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MORPHOMETRY AND GENESIS OF THE MAIN TRANSVERSAL GORGES IN NORTH AND NORTHEAST IRAQ

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ABSRTACT

The north and northeastern parts of Iraq are mountainous region with very rugged topography that attains to about 3600 m (a.s.l.). Hundreds of streams, of different sizes and types, and few rivers dissect these areas, some of them form gorges along their courses, partly are of canyon type. The main lithology, in the area involved, is very hard carbonate rocks that form the carapace of the mountains (almost anticlines) with soft clastic rocks, filling the synclines in between, rarely clastic rocks occur as intercalations with the carbonates. Some of these streams and rivers dissect the anticlines, oriented almost perpendicularly to the trend of the anticlines that is NW – SE and E – W, forming gorges of different sizes with different characters and origins.

This study is an attempt to reveal the morphometry and genesis of the main gorges in the northern and northeastern parts of Iraq. Twenty two gorges were selected; the selected gorges are the main ones that dissect the whole mountain or the whole anticline (a topographic barrier). Those which exist within part of a mountain and/ or an anticline are not included in this study.

For each of the 22 gorges, the lithology, exposed formation(s) and genesis are given. Moreover, the morphometry of each gorge is given too. These include the longitude and latitude of the inlet and outlet; with their heights, beside the height difference between the highest and lowest points along the gorge, length, gradient and sinuosity of the streams along the gorges.

To achieve this study, geological and topographical maps of different scales were used. Moreover, Landsat images were used to select the main gorges, beside other characters that were acquired from GIS applications and remote sensing techniques. The study revealed that the origin of the main gorges is mainly due to structural effect, one is due to karstification and others are due to blockage of the stream either; by mass movements or alluvial fans. They are of superimposed – posterior type.

دراسة مورفوميترية وأصل نشوء المضائق الرئيسية في شمال وشمال شرق العراق

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المستخلص

تعتبر المناطق الشمالية والشمالية الشرقية من العراق مناطق جبلية وعرة وتصل ارتفاعاتها إلى حوالي 3600 متر (فوق مستوى سطح البحر). هذه المناطق الجبلية تمتاز بوجود المئات من الجداول ذات الأنواع المختلفة والعديد من الأنهار، وان بعضها تشكل مضائق في بعض أجزائها. ان غالبية الصخور المتكشفة في المنطقة هي كاربوناتية وذات صلادة عالية جداً ويصل سمكها إلى مئات الأمتار، والتي تشكل الحجم الرئيسي للجبال (الطيات المحدبة) مع بعض الصخور الفتاتية غير الصلدة التي تملأ الطيات المقعرة وتشكل السهول أو الأراضي المتموجة.

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إن بعض هذه الجداول والأنهار تقطع الجبال أو الطيات المحدبة (الاتجاه السائد للطيات هو شمال غرب – جنوب شرق) بشكل عام بصورة عمودية، مكونة مضائق بأشكال وأحجام متنوعة وكذلك ذات أصول مختلفة النشوء. إن هذه الدراسة هي محاولة لإيجاد وتوضيح مورفوميترية وأصل نشوء المضائق الرئيسية في المناطق الشمالية والشمالية الشرقية من العراق. لقد اخترنا 22 مضيقاً من مجموع العشرات من المضائق، وتم اختيار المضائق التي تقطع الجبل أو الطية المحدبة بشكل كامل، أي طرفي الجبل أو جناحي الطية المحدبة. أما تلك التي لا تقطع الجبل أو الطية المحدبة بشكل كامل، فقد استثنيت من هذه الدراسة.

لقد تم دراسة الصخارية الرئيسية والتكوين أو التكوينات الجيولوجية المتكشفة لكل من المضائق الاثنين والعشرين، إضافة الى أصل نشوء كل مضيق، كما تم دراسة المواصفات العامة لكل منها. وتشمل المواصفات مواقع (الإحداثيات الطولية والعرضية) بداية ونهاية المضائق وارتفاعاتها (عن مستوى سطح البحر) وكذلك فرق الارتفاع بين أعلى وأوطأ نقطة على المضيق والطول والانحدار لكل مضيق.

