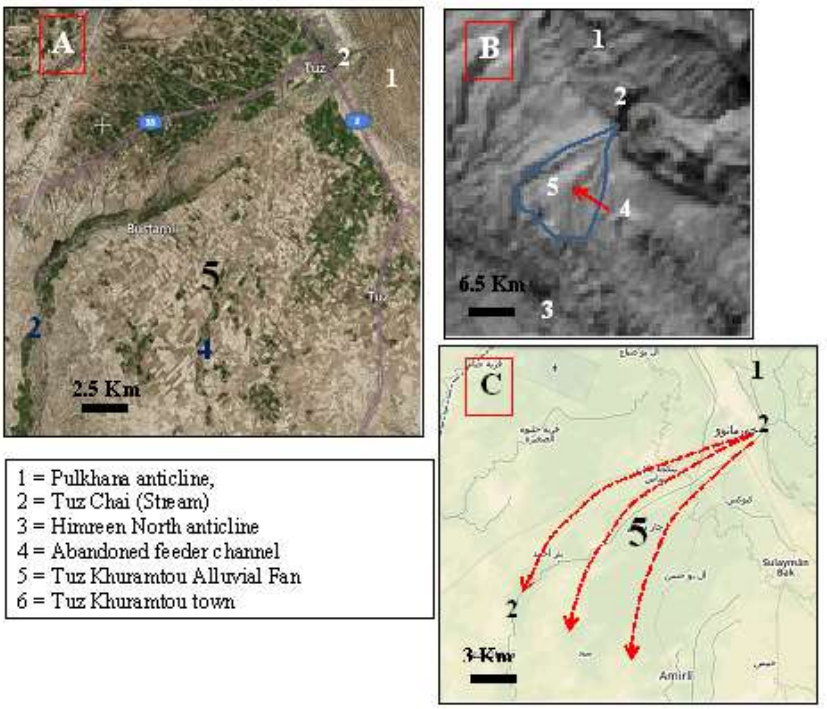

Figure 9: Tuz Khurmatou Alluvial Fan. **A)** HERE map image, note the faint indication for the presence of the fan, **B)** DEM image note clear shape of the fan, **C)** Topographic map

4.5. Kifri Alluvial Fan

Kifri Alluvial Fan is one of the large fans (Fig. 10) that is not recognized and presented on geological maps; it is a complex fan since its growth was ceased due

to the growth of Qumar anticline with more than one feeder channel (Fig. 10). The shape of Kifri Alluvial Fan is very clear in the Google Earth image and DEM image (Fig. 10 A and B, respectively). Its length is 4.52 Km; whereas the maximum width is 4.56 Km. The concave broad shape of the fan is very clear; with typical broad fan form indicating that the coarse materials are the main constituents of the fan. Since the shape of the fans is related to grain size, fans built of coarse and fine gravels has fan shape (Bull, 1991). The materials of the fan are coarse and fine gravels with sand, covered by gypcrete and thin soil cover, the thickness of the fan materials ranges from (5 – 12) m, as it is found in near surrounding water wells. The top soil cover ranges from (2.5 – 3) m. The height of the apex and apron of the fan is 252 m and 212 m, respectively.

In reviewing Figure (10 A), it is very clear that the characters of the alluvial fan are still present although urbanization of Kifri town has hindered it slightly. In Figure (10 B) the alluvial fan is very clear and is already limited; showing a typical broad fan shape. The topographic map (Fig. 10 C) shows very faint indication to the apron area.

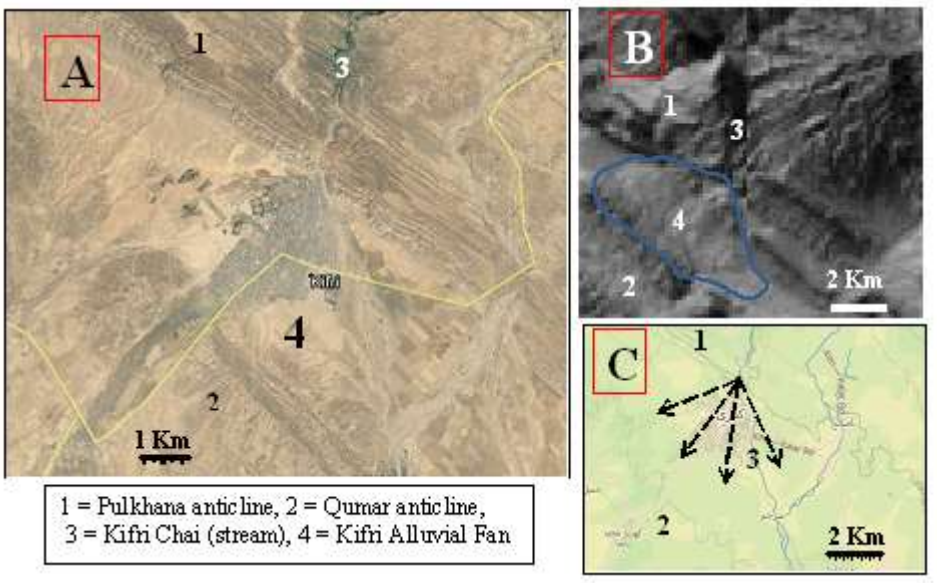

Figure 10: Kifri Alluvial Fan, **A)** Google Earth image; note the clear form of a broad fan shape, **B)** DEM; note the shape and limits of the fan are very clear, and **C)** Topographic map

4.6. Kifri East Alluvial Fan

Kifri East Alluvial Fan is one of the large fans (Fig. 11) that is not recognized and presented on geological maps. It is formed by complex system of feeder channels to develop the fan. Two feeder channels merge together before crossing

