GEOMORPHOLOGY AND MORPHOMETRY OF THE GREATER ZAB RIVER BASIN, NORTH OF IRAQ

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ABSTRACT

The Greater Zab River is one of the main tributaries of the Tigris River. The river runs in the central northern part of Iraq, and then joins the Tigris River south of Mosul city, in the northern central part of Iraq. It has four main tributaries, called; Shamdinan, Haji Beg, Rawandooz and Khazir – Gomal rivers, beside tens of small tributaries and ephemeral streams, which drain directly in the main river. The studied catchment area of the Greater Zab River; in Iraq attains about 13708 Km^2, and extends in the northern and northeastern parts of Iraq, and farther more in Turkey and Iran. The basin of the river is divided into four sub-basins of the aforementioned tributaries and a fifth one, which includes the catchment area that drain directly in the Greater Zab River. The widths of the five sub-basins range from (1.54 – 6.19) Km, whereas their lengths range from (41.4 – 108.3) Km.

The catchment's areas of the Greater Zab River and its four tributaries are covered mainly by carbonate rocks of many formations, which range in age from Triassic to Pliocene – Pleistocene, beside igneous and metamorphic rocks, especially in the northeastern parts. Moreover, fine clastics of Injana and Mukdadiya formations, coarse clastics of Bai Hassan Formation, and marl, limestone and gypsum of the Fatha Formation cover considerable area. Through the courses of the Greater Zab River and its four tributaries, they cross tens of anticlines, almost perpendicularly; some of them have gorge forms, forming 34 water gaps and 15 air gaps, in the studied area. The geomorphology and morphotectonics of the Greater Zab River basin are studied. Six Morphometric indices have determined in this study, using ArcGIS technique, which indicated High, Moderate, Very High, Very High and High relative tectonic activity for the five sub-basins, respectively. Geomorphological and basin drainage maps of the studied area are prepared, too.

دراسة جيومورفولوجية ومورفوميترية لحوض نهر الزاب الأعلى في شمال العراق

فاروجان خاجيك سيساكيان

المستخلص

يعتبر نهر الزاب الأعلى أحد الروافد الرئيسية لنهر دجلة ويجري في وسط شمال العراق ويتكون من أربعة فروع رئيسية هي: شمدينان، حاجي بيك، راوندوز والخازر – الگومل، بالإضافة الى عشرات الفروع الصغيرة والجداول الموسمية التي تصب في النهر مباشرة. تغطي أحواض النهر مع الفروع الأربعة مساحات كبيرة، بلغت المدروسة منها 13708 كم^2 داخل العراق، وتمتد إلى شمال وشمال شرق العراق وكذلك الى داخل تركيا وإيران. تم تقسيم حوض النهر الى أربعة أحواض ثانوية للفروع المذكورة في أعلاه، إضافة الى الحوض الثانوي الخامس الذي يشمل المنطقة التي تغذي نهر الزاب الكبير مباشرة، إضافة الى فروعها الرئيسية. إن عرض الأحواض الخمسة يتراوح بين (1.54– 6.19) كم، بينما تتراوح أطوالها من (41.4 – 108.3) كم.

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يغطى حوض نهر الزاب الكبير بشكل عام بصخور كلسية تتراوح أعمارها من الترياسي الى الپاليوسين – البلايستوسين، وتوجد أيضا صخور نارية ومتحولة في المناطق الشمالية الشرقية، وكذلك صخور فتاتية ناعمة تعود لتكويني إنجانة والمقدادية، ومدملكات وصخور طينية تعود لتكوين باي حسن، إضافة الى صخور الطفل والكلس والجبس العائدة لتكوين الفتحة.

يقطع نهر الزاب الكبير مع فروعه الأربعة خلال مساراتها داخل الحوض الرئيسي عشرات الطيات المحدبة والمقعرة وغالبا بشكل عمودي على إتجاه الطيات، وبعضها تشكل مضايق. تم إجراء دراسة جيومورفولوجية ومورفوتكتونية لنهر الزاب الكبير وفروعه الأربعة، إضافة إلى دراسة ستة عوامل مورفوميترية بواسطة برنامج ArcGIS ولوحظ وجود فرق كبير بين إنحدارات الفروع، وكذلك وجود فرق في إنحدار النهر بين منطقة دخوله الأراضي العراقية ومنطقة تدفقه إلى المنطقة المنبسطة، جنوب مضيق بخمة. كما لوحظ وجود 34 فتحة للمياه (Water Gap) و15 فتحة هوائية (Air Gap).

درست الخصائص المورفوميترية لنهر الزاب الأعلى وفروعه الأربعة، وكذلك مواصفات أحواضها، وتم قياس ستة معامل مورفوميترية للأحواض الثانوية الخمسة باستخدام برنامج ArcGIS وقد أشارت النتائج الى وجود نشاط تكتوني نسبي **عالي ومتوسط وعالي جدا وعالي جدا وعالي** للاحواض الثانوية الخمسة، على التوالي. وكذلك تم إعداد خريطة جيومورفولوجية من مقياس 1: 000 1000 وخريطة التصريف لحوض نهر الزاب الكبير وفروعه الأربعة.

INTRODUCTION

The Greater Zab River is one of the main tributaries of the Tigris River, it enters into the Iraqi territory from Turkey, and includes four main tributaries, called; from north to south: Shamdinan, Haji Beg, Rawandooz, and Khazir – Gomal rivers, beside tens of small tributaries and ephemeral streams. The main trend of the Greater Zab River is N – S, then changes to NW – SE, and finally to NE – SW; after Bekhme gorge until merges into the Tigris River (Fig.1). The catchment area of the river, inside Iraq is about 13708 Km^2, and forms mainly rough landscapes, except the part south of Bekhme gorge. It is covered mainly by carbonates of different formations, igneous and metamorphic rocks; in the northeastern part, while south of the Bekhme gorge, the area is covered by fine and coarse clastics, and marl, limestone and gypsum, which are weakly resistant to erosion, forming hilly and undulatory landscapes.

▪ Location

The studied area is located in the central northern and northeastern parts of Iraq. The Greater Zab River enters into the Iraqi territory northeast of Amadiyah city and merges into the Tigris River, south of Mosul city (Fig.1). It passes through and nearby to different cities and towns, among them are, from north to south, Barzan, Zibar, Rawandooz, Aqra, Shaqlawa, and Quwair. The following coordinates bound the studied area, approximately:

Longitude	43° 00' 00"	45° 12' 00"	E
Latitude	35° 25' 00"	37° 20' 00"	N

▪ Aim

This work aims to study the geomorphology and morphometry of the Greater Zab River basin, inside the Iraqi territory only, to find and evaluate morphometric indices, and to deduce their relation with the tectonic activity of the studied area.

▪ Materials Used and Methodology

In order to achieve the aim of this study, the following materials were used:

- Topographical maps at scale of 1: 100 000 and 1: 250 000
- Geological, hydrogeological and geological hazards maps at different scales
- Landsat images, Google Earth images, and aerial photographs
- ArcGIS technique and relevant extensions
- DEM data; from SRTM

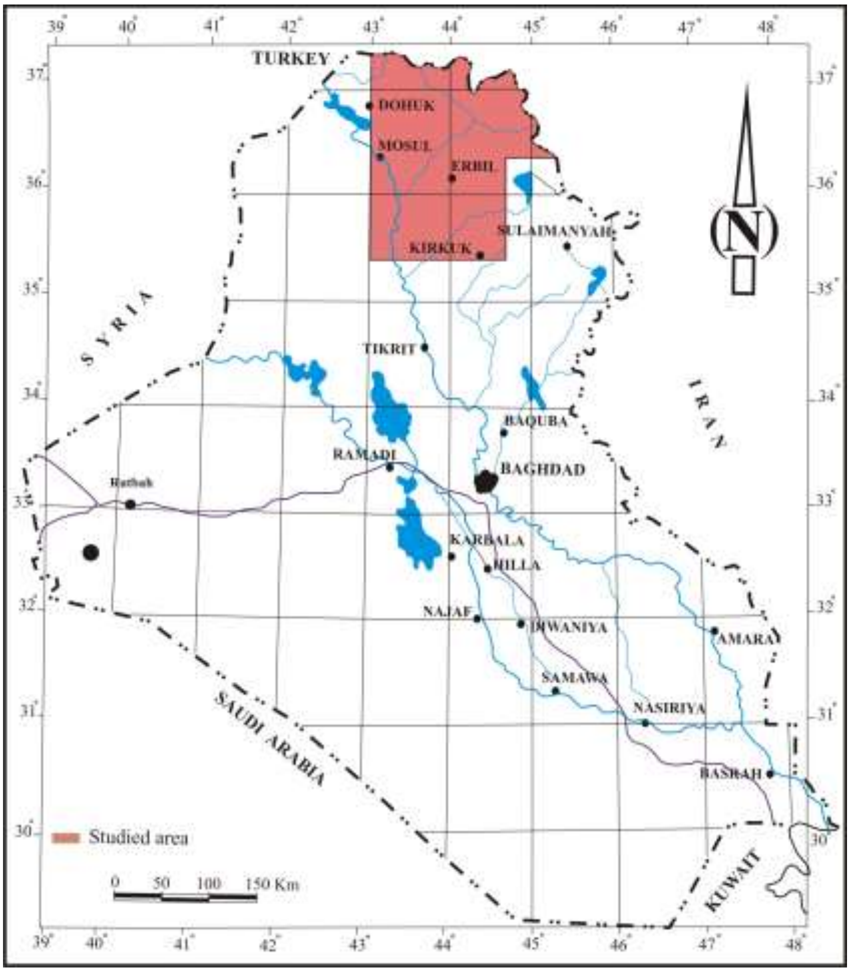


Fig.1: Location map of the studied area

The author used the aforementioned data as an integrated study to achieve the geomorphological and morphometric data. Topographical maps were used to indicate the catchment's areas. To deduce the type of the exposed rocks and Quaternary sediments, geological maps and relevant reports were used. Tectonic and structural maps were used to indicate the structural features, such as faults, folds, which might have contributed in carving the course of the Greater Zab River, and its tributaries. Geological maps, aerial photographs, Landsat images, and Google Earth images were interpreted to compile a geomorphological map of the studied area. ArcGIS technique and relevant extensions were used to measure the six-morphometric parameters, to deduce the stream orders of the main tributaries of the river, and to indicate the water and wind gaps, within the courses of the Greater Zab River and its four main tributaries.

▪ Previous Works

The studied area is considered as one of the remote and very rough areas in Iraq, which have not been perfectly studied, except few regional studies, among them are:

- Site Investigation Co. carried out geological mapping during mid-fifties of the last century, aiming to evaluate the mineral occurrences in the northern part of Iraq. They defined the basics of the Iraqi Stratigraphy.
- Bolton (1956) compiled the geological map of Rawandooz – Galat Dizah area, at scale of 1: 100 000 and defined the exposed formations in the area, it covers part of the studied area.

- Hamza (1997) compiled the Geomorphological Map of Iraq, at scale of 1: 1000 000 and presented some geomorphological units and phenomena in the studied area.
- Sissakian (1997) compiled the Geological Map of Erbil and Mahabad Quadrangles, at scale of 1: 250 000 and presented the exposed geological formations and different structural elements. The studied area is part of these quadrangles.
- Sissakian and Ibrahim (2005) compiled the Geological Hazards Map of Iraq, at scale of 1: 1000 000, and presented some geological hazards in the studied area, especially mass movements, floods and active erosion and tectonics.
- Ma'ala (2007) compiled the Geological Map of Sulaimaniyah Quadrangle, at scale of 1: 2500 000 and presented the exposed geological formations and different structural elements. The studied area is part of this quadrangle.
- Al-Mousawi *et al*. (2008) compiled the Geological Map of Zakho Quadrangle, at scale of 1: 2500 000 and presented the exposed geological formations and different structural elements. The studied area is part of this quadrangle.
- Fouad (2008) compiled the Geological Map of Kani Rash Quadrangle, at scale of 1: 2500 000 and presented the exposed geological formations and different structural elements. The studied area is part of this quadrangle.
- Al-Maamar *et al*. (2009) conducted a geomorphological study on a part of the Greater Zab River, using remote sensing and GIS techniques.
- Abdul Jab'bar (2012) carried out morphotectonic analysis for some selected streams in the folded belt, and deduced their relationship with geological structures, which controls the drainage system and effect of lateral propagation of the folds on streams.
- Sissakian and Fouad (2013) updated the Geological Map of Sulaimaniyah Quadrangle, at scale of 1: 250 000.