استخدمت في هذه الدراسة الخرائط الطبوغرافية والجيولوجية وبمقاييس متنوعة. كما تم استخدام المرئيات الفضائية لاختيار المضائق، إضافة الى استخدام تطبيقات الـ GIS وتقنيات التحسس النائي لتكملة متطلبات هذه الدراسة. وقد تم التوصل بان أصل نشوء المضائق وبشكل عام هو السبب التركيبي، إضافة الى دور التخسف في تكون بعض المضائق، وبعضها الآخر نتيجة لانغلاق الوادي أما بسبب حركات الانهيال أو بسبب وجود المراوح الفيضية، وبشكل مكثف. وقد نسبت هذه الدراسة أصل المضائق المستعرضة الى نوع التراكب – اللاحق.

INTRODUCTION

The north and northeastern parts of Iraq are mountainous areas, attaining up to 3600 m (a.s.l.) with very rugged topography in their major parts. Hundreds of streams of different types and few rivers dissect these parts, some of them form gorges along their courses. Among these numerous streams, only 22 were found to form gorges with canyon character, in some parts of their courses and dissect the whole anticline or mountain, almost perpendicularly. The locations of the studied gorges are shown in Fig. (1), each gorge is given a serial number and name (Table 1). When the gorge has no geographic name, then the nearest known geographic name is used.

The aim of this study is to reveal the genesis of the selected gorges and their main characteristics (morphometry) (Table 1). This study also attempts to explain why the streams dissect perpendicularly a huge rock mass (with few hundred meters of very hard rocks, mainly limestones) through the involved gorges, whilst they can flow in more easy paths, to cross an anticline or a mountain.

METHOD OF WORK AND USED MATERIALS

To perform this study, the following materials were used:

- Topographical and geological maps of 1: 100 000 and 1: 250 000 scales
- Landsat images and Google Earth images
- GIS applications and remote sensing techniques

In selecting the gorges, two main criteria were adopted: The first is: the stream must dissect the whole mountain or anticline, perpendicularly (transversally). The second is; the stream must have a canyon like gorge in a part of its course; otherwise the gorge is excluded from this study. In applying the two mentioned criteria, only 22 gorges were found to coincide with the adopted criteria. The selection of the gorges was performed by using the aforementioned data. The lithology and geological formation(s) of the area involved, for each gorge, were achieved from the available geological maps of 1: 250 000 and 1: 1000 000 scales (Sissakian, 1993, 1995, 1997 and 2000; Ma'ala, 2007; Fouad, 2008 and Al-Mousawi *et al.*, 2008). Unfortunately, no geophysical data are available in the studied area to confirm or otherwise the presence of some subsurface structures that the authors believe they have contributed in the evolution of some studied gorges.