Pulkhana anticline (Point 4 in Fig. 11 A), after crossing Pulkhana anticline they bifurcate into two channels (Point 5 in Fig. 11 A), after developing of Kifri East Alluvial Fan and crossing Qumar anticline they merge together (Point 6 in Fig. 11 A). Moreover, another channel coming from Kifri Alluvial Fan merges to the western channel (Point 7 in Fig. 11 A). The growth of the fan was ceased due to the growth of Qumar anticline (Fig. 11). The shape of Kifri East Alluvial Fan is clear in the Google Earth and DEM images (Fig. 11 A and B, respectively). Its length is 4.56 Km; whereas the maximum width is 2.95 Km. The concave fan shape of the fan is clear; with typical fan form indicating that the coarse materials are the main constituents of the fan. Since the shape of the fans is related to grain size, fans built of coarse and fine gravels has fan shape [19]. The materials of the fan are coarse and fine gravels with sand, covered by gypcrete and thin soil cover, the thickness of the fan materials ranges from (5 – 12) m, as it is found in near surrounding water wells. The top soil cover ranges from (2.5 – 3) m. The height of the apex and apron of the fan is 252 m and 212 m, respectively.

In reviewing Figure (11 A), it is clear that the characters of the alluvial fan are still present although cultivation has hindered it slightly; however the feeder channels have limited the fan. In Figure (11 B) the alluvial fan is clear and is limited; showing a typical fan shape. The topographic map shows no indication to the fan area; therefore, it is not presented.

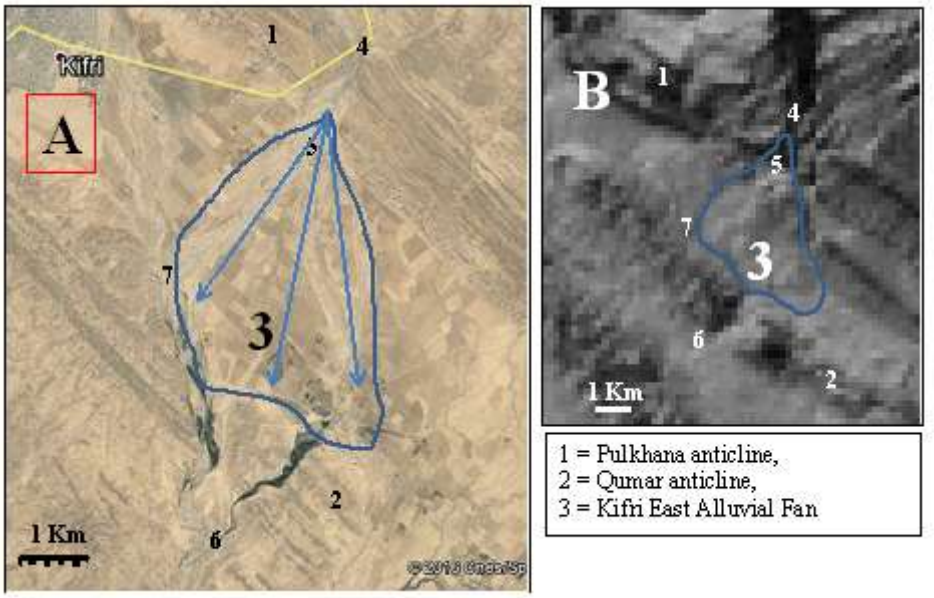

Figure 11: Kifri East Alluvial Fan, **A)** Google Earth image; note the strange channels system and faint fan shape, **B)** DEM image, note the fan shape is clear.

4.7. Al-Adhaim Alluvial Fan

Al-Adhaim Alluvial Fan is one of the large fans (Fig. 12); it is recognized and presented on the geomorphological map of Iraq [20]. The shape of Al-Adhaim

Alluvial Fan is faint in the Google Earth image (Fig. 12 A); whereas, it is clear in DEM image (Fig. 12 B). Its length is 56.1 Km with maximum width of 53.55 Km. The flat fan shape of the fan is clear; indicating that the fine materials are the main constituents of the fan. Since the shape of the fans is related to the grain size, fans built of fine materials have flat fan shape [19]. The materials of the fan are very fine gravels with sand, covered by gypcrete and thick soil cover. The thickness of the fan materials ranges from (5 – 12) m, as it is found in near surrounding water wells and the top soil cover ranges from (2.5 – 3) m. The height of the apex and apron of the fan is 129 m and 60 m, respectively.

In reviewing Figure (12 A), it is very clear that the characters of the alluvial fan are still present although cultivation and sand dunes have hindered the fan shape, especially west of Al-Adhaim River (Fig.12 A). In Figure (12 B) the alluvial fan is clear and is already limited; showing a typical wide and flat fan shape. The fan cannot be seen in topographic map, this is attributed to very flat land surface.

In Figure (12 A), a faint indication can be seen for a small fan originated from an acute meander of Al-Adhaim River. This is attributed; most probably to the presence of lateral scarp along the river course.