GEOLOGICAL SETTING

▪ Geomorphology

A geomorphological map at scales of 1: 1000 000 (Fig.2) is prepared depending on Sissakian (1997 and 2000), Ma'ala (2007), Al-Mousawi *et al*. (2008), Fouad (2008) and Sissakian and Fouad (2012 and 2013). Moreover, Landsat images, Google Earth images, aerial photographs, and topographic maps were used, too. The geomorphological units are described briefly depending on their genetic classification, hereinafter, depending on Sissakian (1993), and Sissakian and Ibrahim (2008).

- **Units of Fluvial Origin:** The following units are developed in the studied area:

  Terraces (Pleistocene): The Greater Zab River and the main tributaries have developed their terraces (Fig.3), usually in two stages; however, locally three stages are developed. The gravels consist of carbonates, silicates and subordinate igneous and metamorphic rocks. The size of the pebbles ranges between (1 – 35) cm, cemented by sandy and calcareous materials. The thickness of the terraces ranges between (1 – 12) m, the height differences between the levels range between (5 – 15) m. The terraces are not presented in Fig. (2) due to scale limitations. Locally, they form isolated plateaus, with different sizes, like the one on top of which Dair Al'loq town is built, along Amadiyah River.

  Alluvial Fans: Tens of alluvial fans are developed in the studied area, witnessing very humid climate during Pleistocene. The fans are composed of carbonate rock fragments of the same formations from which they have derived; with pebbles; cemented by calcareous and sandy materials. The size of the fragments ranges up to 35 cm, and very rarely may be larger. Generally, the thickness of the fans ranges from (3 – 15) m.

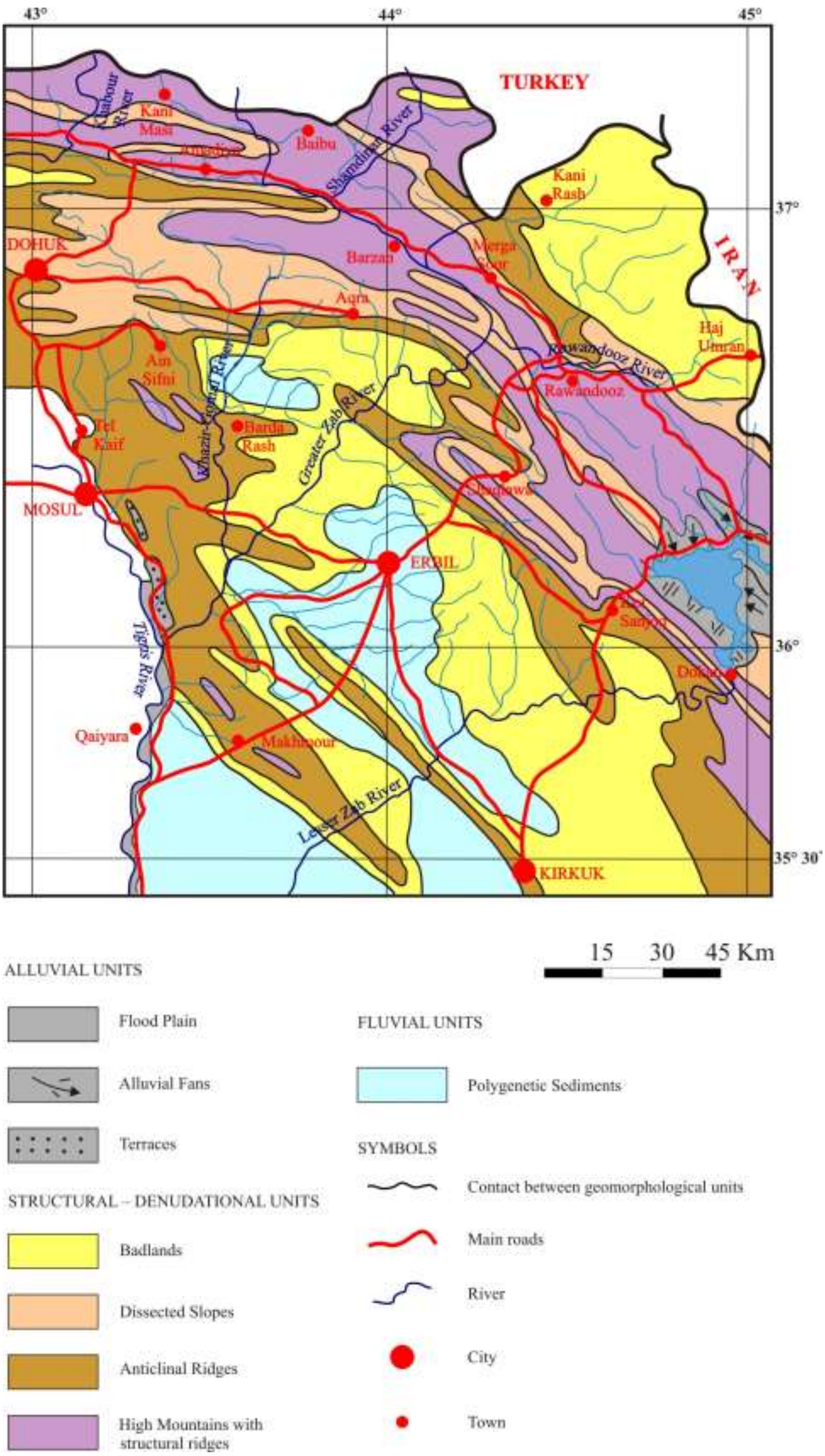


Fig.2: Generalized geomorphological map of the studied area

Fig.3: Terraces along Rawandooz River, near Barsarin village

Calcrete: It is developed in different parts of the studied area**,** usually in form of small plateaus, topping folded rocks. Good example is Amadiyah town, in the extreme northwestern part of the studied area. The thickness of the calcrete ranges from (8 – 15) m, the main constituents are carbonates fragments and pebbles, usually cemented by calcareous and sandy materials (Sissakian and Fouad, 2011).

Valley Fill: The main valleys of the studied area include thick valley fill sediments. The pebbles consist mainly of carbonates, silicates and subordinate igneous, and metamorphic rocks, sand occur also but in fewer amounts, the pebbles are rounded to sub-rounded, with average size of (1 – 40) cm, but may reach to more than 150 cm (Fig.4), mainly spheroidal in shape, with subordinate disk and rode shaped pebbles.

Flood Plain: The Greater Zab River and its main four tributaries and large valleys have developed their own flood plains. The plains are usually not wide, because they cross-ragged mountainous areas, except when the river flows out of the mountainous area, downstream of Bekhme gorge. Their width ranges between few meters up to few hundred meters, however, south of Bekhme gorge, the width ranges up to 2 Km, where locally two stages are developed (active and inactive), the height difference; between the two stages ranges from (2 – 3.5) m. The main constituents of the sediments are fine sand, silt and clay, with very rare fine pebbles, partly cemented by calcareous and sandy materials.

– Units of Structural – Denudational Origin: The following units are developed in the studied area:

Badland: These are very well developed in the southern part of the studied area (Fig.2), especially where the Bai Hassan Formation is exposed. The differential weathering, due to difference in rock hardness, and folded rocks have developed typical badland, which forms very rugged topography, densely dissected by dendritic drainage pattern. Moreover, badlands are also developed in the extreme northeastern part of the area (Fig.2), where igneous and metamorphic rocks are exposed.

Fig.4: Large boulders in valley fill sediments, Tanoon stream, north of Rawandooz (an ephemeral tributary of Rawandooz River, forming a water gap)

Dissected Slopes: These are well developed in the studied area, especially in areas where hard rock formations are exposed. The dip slopes of hard rocks are dissected by valleys (rills), which usually run parallel or semi parallel to the dip direction.

Anticlinal Ridges: These are well developed in the studied area south of Bekhme gorge, especially in Injana and Mukdadiya formations, and partly in Fatha Formation. Due to existence of alternation of hard and soft rocks, strike ridges and valleys are developed also, with trellis drainage pattern. The length of the ridges may reach up to few kilometers, whereas the width and depth of the valleys; did not exceed few tens of meters and few meters, respectively.

Hogbacks and Cuestas: These are well developed in the studied area, within the Injana, Mukdadiya and Bai Hassan formations. The uppermost part of the Pila Spi Formation has developed flatiron morphology.

– **Units of Denudational Origin:** The following units are developed in the studied area:

Pediments: These are well developed in different parts of the studied area; forming thin belts surrounding the main anticlines, slopes and ridges. The constituents of the pediments depend on the parent rocks from which they are derived. In the northern half part of the studied area, they consist of carbonate fragments cemented by clayey and calcareous materials, usually very hardly cemented; locally, the rock fragments are more than one meter in size, and very rarely igneous and metamorphic rocks occur too. In the southern half part of the studied area, the pediments consist of pebbles derived from the Bai Hassan Formation, cemented by sandy and calcareous materials. The thickness is highly variable (1 – 15 m).

Rock Fans: These are developed along some slopes; especially when Pila Spi, Aqra – Bekhme and Qamchuqa formations are exposed. In all cases, the rock fragments and pebbles are spread in form of fans, usually not cemented. The size of the fragments ranges from few centimeters up to 0.5 m; exceptionally may be more.

– **Units of Karst Origin:** Different karst forms are developed in the studied area, like caves and sinkholes. Usually the limestones of different formations are karstified leading to caves of different sizes and shapes. Beside some sinkholes of different sizes, which are developed in Pila Spi and Fatha formations.

– **Geodynamical Processes:** The following processes are developed in the studied area:

Land Slides: These are well developed, usually along the ridges of the anticlines and/ or structural ridges. The size of the slid masses reaches up to few hundred cubic meters.

Toppling: It is common phenomenon along some ridges, which are developed in different formations, in different parts of the studied area. The size of the toppled blocks ranges from (< 0.5 – 5) m^3; a good example is along Basarra gorge, in Qara Dagh Mountain.

Creep: It is very common phenomenon along the claystone slopes of different formations, like Shiranish, Tanjero, Kolosh, and Gercus. The size of the crept areas is within few square tens to few hundred meters, usually steps are developed in successive form, the distance between the steps ranges from (5 – 100) cm, whereas the height of the steps ranges from (5 – 30) cm. However, the mentioned dimensions depend on the slope angle and its height, and the plasticity of the involved materials.

Rock Fall: Rock fall is very rare, it may be present along the steep slopes and high cliffs.

– **Weathering and Erosion:** Different types of weathering and erosion are acting in the studied area; they are described hereinafter, briefly.

Weathering: Mechanical weathering is more active in the studied area, as indicated by the presence of large areas covered very rough topography, and by badlands, especially south of Bekhme gorge (Fig.2), and by existence of dense drainage system, especially the fine drainage and of lower stream orders. However, chemical weathering is partly active; especially in some karstified limestones of different formations, forming caves, like the well-known Shnider cave in Bradost Mountain, and other karst forms like in Qara Dagh Mountain, and Bekhme Formation in Korak Mountain, west of Rawandooz.