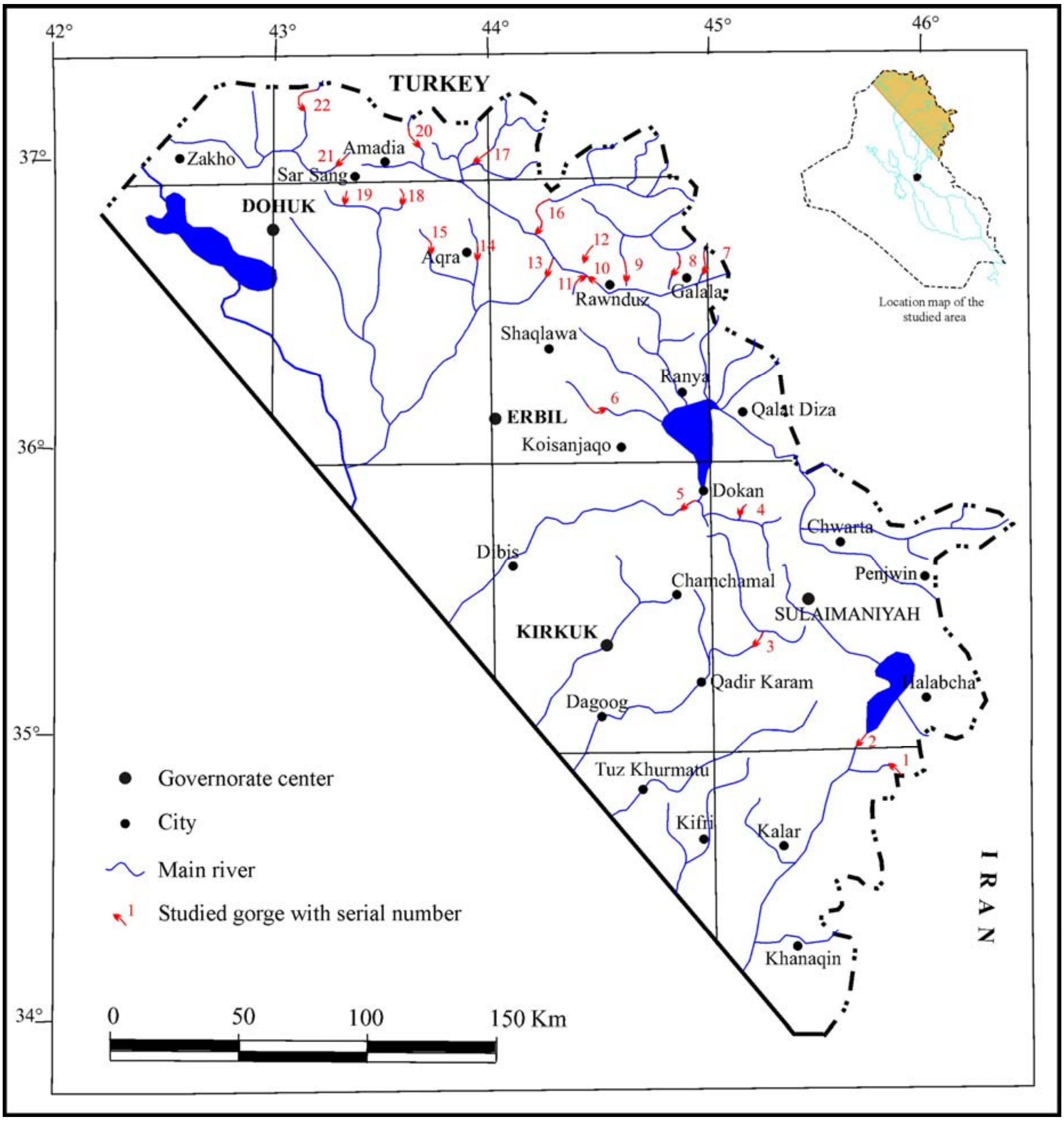


Fig. 1: Location map of the studied gorges

Arc GIS, hydro toolset was used to draw the drainage system of each studied gorge, which illustrates clearly the drainage system in each of the studied gorges. Each drainage system is shown beside the topographic contour map of the gorge. The latter is acquired from the Digital Elevation Model (DEM), using Arc GIS technique. The DEM was computed from the Shuttle Radar Topography Mission (SRTM). The SRTM DEM has a spatial resolution of about 90 m and vectral accuracy in the order of meters to few tens of meters (Ka'ab, 2005). The DEM was used to deduce the length and Thalweg length of the studied streams that was used in calculation of the sinuosity and gradient of each gorge. The sinuosity, which indicates the intensity of stream meandering; shows that the majority of the streams has almost straight courses.