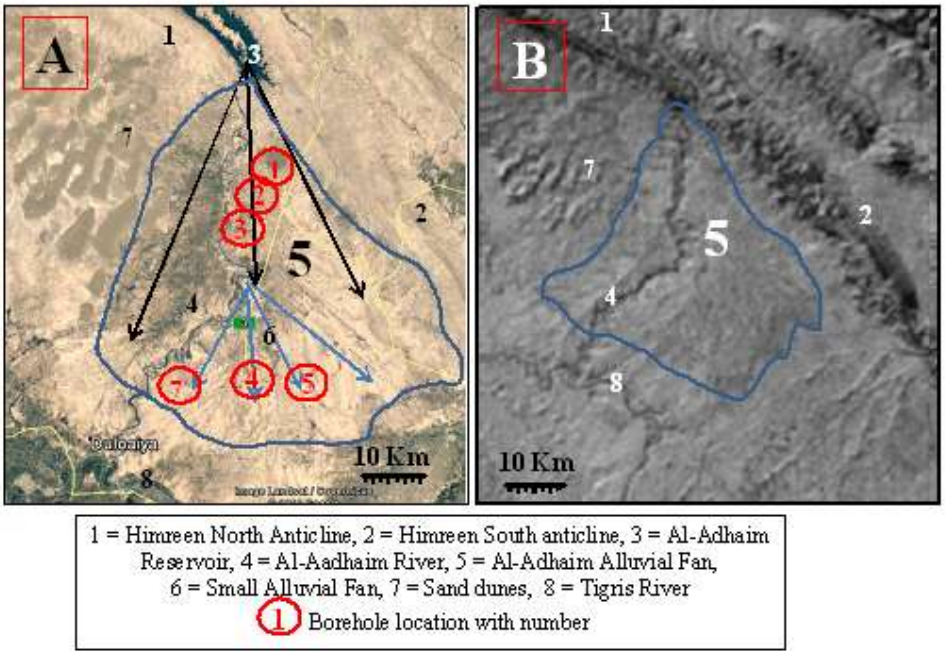

Figure 12: Al-Adhaim Alluvial Fan

A) Google Earth image; note the faint shape of the fan, DEM image; note the shape of the fan is more clear

4.8. Mukdadiya Alluvial Fan

Mukdadiya Alluvial Fan is one of the large fans (Fig. 13) that it is not recognized and presented on geological maps. The shape of Mukdadiya Alluvial Fan is faint in the Google Earth image (Fig. 13 A) and DEM image (Fig. 13 B). Its length is 77.1 Km with maximum width of 69.95 Km. The flat fan shape of the fan is clear; indicating that the fine materials are the main constituents of the fan. Since the shape of the fans is related to the grain size, fans built of fine materials have flat fan shape [19]. The materials of the fan are very fine gravels with sand, covered by thick soil cover. The thickness of the fan materials ranges from (5 – 12) m, as it is found in near surrounding water wells and the top soil cover ranges from (2.5 – 3) m. The height of the apex and apron of the fan is 76 m and 36 m, respectively.

In reviewing Figure (13 A), it is very clear that the characters of the alluvial fan are still present, especially in the apron area although cultivation has hindered the fan shape (Fig.14 A). In Figure (13 B) the alluvial fan is clear and is limited; showing a typical large and flat fan shape. The fan cannot be seen in topographic map, this is attributed to very flat land surface.

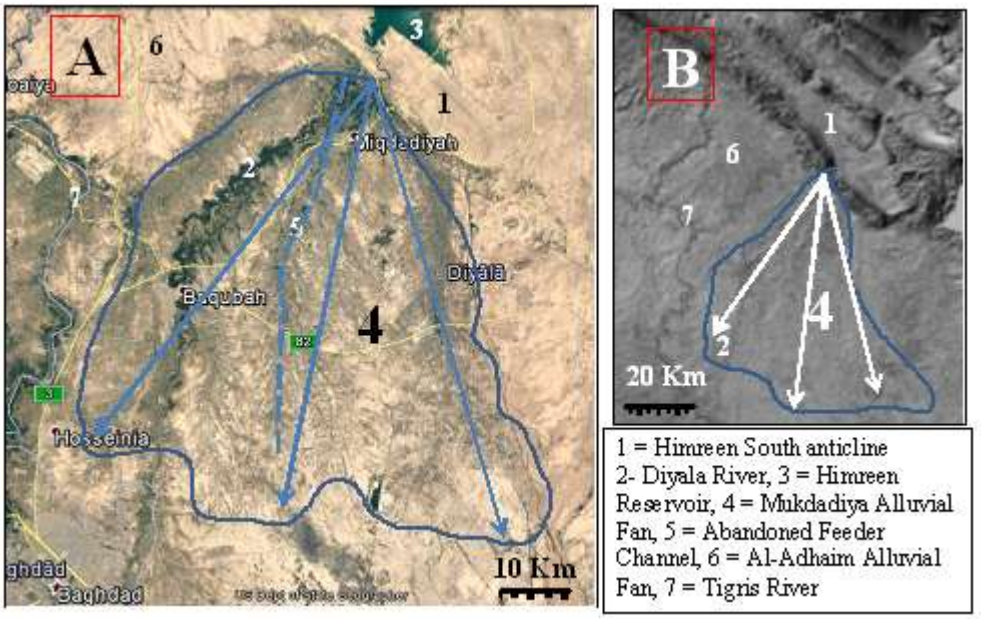

Figure 13: Mukdadiya Alluvial Fan, A) Google Earth image, note the faint limits of the fan and the abandoned feeder channel,
B) DEM image, note only the apron area is clear

4.9. Diyala Alluvial Fan

Diyala Alluvial Fan is one of the large fans (Fig. 14) that it is not recognized and presented on geological maps. The shape of Diyala Alluvial Fan is very faint in the Google Earth image (Fig. 14 A) and in DEM image (Fig. 14 B). Its length is

16.1 Km with maximum width of 15.95 Km. The flat fan shape of the fan is clear; indicating that the fine materials are the main constituents of the fan. Since the shape of the fans is related to the grain size, fans built of fine materials have flat fan shape [19]. The materials of the fan are very fine gravels with sand, covered by thick soil cover. The thickness of the fan materials ranges from (5 – 12) m, as it is found in near surrounding water wells and the top soil cover ranges from (2.5 – 3) m. The height of the apex and apron of the fan is 162 m and 142 m, respectively.

In reviewing Figure (14 A), it is very clear that the characters of the alluvial fan are still present although cultivation has hindered the fan shape (Fig.14 A). In Figure (14 B) the alluvial fan is very faint; only the apron area and the western limits are clear; the fan is limited; showing a typical large and flat fan shape. The fan cannot be seen in topographic map, this is attributed to very flat land surface.