Erosion: The main erosion agent in the studied area is the water. Three types of erosion are acting: Gulley, Rill and Sheet. Gulley erosion is acting in the mountainous areas, especially along the main course of the Greater Zab River and its main tributaries, and main valleys, where water gaps and gorges are developed, like Galley Ali Beg (Fig.5), Shamdinan, Zanta, and Bekhme gorges. Rill erosion is developed on slopes, usually when covered by claystone (Fig.6), and partly on limestones along anticlinal ridges; forming typical flat iron morphology. Sheet erosion is also acting, especially in flat areas covered by soil; south of Bekhme gorge. They are indicted by the presence of removal of the soil in form of grooves of crescent shapes, the length and space difference between them range from (15 – 150) cm and (15 – 35) cm, respectively. However, these dimensions depend on the degree of the slope, amount of the floodwater, presence and absence of vegetation cover, plasticity of the soil, and hardness (degree of cementation) of the soil. The height of the crescent shapes is few centimeters only.

Fig.5: Galey Ali Beg, a tributary of the Rawandooz River, exhibiting deep gulley erosion (forming one of the largest water gaps in the studied area)

Fig.6: Rill erosion along the Tanjero and Shiranish formations (along Sulaimaniyah – Dokan road)

▪ **Stratigraphy**

The exposed formations and Quaternary sediments are reviewed briefly hereinafter, depending on Sissakian (1997 and 2000), Ma'ala (2007), Fouad (2008), and Sissakian and Fouad (2012). The stratigraphic sequence is divided into two parts: **1)** Stratigraphy of the Imbricate, High Folded, and Low Folded Zones, and **2)** Stratigraphy of the Zagros Suture Zone. The Quaternary sediments are described without the aforementioned division. The geological map is presented in Fig. (7).

─ Stratigraphy of the Imbricate, High Folded, and Low Folded Zones: The exposed formations are described briefly, hereinafter.

Kurra China Formation (Upper Triassic): The formation consists of thinly bedded limestone. The exposed thickness of the formation is not more than 50 m.

Baluti Formation (Upper Triassic): The formation consists of hard limestone, dolostone and soft shale. The thickness is about 35 m.

Sarki Formation (Lower Jurassic): The formation consists of massive dolostones and limestones, very hard, white and grey in colour. The thickness is about 300 m.

Sehkaniyan Formation (Lower Jurassic): The formation consists of dolomites and limestones dark in colour, bedded and massive. The thickness ranges from (200 – 250) m.

Sargelu Formation (Lower Jurassic): The formation consists of black, thinly bedded shaley limestone and shales with black chert and brown dolomitic marls, usually very fossiliferous. The thickness ranges from (100 – 125) m.

Naokelekan Formation (Upper Jurassic): The formation consists of laminated shaley limestone, hard dark grey limestone, thinly bedded bituminous limestone and calcareous shale. The thickness is about 14 m.

Barsarin Formation (Upper Jurassic): The formation consists of laminated limestone and dolomitic limestone. The thickness is about 17 m.

Chia Gara Formation (Upper Jurassic – Lower Cretaceous): The formation consists of thinly bedded limestones and shales, containing rich ammonite fauna and grading upwards into yellowish marly limestones and shales. The exposed thickness ranges from (25 – 30) m.

Balambo Formation (Lower Cretaceous): The formation consists of thinly bedded limestones with intercalations of green marl and blue shales, upwards changes to thinly bedded limestones only. The thickness ranges from (600 – 900) m.

Sarmord Formation (Lower Cretaceous): The formation consists of alternations of blue marls with marly limestone, also of limestones and marl. The thickness is about 400 m, but it decreases strongly towards northwest.

Qamchuqa Formation (Lower Cretaceous): The formation consists of massive limestones and dolomites, usually dark grey in colour. The thickness ranges from (300 – 1000) m.

Kometan Formation (Upper Cretaceous): The formation consists of thinly well bedded globigerinal limestone and marly limestone. The light greyish white colour is characteristic feature, especially on aerial photographs. The thickness ranges from (50 – 350) m.

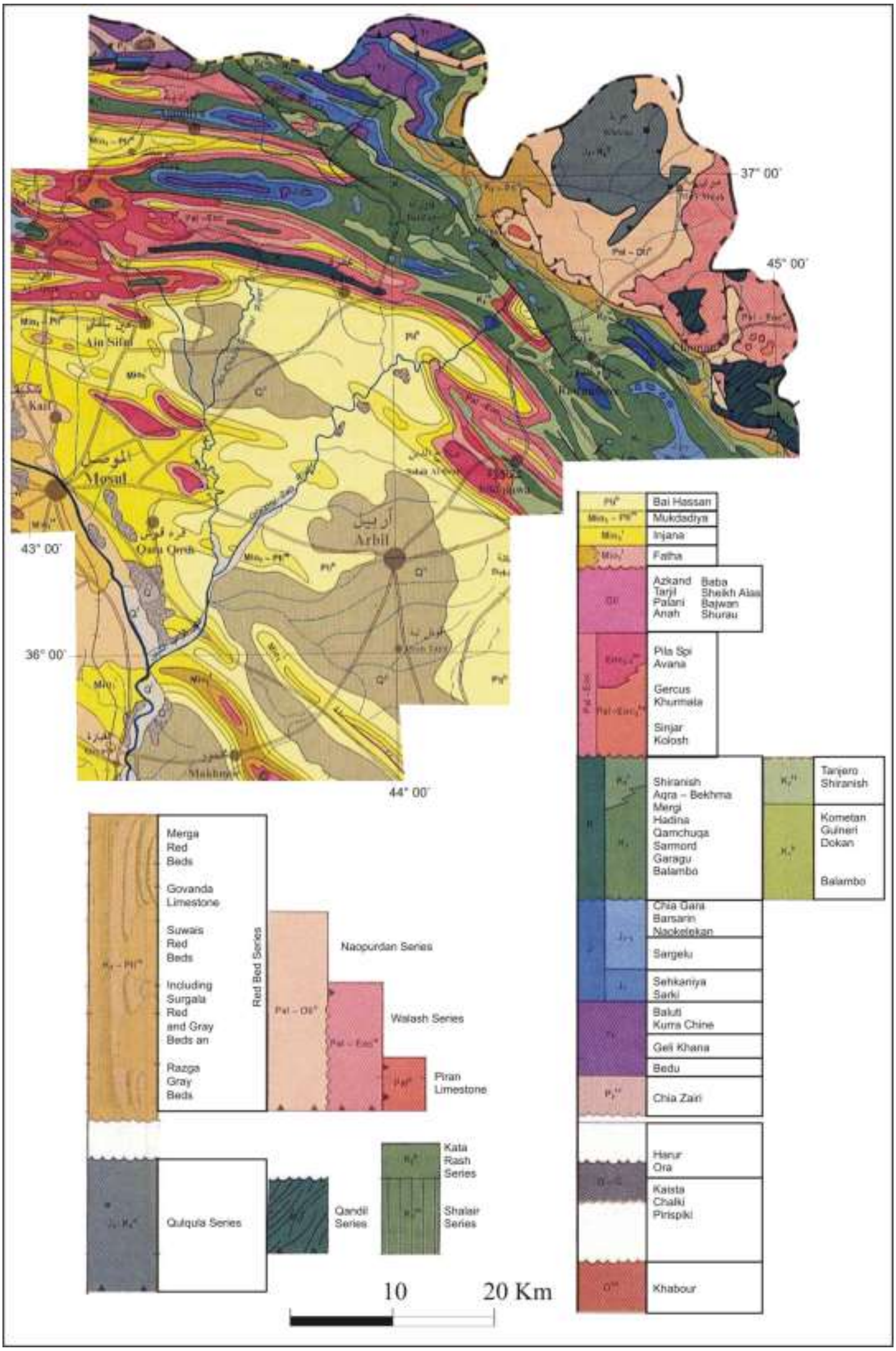


Fig.7: Geological Map of the studied area (after Sissakian and Fouad, 2012)
(Formations older than Kurra China are not described,
because they are not exposed in the studied area)

Aqra – Bekhme Formation (Upper Cretaceous): The formation consists of well bedded limestones and dolostones, locally bituminous, coralline and recrystallized, very hard, light grey in colour. The thickness ranges from (75 – 315) m.

Shiranish Formation (Upper Cretaceous): The formation consists of thinly well bedded marly and chalky limestones, white, yellowish white and greyish white in colour, followed (upwards) by thinly bedded or papery marl, blue and grey in colour with some marly limestone beds too. The thickness ranges from (200 – 500) m.

Tanjero Formation (Upper Cretaceous): The formation consists of alternation of dark green and yellowish green shale, claystone, sandstone and siltstone some conglomerates occur in the upper part and some marly limestones in the lower part. The thickness ranges from (400 – 1000) m.

Kolosh Formation (Paleocene): Consists of fairly hard, black claystone, sandstone, with subordinate shales and conglomerate. The thickness ranges from (150 – 400) m.

Khurmala Formation (Paleocene): Consists of well thickly bedded and hard limestones. The thickness ranges from (10 – 30) m.

Gercus Formation (Eocene): Consists of fairly hard red claystones, sandstones with subordinate conglomerates. The thickness ranges from (150 – 300) m.

Pila Spi Formation (Eocene): Consists of well bedded, hard dolomitic limestone, limestone, with marl and marly limestone. The thickness ranges from (75 – 160) m.

Fatha Formation (Middle Miocene): Consists of alternation of reddish brown claystone, green marl and limestone, and gypsum. The thickness ranges from (100 – 350) m.

Injana Formation (Late Miocene): Consists of alternation of well bedded, reddish brown sandstone, siltstone and claystone. The thickness ranges from (100 – 2000) m.

Mukdadiya Formation (Late Miocene – Pliocene): Consists of alternation of bedded, sandstone; partly pebbly, siltstone and claystone. The thickness ranges from (50 – 660) m.

Bai Hassan Formation (Pliocene – Pleistocene): Consists of alternation of thick conglomerate and reddish brown claystone, with thin grey sandstone. The thickness ranges from (300 – 1000) m.

– **Stratigraphy of the Zagros Suture Zone and Shalair Terrane:** The exposed units are described briefly, hereinafter.

Qandil Metamorphosed Series (Cretaceous): This unit is equivalent to both Bulfat Group and Bulfat Massif. Moreover, it is equivalent to the Lower Qandil Thrust (Bolton, 1956). It is exposed north of Qalat Diza along the frontier with Iran, forming the bulk of Qandil Mountain, also the bulk of Hassarost Mountain. It consists of sheared limestones, phyllites and massive metamorphosed limestone, with some serpentinite intrusions. The thickness of this unit with that of Shalair Series is about 3000 m.

Shalair Series (Albian – Cenomanian): The Shalair Series is exposed north of Qalat Diza, along the frontier with Iran, forming the bulk of Mara Pasta Mountain and part of Qandil Range. The series consists of chlorite sericite phyllites, in the lower part interbedding of quartzites and greywackes. Basalt and olivine basalts are locally present, sheared coralline limestone and fine grained white limestones are present too. The Shalair Series is equivalent to the Upper Qandil Thrust of Bolton (1958). The thickness of this unit is obscure; it is 3000 m, with that of Qandil Metamorphosed Series.

Qulqula Radiolarian Formation (Tithonian – Albian): The formation is exposed north of Qalat Diza and in the northeastern corner of the studied area. It consists of limestones, shales, and white, red and green chert beds, siliceous red or green ferruginous mudstones. The thickness is about 2300 m.

Qulqula Conglomerate Formation (Cenomanian): The formation is exposed only in one locality, near Qulqula village. It consists of thick limestone, conglomerates and cherty grit, interbedded with grey, marly shales, chert and detrital limestone. The thickness is about 1200 m.

Piran Limestone (Cretaceous? – Paleocene): It forms the bulk of Piran Mountain. Moreover, many other scattered outcrops occur too, south of Rayat village forming the Bulk of Garda Mand Mountain and others. It is massive, fossiliferous and reddish or pinkish in colour. No thickness is recorded from the previous works.

Walash Group (Paleocene – Eocene): The group is widely exposed within the eastern margin of the studied area; it forms the Middle Thrust Sheet of Qandil Range. It consists of very thick basic volcanic sequence including agglomerate, lava flows, pillow lavas and ashes with associated dykes. The volcanics are associated with thick sedimentary sequence, similar to that of the Naopurdan Group, thick limestones, red mudstones and clastics. The thickness ranges from (1000 – 3500) m.