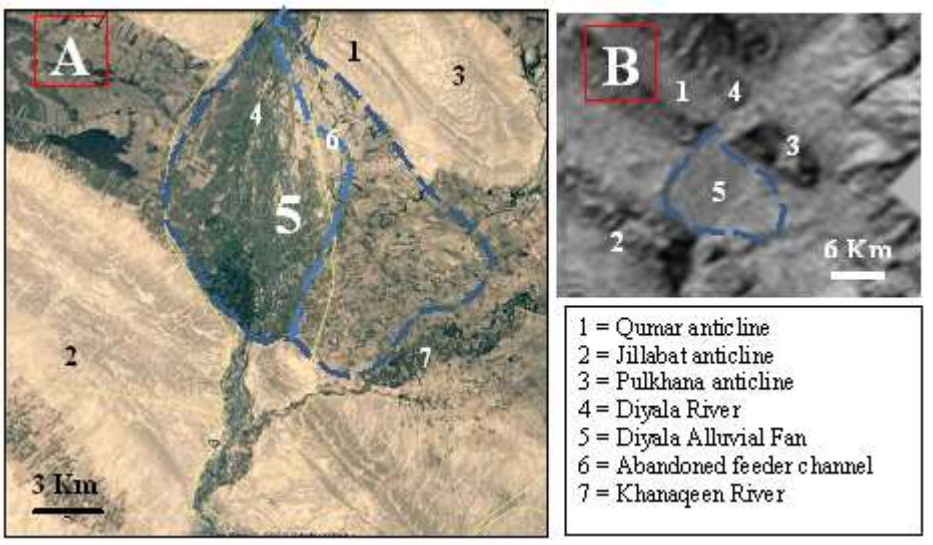

Figure 14: Diyala Alluvial Fan, A) Google Earth image, note the very faint limits of the fan, B) DEM image, the eastern limits are more clear. Also not the effect of the Khanaqeen River on the restriction of the eastern limits of the fan

4.10. Kirkuk South Alluvial Fans

Kirkuk South Alluvial Fans are three fans (Fig. 15) that are not recognized and presented on geological maps. The shapes of Kirkuk South Alluvial Fans are very faint in the Google Earth image (Fig. 15 A) but in DEM image are clear (Fig. 15 B). Their lengths (A, B and C) are 30.80 Km, 26.40 Km and 35.20 Km, respectively, whereas their maximum widths are of 13.20 Km, 14.08 Km and 16.72 Km, respectively. The flat – concave and long fan shape is clear; indicating that the fine materials are the main constituents of the fan. Since the shape of the fans is related to the grain size, fans built of fine materials have long fan shape [19]. The materials of the fan are very fine gravels with sand, covered by gypcrete

and thick soil cover. The thickness of the fan materials ranges from (2.5 – 12) m, as it is found in near surrounding water wells and the top soil cover ranges from (2.5 – 3) m. The heights of the apex of the fans are 231 m, 238 m and 260 m, respectively, whereas the heights of the apron area are 191 m, 187 m and 180 m, respectively.

In reviewing Figure (15 A), it is very clear that the characters of the alluvial fan are vanished by cultivation (Fig. 15 A). In Figure (15 B) the alluvial fans are clear; showing a typical large and long with flat – concave fan shape. In Figure (15 C) the limits of the alluvial fans are faint. The fans cannot be seen in topographic map, this is attributed to very flat land surface.

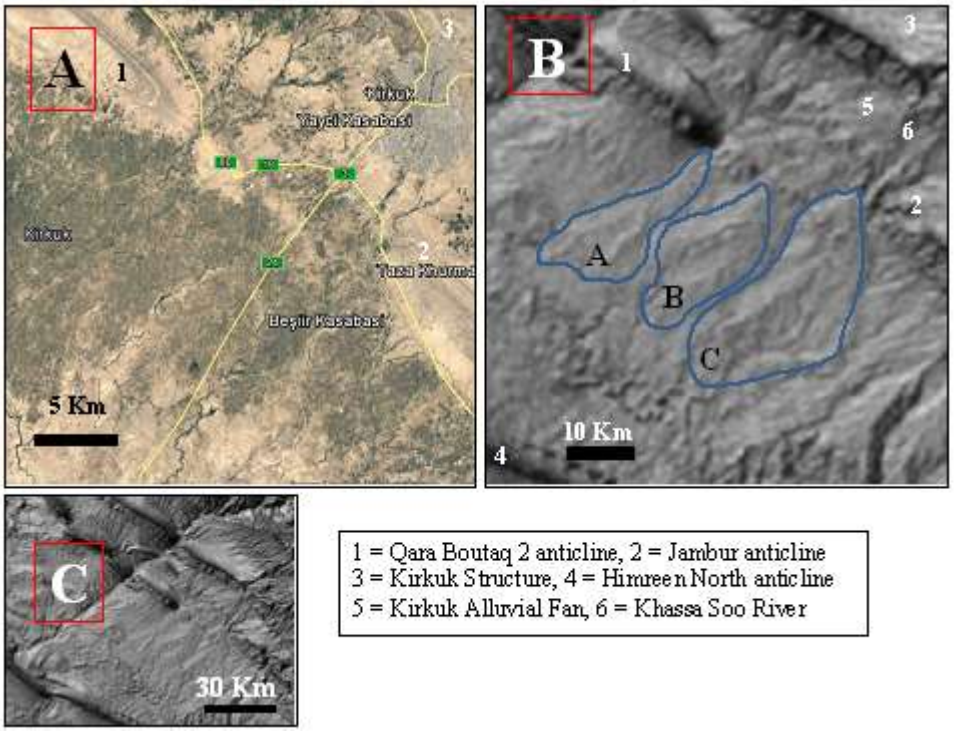

Figure 15: Kirkuk South Alluvial Fans. A) Google Earth image, note that almost there is no indication for the fans, B) Enlarged DEM image, note the fans are clear, C) DEM image, the limits of the fans are faint.

4 Discussion

In the studied area, tens of alluvial fans are developed with different sizes and shapes. However, only eight large alluvial fans are studied and their limits are drawn; their characters are listed in Table (1).

Table 1: Characteristics of the studied alluvial fans

Name		Characters of the alluvial fans						
		Length (Km)	Width (Km)	Coverage area (Km^2)	Height (m)		Gradient (%)	Shape
					Apex	Apron		
Kirkuk		11.00	9.8	53.91	366	288	1.42	Fan
Tawouq		30.40	10.8	328.32	265	171	0.23	Longitudinal
Tuz Khurmatou		16.25	11.70	190.16	234	172	0.38	Longitudinal
Kifri		4.52	4.56652	15.59	243	218	0.33	Broad fan
Kifri East		4.65	2.95	6.41	252	212	0.86	Fan
Al-Adhaim		56.10	53.55	1502.75	129	60	0.12	Fan
Mukdadiya		77.10	69.95	2345.02	76	36	0.05	Fan
Diyala		16.10	15.95	146.12	162	142	0.12	Fan
South Kirkuk	A	30.80	13.20	214.50	231	191	0.13	Longitudinal
	B	26.40	14.08	335.72	238	187	0.19	Longitudinal
	C	35.20	16.72	361.22	260	180	0.23	Longitudinal

The main reasons that the alluvial fans are not presented on the geological maps of different scales [2,21,22,23,24] are:

1- The alluvial fans are very large; therefore, cannot be recognized in the field.

2- No remote sensing data were available during 1977 when the studied area was mapped by regional geological mapping projects.

3- The plantation and/ or urbanization had vanished the characters of the alluvial fans.

4- The top cover soil of the alluvial fans is almost the same in the surrounding areas; therefore, the fans cannot be distinguished in the field from their surrounding areas.

The studied alluvial fans and tens of smaller fans within the studied area are developed by streams where they cross anticlines. In all cases, the streams pass the anticlines and flow in wide and flat plains forming typical conditions for development of alluvial fans. Alluvial fans are formed due to decrease of gradient of a stream; due to drop in local base level, hence the coarse grained solid materials carried by the water are dropped [15,16,19]. As this reduces the capacity of the channel, the channel will change direction over time; gradually building up a slightly mounded or shallow fan shape [25]. Therefore, the sediments are usually poorly sorted. "The fan shape can also be explained with a thermodynamic justification: the system of the sediment introduced at the apex of the fan will trend to a state, which minimizes the sum of the transport energy involved in

moving the sediment and the gravitational potential of material in the cone" [15]. Therefore, there will be iso-transport energy lines forming concentric arcs about the discharge point at the apex of the fan. Thus, the materials will tend to be deposited equally about these lines, forming the characteristic cone shape [26].
The low gradient also causes drop in transporting energy, consequently the iso-transport energy lines will lose their concentric shapes [15,26]. In the studied area, the transporting energy drops down continuously as the streams passes more than one anticline; as far as the deposition place becomes more far from the source area and become more flat. This is another reason that explains the longitudinal fan shapes and losing their concavity.

Some of the studied alluvial fans; like Kirkuk, Kifri, Kifri East and Diyala (Figs. 7, 10, 11 and 14, respectively) have not grown normally. This is attributed to the facing anticlines, which were growing laterally and vertically; therefore, the fans are shorter than others (Table 1). The lateral growth of the anticlines is confirmed by development of many water and air gaps in the (Fig.16) [27].

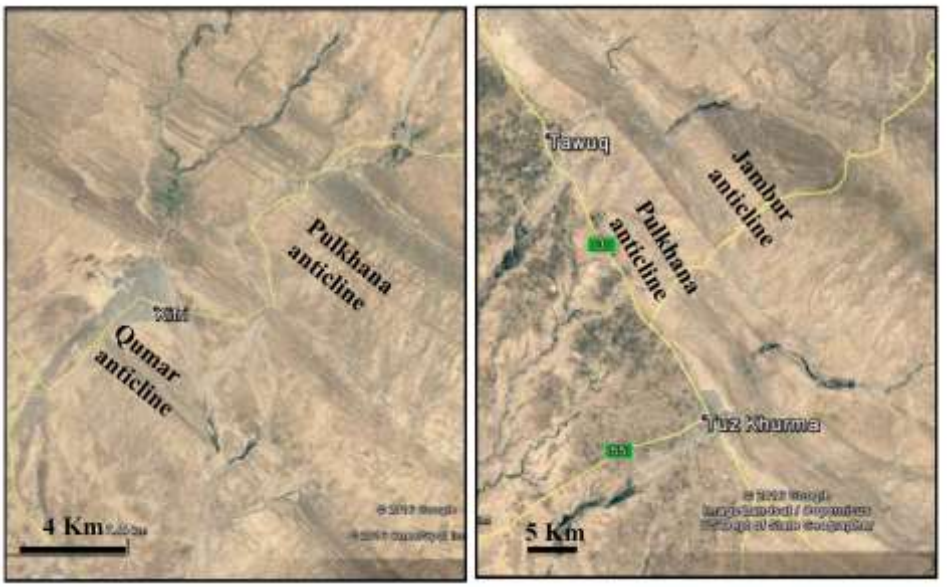

Figure 16: Google Earth images of Pulkhana, Qmuar and Jambur anticlines. Note the developed water and wind gaps

[15] considered Kirkuk Alluvial Fan as a segmented fan due to the facing of growing Jambur anticline (Fig. 7). The current authors are in full accordance with her conclusion; although the lower part of the fan is considered as another alluvial fan and called as Kirkuk South Alluvial Fan (Fan C in Fig. 15).