Naopurdan Group (Paleocene – Oligocene): The group is widely exposed in the eastern part of the studied area. It consists of grey shales, coralline limestone, tuffaceous slates, felsitic volcanics, basic conglomerate, greywackes and sandy shale. The greywackes and sandy shales are also called "Choman Clastics". The thickness of the group, ranges from (1000 – 2000) m.

Suwais Red Bed Series (Paleocene? – Miocene): The series is exposed widely in the eastern part of the studied area. It consists of conglomerates, red shales, red sandstones, and red mudstones. Moreover, grey shales with sandstones and lenticular limestones (Surgala Red and Grey Beds), grey shales, occasionally marly with intercalations of thin beds of greywacke and impure very lenticular limestone (Razga Grey Beds) occur too. The thickness ranges from (500 – 1200) m.

Govanda Limestone (Middle Miocene): The Govanda Limestone is exposed in the eastern part of the studied area. It consists of massive beds of grey limestone. The thickness is about 150 m, but is decreases southeastwards.

Merga Red Beds (Upper Miocene – ? Pliocene): The beds are exposed northeast of Rawandooz town; consist of massive, boulder conglomerate, in the upper part, and red, calcareous, silty shales and pebbly sandstones, in the lower part. The pebbles of the conglomerate are of igneous and metamorphic rocks. The thickness is about 500 m.

– Quaternary Sediments: Different types of Quaternary sediments are developed in the studied area; they include Pleistocene and Holocene ages. They are described hereinafter:

Terraces (Pleistocene): These are developed along the Greater Zab River and its main tributaries. The type of the sediments and their thickness are the same as that of the alluvial fans. However, some of the terraces from Rawandooz and nearby areas, may represent glacial moraines? as described by Wright (1986). No confirmation, however, is given by any of the workers in the area involved, for such sediments.

Alluvial Fan Sediments (Pleistocene – Holocene): The remnants of the fans are preserved in different parts in the studied area. They form flat tops in form of small plateaus, overlying folded rocks of pre-Quaternary formations. The main composition is granules of different sizes of different rocks, cemented by calcareous and sandy cement. The thickness is few meters.

Valley Fill Sediments (Holocene): These are very well developed in the courses of the Greater Zab River and its four main tributaries, usually consist of pebbles of different sizes (few centimeters up to 25 cm) and rock types, mainly limestones, dolomite, silicates and subordinate igneous and metamorphic rocks. The thickness ranges from (< 1 – 5) m, occasionally may be more.

Flood Plain Sediments (Holocene): These are restricted to the Greater Zab River and its four main tributaries; usually consist of sand, silt and clay. Some fine pebbles may rarely occur. The thickness ranges from (< 0.5 – 1.5) m, occasionally may be more.

- **Structural Geology**

The studied area is located within the Imbricate, High Folded and Low Folded Zones, and Zagros Suture Zone, all of them belong to the Unstable Shelf of the Arabian Plate (Al-Kadhimi *et al*., 1996 and Jassim and Goff, 2006). However, Fouad (2012) considered the Unstable Shelf as the Outer Platform of the Arabian Plate, and introduced the Imbricate and Zagros Suture Zones.

Many anticlines and synclines are developed within the studied area; they all are in NW – SE trend, however, in the extreme northwestern part of the area; their trend changes to E – W. The main anticlines, from the north to the south are: Gara, Shireen, Khoshka, Chinara, Bradost, Aqra, Peris, Korak, Handreen, Zozik, Tanun, Gulley Keer, Sarta, Safeen, Mirawa, Shakrook, Hareer, Bash Wash, Barda Rash, Permam, Kamosk, Makook, Ain Al-Safra, Girda Baski, and Dameer Dagh (Fig.8 and Table 1). Some of the anticlines form water shades within the sub-basins, others form strike ridges and valleys, which have controlled the drainage pattern and basin's shapes. Many anticlines have influenced the course of the Greater Zab River and its main four tributaries, usually forming curves along their plunge areas. However, locally, the courses of the rivers cross the anticlines perpendicularly, due to many reasons (Sissakian and Abdul Jabbar, 2010). The Main Zagros Thrust Fault of the Zagros Suture Zone also runs within the extreme northern and northeastern parts of the studied area, causing very complicated structural frame work of the involved area.

- **Neotectonics**

Since the Alpine Orogeny is still active; therefore, the majority of the studied area is up warped, except some strips south of Bekhme gorge, where they are down warped areas. The amount of up warping ranges between (0 – 1000) m, whereas the down warping amount ranges between 0 to –1500 m. The rates of the up warping and down warping are 0.8 and – 0.8 cm/ 100 years, respectively (Sissakian and Deikran, 1998).

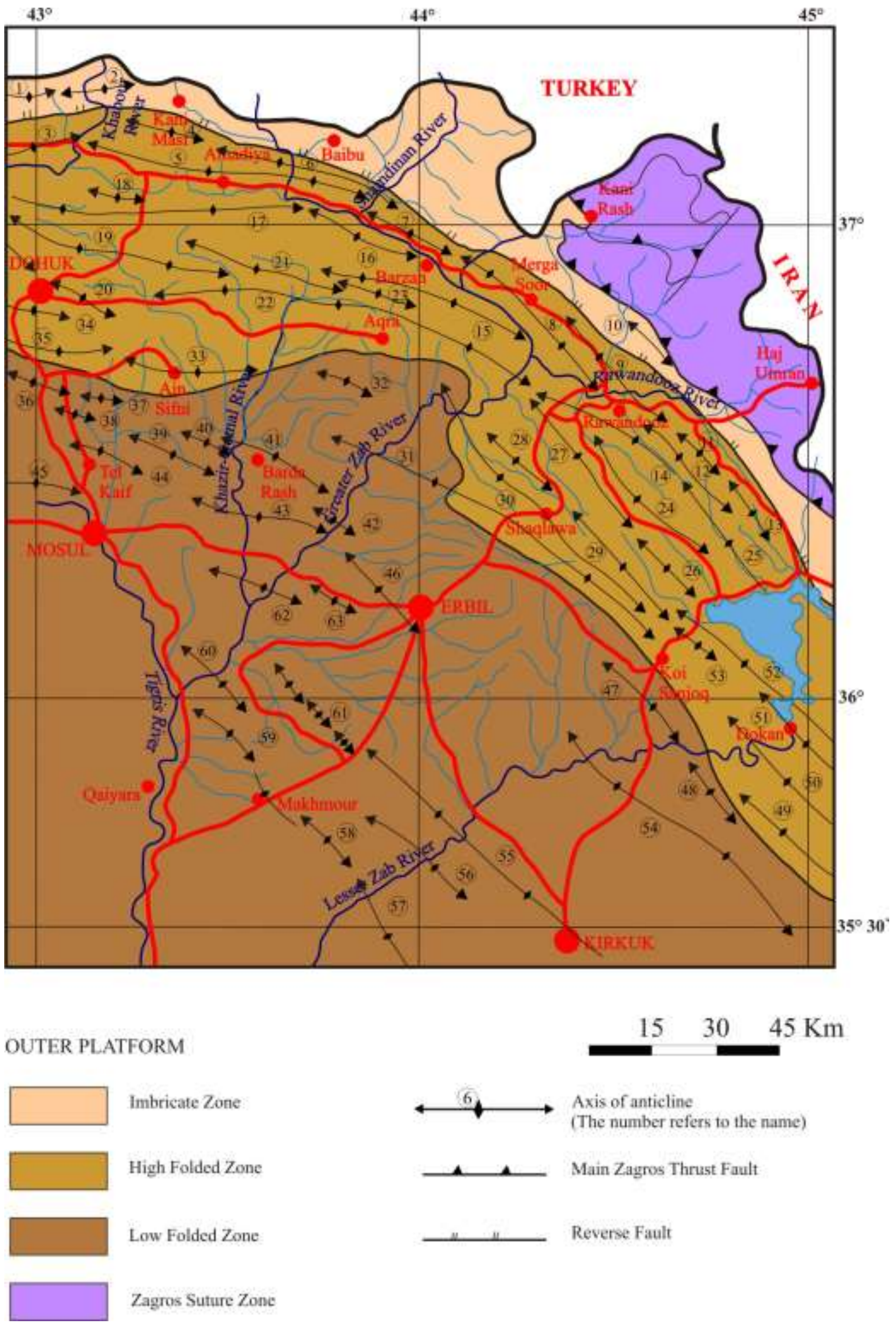


Fig.8: Structural map of the studied area
(compiled from Al-Kadhimi *et al*., 1997 and Fouad, 2012)
(for the names of the anticlines, refer to Table 1)

Table 1: Serial numbers and names of the anticlines in the studied area
(Refer to Fig.8 for location of the anticlines)

No.	Anticline	No.	Anticline	No.	Anticline	No.	Anticline
1	Diari	17	Gara	33	Ain Sifni	49	Qara Dagh
2	Kaista	18	Sar Sang	34	Dohuk	50	Tasloojah
3	Zakho	19	Kiri Rabatki	35	Dankhtgash	51	Dokan
4	Komark	20	Zawita	36	Dahqan	52	Khalikan
5	Matina	21	Khoshka	37	Kand	53	Bustana
6	Shmadinan	22	Aqra	38	Tall Squf	54	Cham Chamal N
7	Sheereen	23	Peris	39	Ba'shiqa	55	Kirkuk
8	Bradost	24	Paliwan	40	Maqloub	56	Bai Hassan
9	Handireen	25	Ranyah	41	Bard Rash	57	Qara Boutaq
10	Tanoon	26	Spindara	42	Girda Baski	58	Qara Chough S
11	Bash Wash	27	Hareer	43	Ain Al-Safra	59	Qara Chough N
12	Karoohk	28	Almawan	44	Tal Kaif	60	Guwair
13	Komitan	29	Shakrook	45	Juwaira	61	Avanah
14	Koreck	30	Garda Jal	46	Erbeel	62	Damir Dagh W
15	Chinara	31	Safeen	47	Taq Taq	63	Damir Dagh E
16	Garya	32	Garda Sheen	48	Dara Quta		

GREATER ZAB RIVER BASIN

The studied part of the Greater Zab River Basin covers an area of about 13708 Km^2; it is surrounded by the Lesser Zab River basin; from south and east, and the Tigris River basin from north and west (Fig.9). It is divided into five sub-basins of the four main tributaries; Shamdinan, Haji Beg, Rawandooz, and Khazir – Gomal Rivers, and a sub-basin including areas, which drain directly in the Greater Zab River, by means of tens of small tributaries and ephemeral streams (Fig.9). The coverage areas of the four sub-basins are (839.4, 1101.2, 2681.9 and 2185.8) Km^2, respectively, the remaining area, which is about 6899.3 Km^2, drains directly in the Greater Zab River, out of the main four tributaries, it is called; in this study, Greater Zab sub-basin. The largest sub-basin is that of the Greater Zab River (Table 2).

The drainage system within the Greater Zab River's basin is generally of parallel and dendritic types. This is because the drainage system is controlled structurally, in the majority of the catchment's area, due to the presence of anticlinal ridges. However, in the northeastern part, where igneous and metamorphic rocks are exposed, and within areas covered by soft clastics (Fig.7), the drainage system is dendritic, and form bad land morphology (Fig.2).

- **Characteristics of the Five Sub-basins**

The characteristics of the five sub-basins of the Greater Zab River (Fig.9) are presented in Table (2). They are deduced digitally using ArcGIS, hydrological extension. However, the characteristics may change when the whole basin (outside Iraq) is considered. The main trend of the rivers is almost NE – SW and NW – SE, although they cross many topographic highs of NW – SE trend, which are formed due to the presence of anticlines (Figs.8 and 9).