The studied alluvial fans have either typical fan form or have longitudinal forms. In the former case, the main constituent of the fans is coarse gravels overlain by finer gravels and sands, whereas in the latter case, the main constituent is fine

gravels overlain by sands. In both cases, the growth of the fans had effected by different factors, which had caused changes in their typical fan shapes. Those factors are discussed hereinafter.

a- **Growing Anticline:** A typical example is Kirkuk Aluvial Fan that faces the growing Jambur anticline (Fig. 7). The growing Jambur anticline had ceased the growing of the alluvial and caused its segmentation into two individual fans, called in the current study as Kirkuk South Alluvial Fan (Fan C in Fig. 15). This is also confirmed by [15]. Another example is Diyala Alluvial Fan (Fig. 14), where the growth of the fan is ceased by Jillabat anticline; leading to asymmetrical fan towards east. The southeastern continuation of the northeastern limb of Jillabat anticline gives wider area for growing of the fan rather than the northwestern continuation of the same limb of the anticline. However, the existing of Khanaqeen River that flows in opposite direction to the growth of the fan (Fig. 14) had ceased the growth of the proximal part of the fan.

b- **Presence of River Facing the Alluvial Fan:** In both of Mukdadiya and Al-Adhaim Alluvial Fans, the Tigris River attacks the proximal parts of the fans leading to unusual fan shapes (Figs. 11 and 12). In the first case the, the western limits of the fan are not smooth due to the Tigris River's action, whereas in the latter case, the southern and eastern limits of the fan are not smooth due to the action of the Tigris and Diyala Rivers, respectively.

c- **Presence of Two Anticlines:** When the alluvial fan is developed between two anticlines with small spacing distance, then the growth of the fan will be limited to the available space. Good examples are Kifri and Kifri East Alluvial Fans (Figs. 10 and 11, respectively); their lengths are 4.52 Km and 4.65 Km, respectively. In comparing the feeder channels of both fans with those of Tawouq and Tuz Khrmatou Alluvial Fans, it is very clear that almost all feeder channels have the same size and drainage basins. But, the lengths of Tawouq and Tuz Kurmatou Alluvial Fans are 30.40 Km and 16.25 Km, respectively, which are more than double length of Kifri and Kifri East Alluvial Fans.

In the west of the studied area, The Lesser Zab River flows crossing three anticlines; Kirkuk Structure, Bia Hassan and Qara Boutaq anticlines; from northeast to southwest (Fig. 17). It can be seen that no alluvial fan is developed after crossing of the anticlines, which is not the same case for the studied and presented alluvial fans in the current study. This is attributed to the following reasons:

a) **Meandering:** The Lesser Zab River exhibits intense meandering through its course in the studied area (Fig.18, A, B, C and D), which means the river is

in old age as indicated from the presence of: **1)** Wide meandering, **2)** Ox-bow lakes, **3)** Natural levees, and **4)** Sand bars [28,29]; consequently, the current is very low. Therefore, no coarse sediments can be carried and all the carried sediments are deposited as flood plain sediments.

b) Gradient: The elevation differences before and after the crossing of the Lesser Zab River to the three anticlines is low; therefore, the gradients are low too. The elevation difference and distance of the three crossings are: 20 m, 3 m and 4 m, whereas the lengths of the crossings are: 10.8 Km, 7. 02 Km and 2.70 Km, the gradients are: 0.18%, 0.041% and 0.15%, respectively in Kirkuk Structure, Bai Hassan and Qara Boutaq anticlines. Some of the studied alluvial fans have gradients equal or slightly lower than the mentioned gradients (Table 1); this is attributed to the fact that the river forms intense meandering during the crossings (Fig. 18, A and C); therefore, the meandering contributes with the low gradient in decreasing the river's velocity.

The main constituents of the studied alluvial fans are almost the same. This is attributed to the following aspects: 1) The source areas of the alluvial fans are covered with the same geological formations, which consist mainly of fine clastics, conglomerate and gypsum and limestone. The last two lithologies are rarely exposed, 2) The size of the feeder channel is almost in the same range, although few of them are shorter, like those of Kifri Alluvial Fans, 3) The percentage of the fine clastics increases in those fans that are located in the southern part of the studied area. This is attributed to the fact that the feeder channels have deposited their coarse load in those fans that are located in the upstream areas; per feeder channel (Fig. 18).

Figure (18) show three cross sections in Al-Adhaim Alluvial Fan it shows the presence of gravels in B.H. 1 (Figs. 11 and 18), whereas in the remaining boreholes no gravels were encountered. This is attributed to the location of B.H. 1, which is in the apex of the fan; therefore, gravels were deposited. Even those gravels, which are encountered in B.H. 1 are of fine pebbles, up to 2 cm in size [20]. The described mud in the encountered sediments in the boreholes includes gypsiferous soil and/ or gypcrete.