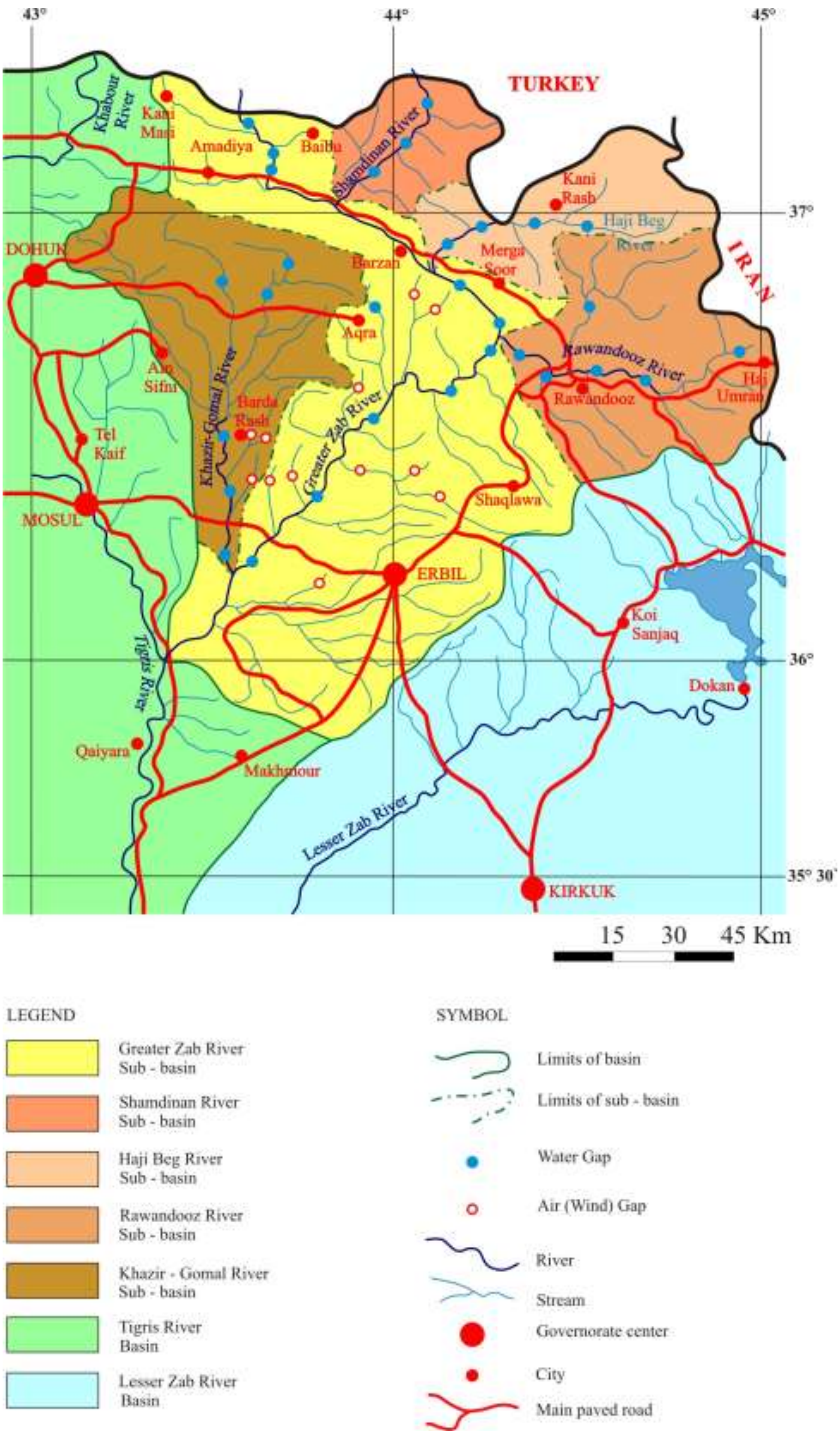


Fig.9: Drainage basin map of the Greater Zab River, with the sub-basins of the four tributaries

Table 2: Characteristics of the studied five sub-basin
(Lengths are in Km, areas in Km^2, height and width in m)

Tributary and sub-basin Characteristics	Greater Zab	Shamdinan	Haji Beg	Rawandooz	Khazir – Gomal
Coverage area	6899.3	839.4	1101.2	2681.9	2185.8
Coverage of half right basin area	2369.4	484.4	640.5	1676.66	1001.8
Length of the basin	108.3	41.4	62.7	63.1	98.5
Width of the basin	61.9	36.3	15.4	60.9	28.4
Length of the stream	208.669	41.832	49.082	56.132	86.973
Width of the stream	801	85	103	95	378
Horizontal stream length	99.374	35.549	44.169	50.96	78.549
Highest point in basin	1601.61	1605.07	2108.09	2045.21	1616.98
Lowest point in basin	202.34	608.15	510.98	423.09	208.01
Average height in basin	900.7	1100.8	1256.9	1202.7	902.4
Number of Water/ Air (Wind) gaps	11/ 9	3/ –	4/ –	7/ –	6/ 3
Gradient (%)	1.41	2.8	3.5	3.2	1.8
Channel Sinuosity: Before outlet/ After outlet	Straight/ Irregular	Transitional	Transitional	Regular	Regular

– Not present

In reviewing the gradient details of the Greater Zab River and its four tributaries (Table 2), which were deduced using ArcGIS programme, hydrological extension, it can be seen that there is clear difference between the gradient of the rivers. The low gradient of the Greater Zab and Khazir – Gomal Rivers (Table 2) is attributed to their horizontal lengths (99.374 and 78.549) Km, respectively, as compared with the length of the other three rivers (35.549, 44.169 and 50.96) Km, respectively. Moreover, only the first two rivers flow out of the mountainous area, where the slope of the ground is lower than in the mountainous area.

Following the sinuosity classification of Shcumm (1963) in Singh (2010), the channel sinuosity of the Greater Zab River and its four tributaries is classified (Table 2). Because the Greater Zab River exhibits different sinusitis along its course, before and after Bekhme gorge (Fig.9), therefore, it is divided into two main parts (straight and irregular). This division is performed due to main differences in the lithology and structural affect along its course (Figs.3, 8 and 9) in the two parts. However, within the courses of the five rivers, each course exhibits, locally different sinuosity from the main one (Fig.9).

- **Structural and Topographical Effect**

The existing structures (Fig.8) in the studied area have manifested their shapes and lengths on the topography. The axes of the anticlines form usually water shades, which locally coincide with the sub-basin limits. However, some water shades occur within the same sub-basin, irrespective to the presence or otherwise of the anticlinal axis. The five rivers cross many anticlines forming water gaps; the number of water gaps in each river is mentioned in Table (2). The Greater Zab River has 11 water gaps and 9 air gaps, Shamdinan River has 3 water gaps, Haji Beg River has 4 water gaps, Rawandooz River has 7 water gaps, and Khazir – Gomal River has 6 water gaps and 3 air gaps (Fig.9). The development of the water and air gaps also may indicate Neotectonic activity in the involved area, due to propagation of the folds (Keller and Printer, 2002).

The general shape of the Khazir – Gomal River sub-basin is longitudinal, especially after its outlet from the mountainous area (Bekerman gorge), whereas the shapes of the remaining sub-basins are almost rectangular, except the middle part of the Greater Zab sub-basin, which is longitudinal (Fig.9). It is worth mentioning that the longitudinal basin is indication for a Neotectonic activity in the basin area (Dhebozorgi *et al*., 2010).

The Greater Zab and Khazir – Gomal rivers, after their outlets from the mountainous areas, and Shamdinan River have almost transversal direction to the existing structures (Figs.8 and 9). The Greater Zab River, before its outlet from Bekhme gorge, and Haji Beg and Rawandooz rivers have almost parallel direction to the existing structures (Figs.8 and 9), and flow in synclinal valleys, mainly.

Figure (9) shows that locally the Khazir – Gomal River's sub-basin may capture by erosion the Greater Zab River sub-basin, causing considerable decrease in the coverage area of the latter sub-basin. This is attributed to the flow direction of the main streams and valleys that drain in both rivers. In the former river, the streams and valleys flow approximately in N – S direction, whereas in the latter; the streams and valleys flow approximately in both E – W and W – E directions. Therefore, the erosion ability in the streams of the former river is more effective, because the gradient in N – S direction is more than E – W or W – E direction. However, the climatic changes and lithological aspect should not be ignored in such cases. Nevertheless, because the involved areas are under the same climatic conditions, and the two sub-basins have almost the same lithology (Fig.7), therefore only the erosion is concerned in this aspect (Bull, 1991 and 2009).

In some parts of the studied area, the five rivers and other minor streams cut the structures in **V shape** valleys, because the carved rocks are mainly of carbonates. The V-shaped gorges; like "Zanta, Bekhme, Bekerman and Gulley Ali Beg gorges", suggest propagation of the anticlines (Ramsey *et al*., 2008). However, the indication of the propagation direction is out of the scope of this study.

- **Stream Orders**

To extract the stream orders in the Greater Zab River's basin, ArcGIS technique, hydrological extension was used; the stream orders map is shown in Fig. (10). When reviewing the stream orders map, it can be seen that the Greater Zab River starts with fifth order stream, then changes to the fourth order, when Rawandooz River merges in, then to third order, when Haji Beg River merges in. The Shamdinan River starts with fourth order and changes after about 8 Km to third order and continues so until the Iraqi – Turkish borders. The Haji Beg River starts with third order and continues so until it bifurcates into two main branches, there it changes to second order. The Rawandooz River starts with the fifth order then changes to the fourth order, near Barsarin village, and then continues in third and second orders. The Khazir – Gomal River starts with fourth order until the junctions of its tributaries, there it changes to third order until Bekerman gorge, there it changes to second order and continues so until few kilometers north of Bekerman gorge, there it changes to first order.

It is worth mentioning that the constructed stream orders map (Fig.10) lacks the details of the stream orders of the very fine branches, because the majority of the studied area is characterized by very dense drainage system, which is attributed to the structural effect and type of the exposed rocks, especially in igneous, metamorphic and clastics rocks. Therefore, only the main five streams and part of their branches are marked. Otherwise, the map will be very dense and almost unreadable; however, the presented details are sufficient to clarify the stream orders of the Greater Zab River and its four main tributaries.

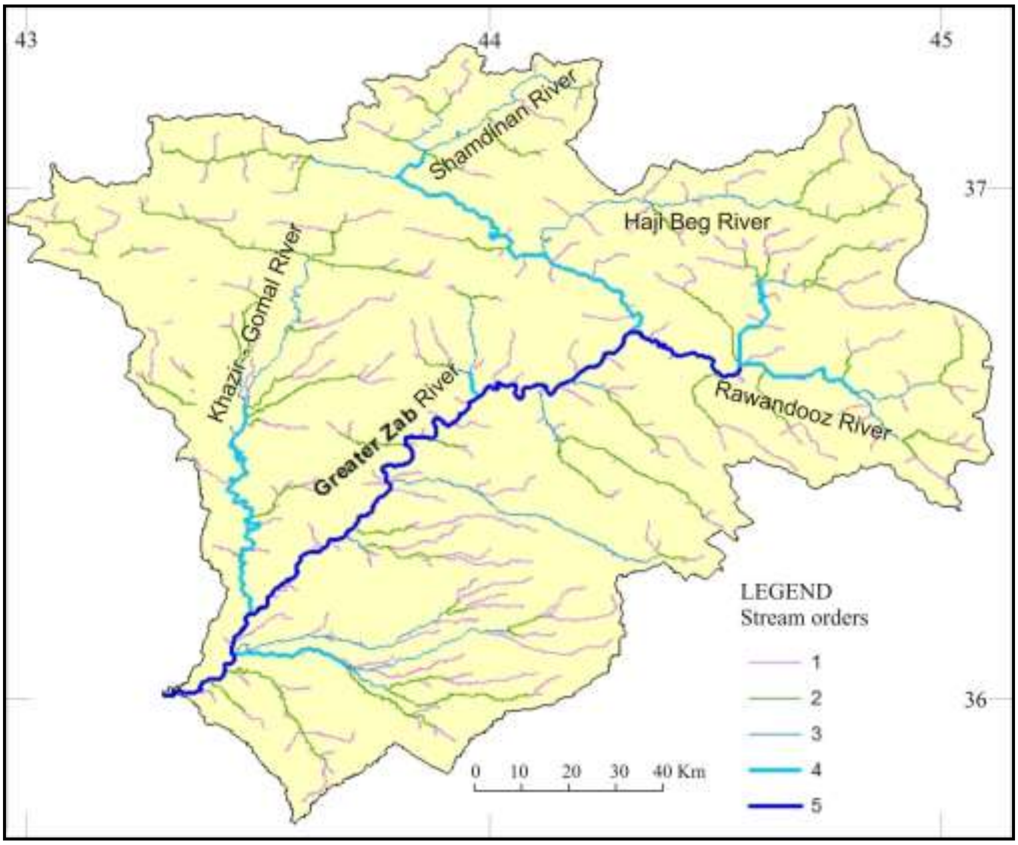


Fig.10: Stream orders map of the studied area (Deduced by ArcGIS)

▪ Geomorphic Indices

Geomorphic indices, which are useful for studying active tectonics, include six factors (Dhebozorgi *et al*., 2010). The six factors of the five sub-basins are studied and the values were determined (Table 2), using ArcGIS, Hydrological extension. DEM of the studied area (Fig.11) was used to indicate the required values for calculating the six factors; the results are mentioned in Table (3). The six factors are described hereinafter.

― **Stream-gradient Index (*SL*):** This index can be used to indicate whether a stream has reached equilibrium. The index also can be used to evaluate relative tectonic activity; the higher values indicate more active tectonic basins (Keller and Pinter, 2002). The Stream Gradient Index (*SL*) is classified into three classes: **1)** ($SL \geq 500$), **2)** ($300 \geq SL < 500$), and **3)** ($SL < 300$) (El-Hamdouni *et al*., 2007). The index is defined as:

$$SL = (\Delta H / \Delta L_r) L_{sc} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

where:

ΔH is change in altitude,

ΔL_r is length of a reach,

L_{sc} is the horizontal length from the watershed divide to midpoint of the reach.

From applying the required parameters (Table 2) in equation (1) to calculate the Stream-gradient Index **(*SL*)**, it was found that the Greater Zab River and its four tributaries have class orders of 1, 2, 1, 1 and 1, respectively (Table 3). This indicates that the coverage area of the Shamdinan River sub-basin is more active tectonically, as compared to the other four sub-basins, because low values of *SL* indicate areas that are more active.

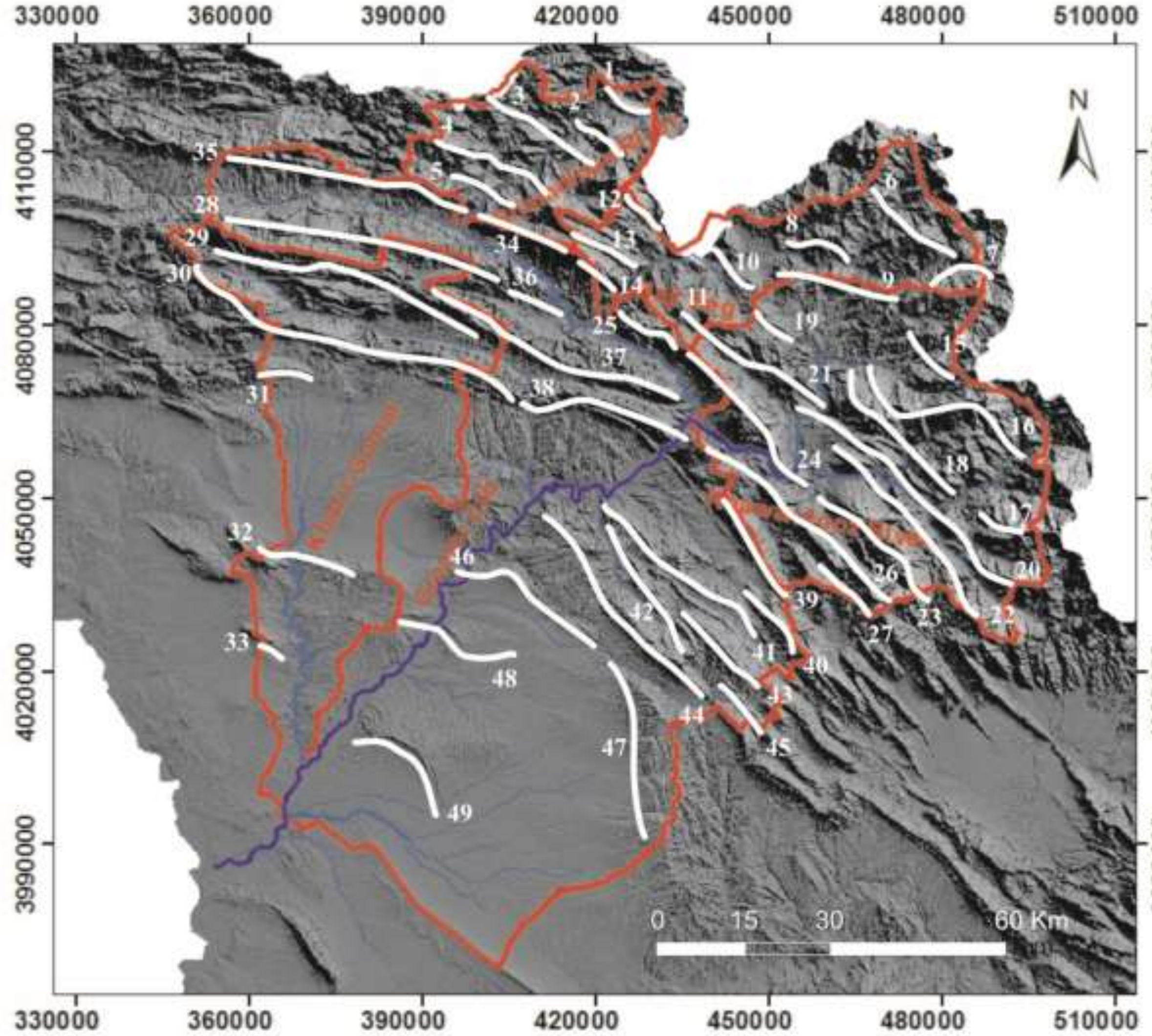


Fig.11: DEM of the studied area
(Derived from the Shuttle Radar Topography Mission, SRTM)
(The red lines are the boundaries of sub-basins the white lines are the studied mountain fronts, with serial numbers)

Table 3: Six Geomorphic Indices of the four tributaries of the Greater Zab River

Factors \ Sub-basin	Greater Zab (1)	Shamdinan (2)	Haji Beg (3)	Rawandooz (4)	Khazir – Gomal (5)	Class				
						1	2	3	4	5
Stream Gradient Index (*SI*)	639.668	423.58	743.20	736.33	636.24	1	2	1	1	1
Asymmetric Factor (*Af*)	66.66	53.68	58.16	70.90	66.65	1	3	3	1	1
Hypsometric Integral (*Hi*)	0.499	0.494	0.467	0.481	0.492	2	2	2	2	2
Ratio of Width to Height (*Vf*)	0.34	0.14	0.14	0.18	7.4	1	1	1	1	3
Basin Shape Index (*Bs*)	1.75	1.14	4.07	1.04	3.47	3	3	1	3	2
Mountain Front Index (*J*)	1.050	1.106	1.082	1.060	1.037	1	2	1	1	1

─ **Asymmetric Factor (*Af*):** This index can be used to evaluate tectonic tilting at the scale of the drainage basin (Keller and Pinter, 2002). The Asymmetric Factor is classified into three classes: **1)** ($Af \geq 65$ or $Af < 35$), **2)** ($35 \leq Af < 43$ or $57 \leq Af < 65$) and **3)** ($43 \leq Af < 57$) (El-Hamdouni *et al*., 2007), it is defined as:

$$Af = 100\ (A_r / A_t) \quad (2)$$

where:

A_r is the area of a part of a watershed on the right of the master stream (looking downstream)

A_t is the total area of the watershed

From applying the required parameters (Table 2) in equation (2) to calculate the Asymmetric Factor (*Af*), it was found that all sub-basins except Shamdinan are significantly either greater than 50 (Table 3), which means that the four sub-basins; might be are tectonically more active than Shamdinan Sub-basin.

─ **Hypsometric Integral (*Hi*):** This index describes the relative distribution of elevation in a given area of a landscape particularly a drainage basin (Strahler, 1952; in Dehbozorgi *et al*., 2010). The index is classified into three classes: **1)** **(**$Hi \geq 0.5$), **2)** ($0.4 \leq Hi < 0.5$) and **3)** ($Hi < 0.4$) (El-Hamdouni *et al*., 2007). The index is defined as mentioned in equation (3) (Mayer, 1990 and Keller and Pinter, 2002):

$$Hi = (\text{average elevation} - \text{min. elev.}) / (\text{max. elev.} - \text{min. elev.}) \quad (3)$$

From applying the required parameters (Table 2) in equation (3) to calculate the Hypsometric Integral **(*Hi*)**, it was found that all five sub-basins have class order no.2 (Table 2). This indicates that the five sub-basins have concave – convex hypsometric curves.

─ **Ratio of Valley Floor Width to Valley Height (*Vf*):** This index is also sensitive to tectonic uplift, it is divided into three classes: **1)** ($Vf \leq 0.5$), **2)** ($0.5 \leq Vf < 1.0$) and **3)** ($Vf \geq 1$) (El-Hamdouni *et al*., 2007). The index is defined as mentioned in equation (4) (Dehbozorgi *et al*., 2010):

$$Vf = 2Vf_w\ (A_{ld} + A_{rd} - 2A_{sc}) \quad (4)$$

where:

Vf_w is the width of the valley floor

A_{ld} and A_{rd} are the altitude of the left and right divides (looking downstream)

A_{sc} is the attitude of the stream channel (Bull, 2007).

From applying the required parameters (Table 2 and Fig.12) in equation (4) to determine the Ratio of Valley Floor Width to Valley Height **(*Vf*)**, calculated from the drawn cross sections (Fig.12) using DEM (Fig.11), it was found that all sub-basins has class order no.1, except Khazir – Gomal River's sub-basin has class no. 3 (Table 3). This indicates that all tributaries have U-shaped valleys, except Khazir – Gomal River, which has V-shaped valley.