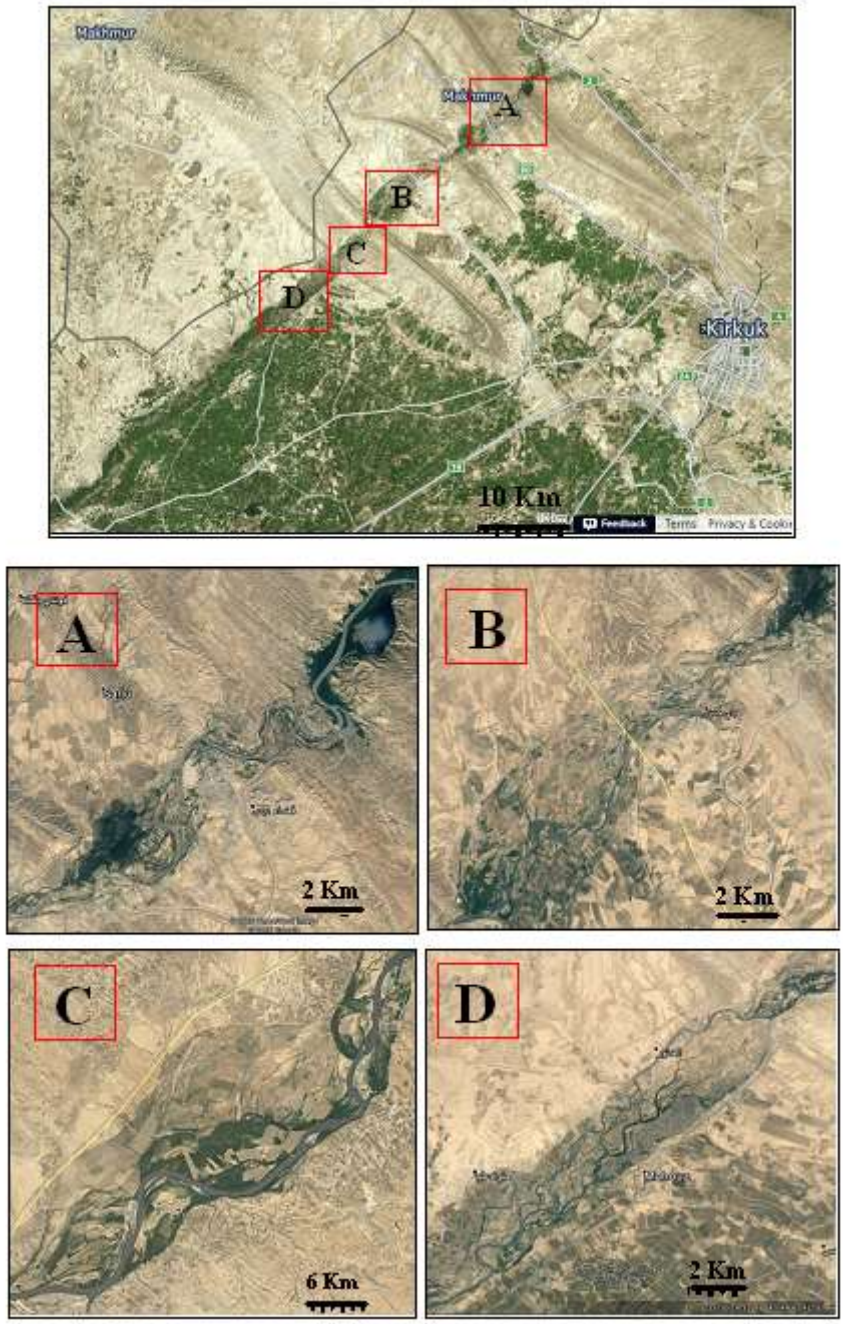

Figure 17: Flash Earth image of the Lesser Zab River with four captions of Google Earth images showing the details of the intense meandering of the river.

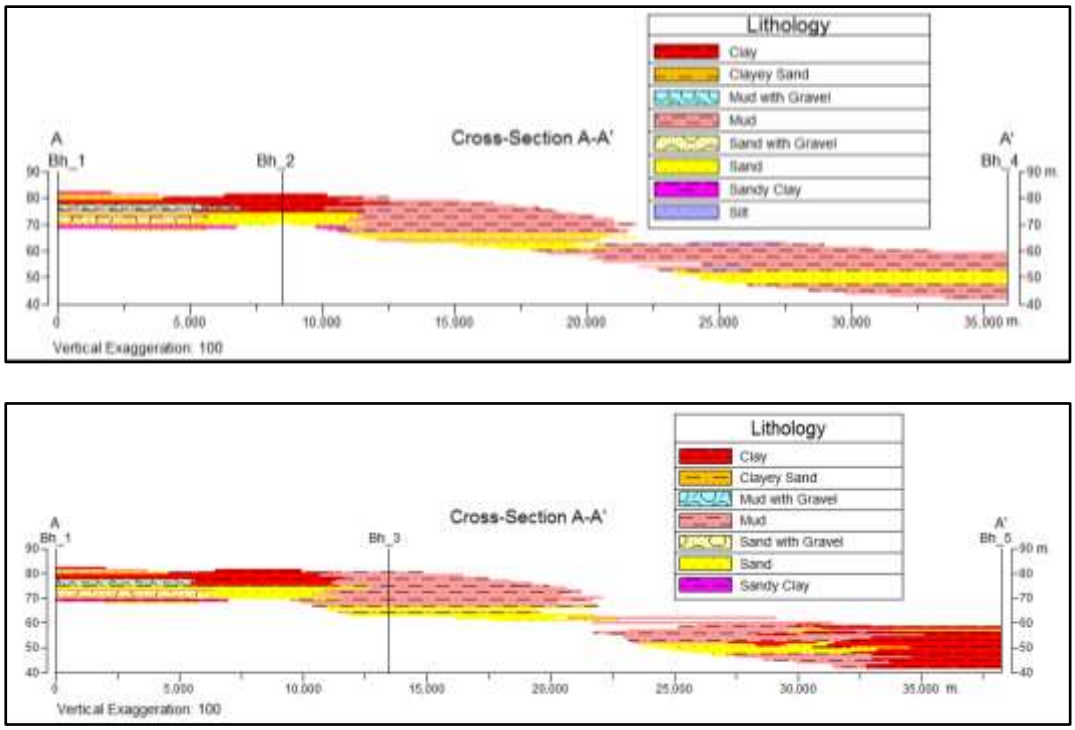

Figure 18: Three cross sections in Al-Adhaim Alluvial Fan. For location of boreholes refer to the Figure 11.

In Al-Adhaim Alluvial Fan, small fan is radiated (Point 6 in Fig.11) within the original main fan. This may be attributed to the intense meandering of Al-Adhaim River at that location (Fig. 19). During main floods of the river, the water current couldn't follow the intense meandering; therefore, flooded out of the course and developed small alluvial fan (Fig. 11).

Figure 19: Google Earth image showing intense meandering of Al-Adhaim River

5 Conclusions

Tens of alluvial fans were not recognized and mapped in the studied area and near surroundings during the regional geological mapping. This is attributed; mainly due to large coverage areas of the fans, vanishing of the fan shape due the cultivation and urbanization.

The growth of the alluvial fans is locally restricted by facing anticline, which in term was growing; therefore, ceased the growth of the fan. A good example is Kifri, Kifri East and Kifri West Alluvial Fans. Other alluvial fans were segmented due to upward movement of a facing anticline; a good example is Kirkuk Alluvial Fan.

The normal concave fan shape in the studied area is hardly visible; this is attributed to the large coverage areas of the fans and fine size of the constituents. Moreover, the no gravels are present in those fans, which are developed in areas where other fans are developed in upstream areas, since the pebbles were deposited in those upstream fans. However, in the same alluvial fan, gravels occur in the apex areas; whereas, only sand and mud occur in the proximal parts, due the decrease in the gradient of the feeder channels; consequently, decreases the ability of carrying the coarse constituents.