─ **Basin Shape Index (*Bs*):** It is also called "Elongation Ratio", it describes the horizontal projection of a basin, and it is classified into three classes: **1)** ($Bs \geq 4$), **2)** ($3 \leq Bs < 4$) and **3)** ($Bs \leq 3$) (El-Hamdouni *et al*., 2007). It is defined as mentioned in equation (5) (Rameriz-Herrera, 1998):

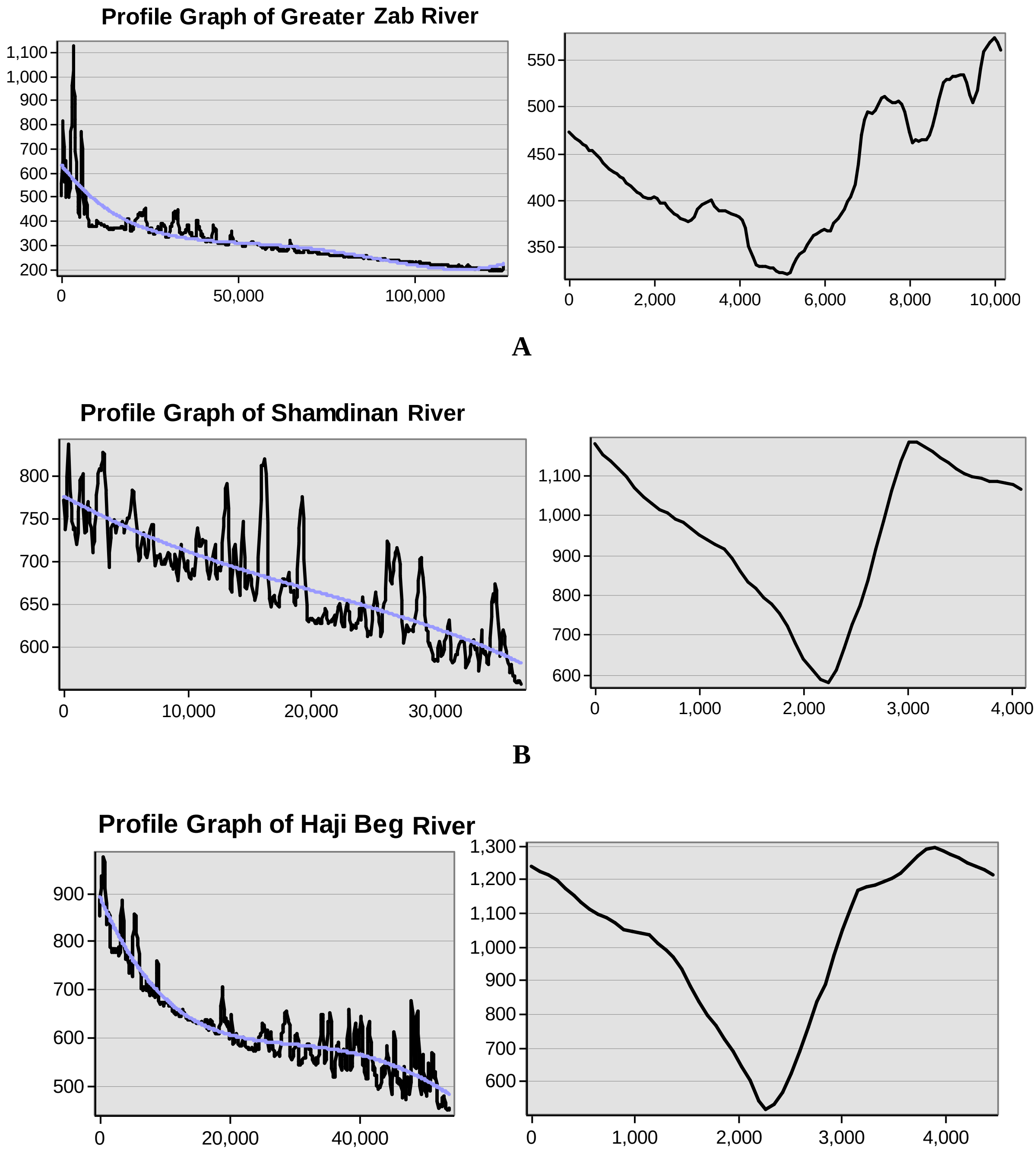
$$Bs = B_l / B_w \quad (5)$$

where:

B_l is the length of a basin measured from the highest point

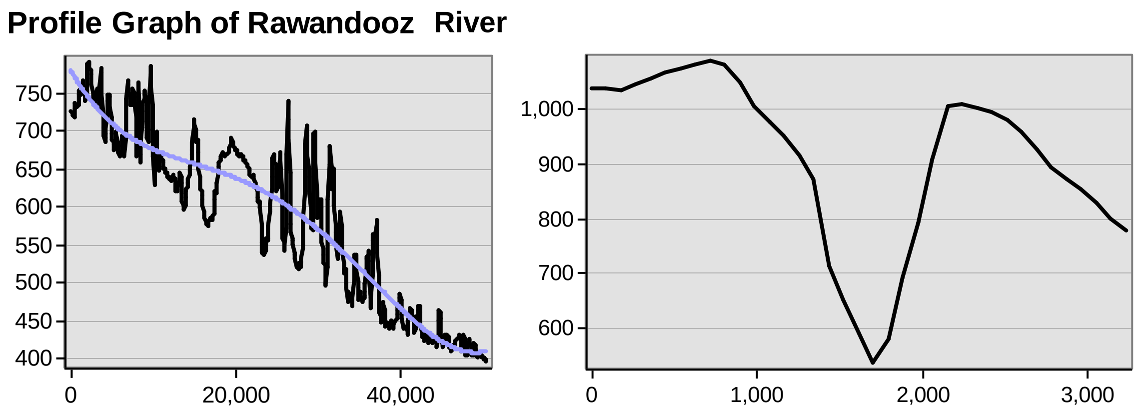
B_w is the width of a basin measured at its widest point

From applying the required parameters (Table 2) in equation (5) to calculate the Basin Shape Index ***(Bs)***, using DEM (Figs.11 and 12), it was found that the five sub-basins have class orders no. 3, 3, 1, 3 and 2, respectively (Table 3). This indicates that Haji Beg and Khazir Gomal sub-basins have more longitudinal shape than the other three sub-basins, indicating more tectonically active areas.



C

Fig.12: Longitudinal and cross sections of the five tributaries
(in the middle part of the course) **A)** Greater Zab, **B)** Shamdinan, **C)** Haji Beg,
(deduced by ArcGIS, hydrological extension,
horizontal distances and heights are in meter)



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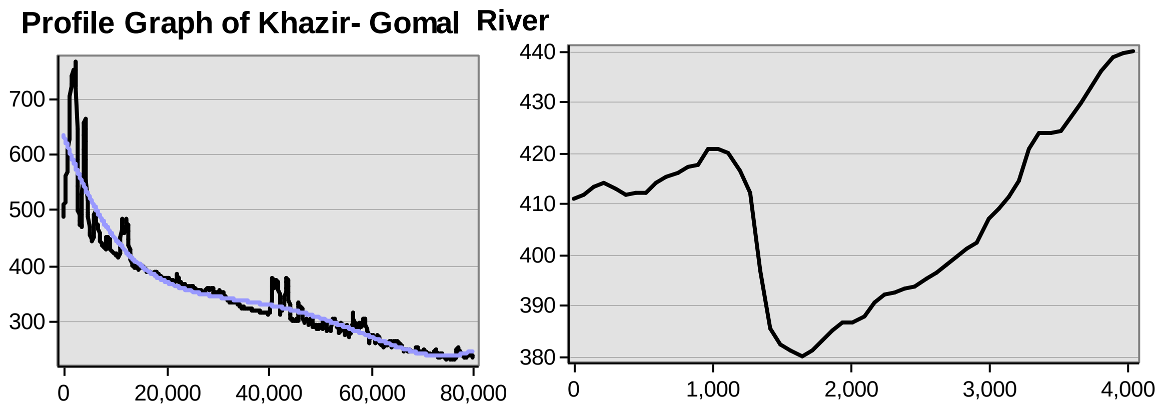

E

Cont. Fig.12: Longitudinal and cross sections of the five tributaries
D) Rawandooz, and **E)** Khazir – Gomal

― **Mountain Front Sinuosity Index (*J*):** It represents a balance between stream erosion processes tending to cut some parts of a mountain front and active vertical tectonics that tend to produce straight mountain fronts (Keller and Printer, 1996). The index is divided into three classes: **1)** ($J < 1.1$), **2)** ($1.1 \leq J < 1.5$) and **3)** ($J \geq 1.5$) (El-Hamdouni *et al.*, 2007). The index is defined as mentioned in equation (6) (Keller and printer, 2002):

$$J = L_i / L_s \qquad (6)$$

where:
L_i is the planimetric length of a mountain front along the mountain-piedmont junction
L_s is the straight line length of the front

From applying the required parameters (Table 2) in equation (6) to calculate the Mountain Front Sinuosity Index **(*J*)**, 48 mountain fronts (Fig.11) were selected and calculated from the DEM (Table 4). The calculated mountain fronts are included within the five sub-basins as 5, 9, 12, 6 and 16 fronts in Shamdinan, Haji Beg, Rawandooz, Khazir - Gomal, and Greater Zab sub-basins, respectively. The average *Li* and *Ls* of the five sub-basins are: 17.233 and 15.575, 13. 443 and 12.425, 23.912 and 22.555, 26.947 and 25.971, and 28.883 and 27.496 respectively. The average *J* values were found to be 1.106, 1.082, 1.060, 1.037, and 1.05, respectively for the aforementioned five sub-basins (Table 3).

Table 4: The calculated Mountain Fronts in the studied area

No.	Mountain Front Length (Km)		No.	Mountain Front Length (Km)		No.	Mountain Front Length (Km)	
	Ls	*Li*		*Ls*	*Li*		*Ls*	*Li*
1	6.794	7.711	**17**	32.776	34.934	**33**	21.982	23.133
2	11.086	12.406	**18**	9.481	10.135	**34**	42.069	42.881
3	24.521	27.727	**19**	11.888	12.257	**35**	14.141	15.061
4	23.070	24.727	**20**	30.155	32.570	**36**	29.299	30.552
5	12.402	13.593	**21**	18.836	20.028	**37**	48.609	50.696
6	16.477	17.763	**22**	44.974	46.271	**38**	39.946	41.128
7	12.593	12.921	**23**	23.334	24.378	**39**	24.252	25.259
8	12.025	12.515	**24**	27.682	29.674	**40**	15.205	16.420
9	19.262	22.871	**25**	35.402	38.531	**41**	38.152	41.854
10	10.498	10.938	**26**	20.268	21.417	**42**	18.342	19.048
11	7.009	8.739	**27**	15.066	15.502	**43**	20.173	21.334
12	10.283	11.012	**28**	54.759	56.520	**44**	46.092	47.958
13	12.759	13.062	**29**	49.550	51.483	**45**	30.764	32.730
14	10.918	11.166	**30**	10.354	10.440	**46**	25.594	26.190
15	6.712	7.084	**31**	20.860	21.819	**47**	4.869	5.162
16	9.156	9.659	**32**	5.240	5.919	**48**	20.448	22.726

Serial No. of Mountain Fronts: (1 – 5) Shamdinan Sub-basin, (6 – 14) Haji Beg Sub-basin, (15 – 26) Rawandooz Sub-basin, (27 – 32) Khazir Gomal Sub-basin, (33 – 48) Greater Zab Sub-basin

EVALUATION OF RELATIVE TECTONIC ACTIVITY

In this study, the average of the six measured geomorphic indices (*Iat*) was used to evaluate the distribution of relative tectonic activity, following El-Hamdouni *et al*. (2007). Accordingly, the values of the index were divided into four classes to define the degree of active tectonics: **1)** Very high (1.0 ≤ *Iat* < 1.5), **2)** High (1.5 ≤ *Iat* < 2.0), **3)** Moderate (2.0 ≤ *Iat* < 2.5), and **4)** Low (*Iat* < 2.5).

The results of the measured indices and average *Iat* are shown in Table (5). From reviewing the acquired data (Table 5), it is clear that the five sub-basins have the following classes of relative tectonic activity: High, Moderate, Very High, Very High, and High of the Greater Zab River and its four tributaries, respectively (Table 5). Moreover, the percentages of the relative activity in the studied area are as follows: 27.6% of the studied area suffers from Very High tectonic activity, 66.2% suffers from High tectonic activity and 6.124% of the studied area suffers from Moderate tectonic activity.

Table 5: Values of relative tectonic activity of the five sub-basins

Sub-basin	Area (Km^2)	Class *SL*	Class *Af*	Class *Hi*	Class *Vf*	Class *Bs*	Class *J*	Value *Iat*	Class *Iat*	Tectonic activity
Greater Zab	6899.3	2	1	2	1	3	1	1.5	2	High
Shamdinan	839.4	2	3	2	1	3	2	2.166	3	Moderate
Haji Beg	1101.2	1	3	2	1	1	1	1.5	1	V. High
Rawandooz	2681.9	1	1	2	1	3	1	1.5	1	V. High
Khazir – Gomal	2185.8	1	1	2	3	2	1	1.666	2	High

DISCUSSION

The four tributaries of the Greater Zab River: Shamdinan, Haji Beg, Rawandooz, and Khazir – Gomal Rivers have their own sub-basins within the main basin of the Greater Zab River. However, in some parts of the main basin, considerable areas are out of the four sub-basins, those areas drain directly to the Greater Zab River, and are called in this study as Greater Zab River Sub-basin.