References

[1] Sissakian, V.K., 2000. Geological Map of Iraq, scale 1:1000000, 3rd edition. Iraq Geological Survey's Publications, Baghdad, Iraq.

[2] Sissakian, V.K. and Fouad, S.F., 2012. Geological Map of Iraq, scale 1:1000000, 4th edition. Iraq Geological Survey's Publications, Baghdad, Iraq.

[3] Yacoub, S.Y., 1983. The Geology of Mandali Area. Iraq Geological Survey (GEOSURV) internal report no. 1383.

[4] Domas, J., 1983. The Geology of Karbala Kut and Ali Al-Gharbi Area. Iraq Geological Survey (GEOSURV) internal report no. 1384.

[5] Jassim, S.Z., 1985. Early Pleistocene gravel fan of the Tigris River from Al-Fatha to Baghdad, Central Iraq. Journal of Geological Society of Iraq, Vol. 14, p. 25 – 34.

[6] Yacoub, S.Y., Sissakian, V.K. and Deikran, D.B., 1990. Final Geological Report Contract of the Earth Sciences Activities (C.E.S.A.). Iraq Geological Survey (GEOSURV) internal report no. 2022.

[7] Yacoub, S.Y., Deikran, D.B. and Ubaid, A.Z., 1991. Local Geological Stage Report, Vol.1, Contract of the Earth Sciences Activities (C.E.S.A.). Iraq Geological Survey (GEOSURV) internal report no. 2016.

[8] Hamza, N.M., 1997. Geomorphological Map of Iraq, scale 1: 1000 000. Iraq Geological Survey (GEOSURV) Publications, Baghdad, Iraq.

[9] Barwari, A.M., Yacoub, S.Y. and Buni, Th.J., 2003. Quaternary Sediments Map of Iraq, scale 1: 1000 000. Iraq Geological Survey (GEOSURV) Publications, Baghdad, Iraq.
[10] Sissakian, V.K. and Abdul Jab'bar, M.F., 2013. Geomorphology and Morphometry of the three tributaries of Adhaim River, Central Part of Iraq. Journal of Research in Environmental Science and Toxicology (ISSN: 2315-5698). Vol. 2, No.3.
[11] Yacoub, S.Y., 2011a. Geomorphology. In: Geology of the Mesopotamia Plain. Iraqi Bulletin of Geology and Mining, Special Issue, No.4, p. 7 – 32.
[12] Yacoub, S.Y., 2011b. Stratigraphy. In: Geology of the Mesopotamia Plain. Iraqi Bulletin of Geology and Mining, Special Issue, No.4, p. 47 – 82.
[13] Yacoub, S.Y., Al-Jaf, A.O. and Kadhim, T.H., 2012. Geomorphology. In: Geology of the Low Folded Zone. Iraqi Bulletin of Geology and Mining, Special Issue No. 5, p. 7 – 37.
[14] Fouad, S.F., 2012. Tectonic Map of Iraq, scale 1: 1000 000, 3rd edit. Iraq Geological Survey (GEOSURV) Publications, Baghdad, Iraq.
[15] A.G.I. (American Geological Institute), 1962. Dictionary of Geological Terms. New York: Dolphin Books. Wikipedia, the Free Encyclopedia.
[16] Huggett, R.J., 2013. Fundamentals of Geomorphology. Routledge, ISSBN 0415390834, 9780415390835.
[17] Sissakian, V.K. and Abdul Jab'bar, M.F., 2014. Classification of Alluvial Fans in Iraq. Iraqi Bulletin of Geology and Mining, Vol.10, No.3, p. 43 – 67.
[18] Abdul Jab'bar, M.F., 2015. Geomorphology and Morphometryof Segmented Kirkuk Alluvial Fan, Central Part of Iraq. Iraqi Bulletin of Geology and Mining, Vol. 11, No. 2, p. 27 – 44.
[19] Bull, W.B., 1991. Geomorphic Responses to Climate Change. Oxford University Press.
[20] Hamza, N.M. and Domas, J., 1980. The Geology of the Adhaim Area. Iraq Geological Survey (GEOSURV) Library report no. 1381.
[21] Sissakian, V.K., 1978. Report on the Regional Geological Survey of the Tuz Khurmatu, Kifri and Kalar Area. Iraq Geological Survey (GEOSURV) Library report no. 902.
[22] Youkhanna, R.Y. and Hradecky, P., 1978. Report on regional geological mapping of Khanaqin – Maidan Area. GEOSURV, int. rep. no. 903.
[23] Sissakian, V.K. and Fouad, S.F., 2014. Geological Map of Kirkuk Quadrangle, scale 1:250000, 2nd edition. Iraq Geological Survey's Publications, Baghdad, Iraq.
[24] Barwari, A.M. and Slewa, N.A., 2014. Geological Map of Khanaqeen Quadrangle, scale 1:250000, 2nd edition. Iraq Geological Survey's Publications, Baghdad, Iraq.
[25] Sissakian, V.K., 2011. Alluvial Fans of Sinjar Mountain, NW Iraq. Iraqi Bulletin of Geology and Mining, Vol. 7, No. 2, p. 9 – 26.
[26] National Aeronautics and Space Administration, 2009. Geomorphology from Space; Fluvial Landforms, Chapter 4. Internet data.

[27] Keller, E.A. and Pinter, N., 2002. Active Tectonics, Earthquakes, Uplift and Landscape, 2nd edition. Prentice Hall, 362 pp.
[28] Imoor, L., 2006. Classifying Rivers, Three Stages of River Development. Geotech.com. www.sswm.info/sites/default/files/reference
[29] Khatsuria, R.M., 2010. How and why rivers meander. Hydrotopics. hydrotopics.wordpress.com/2010/10/05/how-and-why