The calculated Stream-gradient Index (***Sl***) of the five tributaries indicates high tectonic activity for all the sub-basins, except Shamdinan. This is indicated by low values of ***Sl***, because the five tributaries have class orders of 1, 2, 1, 1, and 1, respectively (Table 3). These low and moderate class values may indicate high to medium tectonic activity in the involved area (Dehbozorgi *et al*., 2010). The Basin Shape Index (***Bs***) has class values of 1, 3, 2, 1 and 1 for the five tributaries, respectively (Table 3), indicating longitudinal shape; except Shamdinan sub-basin, consequently indicate active tectonic areas (Dehbozorgi *et al*., 2010). However, from single index, or even 2 or 3 indices, the relative tectonic activity cannot be determined. Therefore, the average value of the 6 indices (***Iat)*** was determined (Table 5), which indicates High, Moderate, Very High, Very High and High relative tectonic activity for the five sub-basins, respectively (Table 5)

The Greater Zab River and its four tributaries, with their main sub-tributaries cross many anticlines and/ or topographic highs in their courses. However, locally they may flow parallel to an anticline, then crosses it in a gorge; like Bekerman, Zanta, Galley Ali Beg, Barsarin and Bekhme. Along their courses, they exhibit water and air gaps. The Greater Zab, Shamdinan, Haji Beg, Rawandooz and Khazir – Gomal Rivers have the following water/ air gaps: 13/ 9, 3/ 0, 3/ 0, 7/ 0, and 3/ 6, respectively (Table 1).

The type of the exposed rocks and present sediments along the courses of the Greater Zab River and its four tributaries with the existing folds; anticlines and synclines have played a big role in stream's shape and pattern, and the sub-basin's extension and shape. The conglomerates and claystones of Bai Hassan Formation, which cover considerable parts of the Greater Zab River sub-basin's area have formed dendritic drainage pattern, due to their weak resistance to erosion. The clastics of Mukdadiya and Injana formations usually have developed trellis drainage pattern in form of strike ridges and valleys, due to existence of alternation of hard (sandstone) and weak (claystone) rocks. However, many tributaries form parallel pattern due to existence of hard carbonates and many anticlinal structures. Moreover, dendritic pattern is developed in igneous and metamorphic rocks, in the extreme northeastern part of the studied area and in the southern half part, due to existence of clastics of Fatha, Injana, Mukdadiya and Bai Hassan formations (Sissakian, 2000 and Sissakian and Fouad, 2012) (Fig.7).

The present folds, anticlines and synclines even those that are surrounding the Greater Zab River's basin have played big role on the extension of the basin and sub-basins of the four tributaries. They have formed water gaps; examples are along Zanta, Bekhme, Bekerman, Galley Ali Beg, Balanda gorges (Fig.9).

The main water shades of the five sub-basins are developed due to topographic affect, which mainly express folds rather than lithological changes. However, some exceptions occur in the northeastern part of the Shamdinan, Haji Beg and Rawandooz Rivers Sub-basins.

Within the five sub-basins, many small local basins are developed due to local water shades. Those water shades are mainly formed due to structural effect, due to axis of anticlines and or anticlinal ridges. However, very locally the water shades are developed due to lithological changes, which usually change the hardness. All of the developed water shades are small with limited lengths and with very small coverage areas, as compared with the coverage area of the main sub-basin in which they have developed.

The courses of the Greater Zab River and the four tributaries have almost straight lines, because they flow either parallel to the present anticlines and/ or flow within a gently to moderately sloping plain, parallel to the slope direction. However, the Greater Zab and Khazir – Gomal rivers exhibit meandering forms after Bekhme and Bekerman gorges, respectively, this is attributed to a very gentle gradient, which has decreased the ability of the streams in carving of the rocks, therefore, meanders are developed (Figs.9 and 10).

CONCLUSIONS

The following conclusions are acquired from this study:

- The Greater Zab River basin includes five sub-basins; the Greater Zab Sub-basin is the largest one, followed by sub-basins Rawandooz, Khazir – Gomal, Haji Beg and Shamdinan.
- Within each of the five sub-basin, many minor local basins are developed, the water shades are formed either due to the presence of folds or difference in lithology.
- The highest main gradient is that of the Haji Beg River (3.5) followed in decreasing order by Rawandooz (3.3), Shamdinan (2.8), Khazir – Gomal River (1.8) and the lowest one is that of the Greater Zab River (1.41). However, the gradient of the Greater Zab River, before Bekhme gorge is higher than the main gradient, this is attributed to the course of the river along a non-mountainous area, after crossing the Bekhme gorge.
- Five orders of streams were recognized in the studied area. The Greater Zab River starts with the fifth order and ends with the third orders. Shamdinan River starts with the third order and ends with the first order. Haji Beg River starts with the third order and ends with the first order. Rawandooz River starts with the fifth order and ends with the first order. Khazir – Gomal River starts with the fourth order and ends with the first order.
- The five sub-basin have relative tectonic activity of High, Moderate, Very High, Very High and High, respectively. This was estimated by calculating the six geomorphic parameters and their average values (***Iat***), which indicate their class values (2, 3, 1, 1 and 2, respectively).
- From the total coverage areas of the five sub-basins, 27.59% (coverage areas of Haji Beg and Rawandooz sub-basins) suffers from Very High relative tectonic activity, 66.2% (Greater Zab and Khazir – Gomal sub-basins) suffers from High tectonic activity and 6.124% of the area (coverage area of Shamdinan Sub-basin) suffers from Moderate tectonic activity.
- The following water/ air gaps are developed in the Greater Zab, Shamdinan, Haji Beg, Rawandooz, and Khazir – Gomal rivers: 11/ 9, 3/ 0, 4/ 0, 7/ 0, and 6/ 3, respectively.
- Geomorphological map is compiled for the studied area, at scale of 1: 1500 000, including 12 main units of four different origins, which are: Alluvial, Structural – Denudational, Denudational and Karst origins. However, glacial moraine might be present, too.

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REFERENCES

Abdul Jab'bar, M.F., 2012. Effect of Neotectonics Activity on Selected Structures in North and Northeastern part of Iraq. Unpub. M.Sc. Thesis, University of Baghdad, 113pp.

Al-Kadhimi, J.A.M., Sissakian, V.K., Fattah, A.S. and Deikran, D.B., 1996. Tectonic Map of Iraq, scale 1: 1000 000, 2nd edit., GEOSURV, Baghdad, Iraq.

Al-Maamar, A.F., Khader, M.A. and Hattab, A.A., 2009. Geomorphological study of Greater Zab River and tributaries, using remote sensing and GIS. GEOSURV, int. rep. no. 3249.

Al-Mousawi, H.A., Sissakian, V.K. and Fouad, S.F., 2008. The Geology of Zakho Quadrangle, scale 1: 250 000. GEOSURV, Baghdad, Iraq.

Bolton, C.M.G., 1956. The Geology of the Rawanduz – Gala Dizeh area. Site Investigation Co. Report. GEOSURV, int. rep. no. 268.

Bull, W.B., 1991. Geomorphic Responses to Climate Change. Oxford University Press, 326pp.

Bull, W.B., 2007. Tectonic Geomorphology of Mountains. A new approach to paleoseismology. Blackwell, Malden, 328pp.

Bull, W.B., 2009. Tectonically Active Landscapes. Whilley, Blackwell, 326pp.

Dehbozorgi, M., Pourkermani, M., Artin, A., Matkan, A.A., Motamedi, H. and Hosseiniasl, A., 2010. Quantitative analysis of relative tectonic activity in the Sarvestran area, Central Zagros, Iran. Geomorphology, doi:10.1016/j.gemorph. 2010.05.002. Elsevier, 13pp.

El-Hamdouni, R., Irigraray, C., Fernandez, T., Chacon, J. and Keller, E.A., 2007. Assessment of relative active tectonics, southwest border of Sierra Nevada (southern Spain). Geomorphology, Vol.96, p. 150 – 173.

Fouad, S.F.A., 2008. Geological Map of Kani Rash Quadrangle, scale 1: 250 000. GEOSURV, Baghdad, Iraq.

Fouad, S.F.A., 2012. Tectonic Map of Iraq, scale 1: 1000 000, 3rd edit. GEOSURV, Baghdad, Iraq.

Hamza, N.M., 1997. Geomorphological Map of Iraq, scale 1: 1000 000. GEOSURV, Baghdad, Iraq.

Jassim, S.Z. and Goff, J.C., 2006. Geology of Iraq. Dolin, Prague and Moravian Museum, Brno. 341pp.

Keller, E.A. and Pinter, N., 2002. Active Tectonics, Earthquakes, Uplift and Landscape, 2nd edit. Prentice Hall, 362pp.

Ma'ala, Kh.A., 2007. Geological Map of Sulaimaniyah Quadrangle, scale 1: 250 000. GEOSURV, Baghdad, Iraq.

Mayer, L., 1990. Introduction to Quantitative Geomorphology. Prentice Hall, Englewood, Cliffs, NJ., 380pp.

Ramirez-Herrera, M.T., 1998. Geomorphic assessment of active tectonics in the Acambay Grabben, Mexican Volcanic Belt. Earth Surface Processes and Landforms, Vol.23, p. 317 – 332.

Ramsey, L.A., Walker, R.T. and Jackson, J., 2008. Fold evolution and drainage development in the Zagros Mountains of Fars Province, SE Iran. Basin Researches. Blackwell Publishing Ltd., 26pp.

Singh, S., 2010. Geomorphology, 4th reprint. Prayag Pustak Bhawan, India, p. 355 – 384.

Sissakian, V.K., 1993. Work Procedures of Iraq Geological Survey, Part 8, Geomorphology. GEOSURV, int. rep. no. 1989.

Sissakian, V.K., 1997. Geological Map of Erbil and Mahabad Quadrangles, scale 1: 250 000. GEOSURV, Baghdad, Iraq.

Sissakian, V.K., 2000. Geological Map of Iraq, scale 1: 1000 000, 3rd edit. GEOSURV, Baghdad, Iraq.

Sissakian, V.K. and Deikran, D.B., 1998. Neotectonic Map of Iraq, scale 1: 1000 000. GEOSURV, Baghdad, Iraq.

Sissakian, V.K. and Ibrahim, F.A., 2005. Geological Hazards Map of Iraq. GEOSURV, Baghdad, Iraq.

Sissakian, V.K. and Ibrahim, F.A., 2008. Geological Hazards Map of Kani Rash Quadrangle, scale 1: 250 000. GEOSURV, int. rep. no. 3112.

Sissakian, V.K. and Abdul Jabbar, M.F., 2010. Morphometry and genesis of the main Transversal Gorges in North and Northeast Iraq. Iraqi Bull. Geol. Min., Vol.6, No.1, p.95 – 120.

Sissakian, V.K. and Fouad, S.F.A., 2011. The Origin of Amadiya Plateau, Dohuk Governorate, North Iraq. Iraqi Bull. Geol. Min., Vol.7, No.1, p. 93 – 98.

Sissakian, V.K. and Fouad, S.F.A., 2012. Geological Map of Iraq, scale 1: 1000 000, 4th edit. GEOSURV, Baghdad, Iraq.

Sissakian, V.K. and Fouad, S.F.A., 2013. Geological Map of Sulaimaniyah Quadrangle, scale 1: 250 000, 2nd edit. GEOSURV, Baghdad, Iraq.

Wright, H.E., 1986. Pleistocene Glaciation in Kurdistan. Translated into Arabic by: Khorshid, F.H., Al-Bidlesi Book Shop, Baghdad, 88pp.

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