Table 1: Characteristics of the studied gorges

No.	Name	Inlet			Outlet			Length (m)	Thalweg length (m)	Sinuosity	Gradient (%)	Highest point (m)	Lowest point (m)	Height difference (m)	Genesis
		Longitude (E)	Latitude (N)	Elevation (m) (a.s.l.)	Longitude (E)	Latitude (N)	Elevation (m) (a.s.l.)								
1	Sartak	45° 44' 42.47"	35° 02' 52.73"	916	45° 44' 35.75"	35° 02' 52.18"	805	2511	2694	1.072	4.4	956	906	50	Solution
2	Darbandi Khan	45° 42' 15.64"	35° 06' 40.20"	396	45° 42' 04.77"	35° 06' 13.30"	382	1989	1772	1.122	0.7	872	396	456	Near to plunge
3	Deleza	45° 11' 36.44"	35° 27' 40.45"	687	45° 09' 31.11"	35° 26' 38.70"	652	4889	4532	1.078	0.7	1120	660	560	Lineament
4	Pira Magroon	45° 07' 53.90"	35° 50' 33.66"	1012	45° 06' 21.62"	35° 50' 02.39"	776	2685	2582	1.039	8.7	1140	951	189	Plunge + All. fan
5	Sitak	44° 57' 57.92"	35° 52' 51.93"	481	44° 55' 55.61"	35° 52' 34.60"	422	4435	4120	1.076	1.4	908	413	495	Near to plunge
6	Samaqului	44° 35' 14.76"	36° 10' 15.80"	721	44° 36' 28.60"	36° 10' 58.55"	610	2317	2181	1.062	5.7	1021	665	356	Lineament
7	Rayat	44° 57' 32.67"	36° 40' 39.78"	1376	44° 54' 21.67"	36° 39' 19.22"	1160	7702	5560	1.174	3.8	2462	1315	1047	Lineament
8	Galala	44° 47' 19.64"	36° 35' 19.39"	883	44° 45' 57.73"	36° 34' 46.50"	811	4103	3835	1.069	1.8	1872	840	1032	Deep seated fault
9	Barsarin	44° 42' 27.78"	36° 38' 40.38"	800	44° 41' 20.44"	36° 37' 16.74"	708	3995	3794	1.052	2.4	1522	748	774	Deep seated fault
10	Gali Ali Beg 1	44° 29' 12.92"	36° 37' 50.71"	562	44° 27' 23.44"	36° 37' 44.91"	539	8259	7231	1.142	0.3	2093	546	1547	Fault
11	Gali Ali Beg 2	44° 25' 04.01"	36° 37' 05.08"	705	44° 27' 23.44"	36° 37' 44.91"	539	6721	4433	1.516	3.7	1261	522	839	Fault + rock fall
12	Diyana	44° 15' 28.51"	36° 51' 55.21"	940	44° 12' 42.90"	36° 50' 02.21"	537	8242	7000	1.177	5.7	1574	851	723	Near to plunge + sliding
13	Bekhme	44° 16' 21.42"	36° 42' 19.08"	452	44° 13' 52.45"	36° 40' 10.49"	390	7137	6599	1.081	0.94	1519	412	1107	Deep seated fault
14	Galley Zanta	43° 58' 16.16"	36° 46' 42.82"	658	43° 58' 10.91"	36° 43' 52.72"	470	5212	5123	1.017	3.6	1112	595	417	Near to plunge
15	Bakriman	43° 39' 38.90"	36° 51' 24.72"	506	43° 39' 19.63"	36° 48' 42.22"	478	5685	5137	1.106	0.6	958	521	437	Near to plunge
16	Zibar	44° 12' 56.24"	36° 57' 35.42"	681	44° 07' 20.40"	36° 51' 43.72"	497	28805	20780	1.386	0.8	1043	527	516	Fault
17	Shamdinan	44° 00' 09.22"	37° 07' 46.47"	704	43° 50' 41.93"	37° 01' 45.57"	615	26549	24045	1.104	0.37	1347	631	716	Intense folding
18	Galley Dera Luke	43° 40' 08.61"	37° 07' 50.16"	835	43° 35' 29.76"	37° 04' 18.08"	670	8217	8015	1.025	1.8	2167	691	1476	Lineament
19	Zawita	43° 10' 12.63"	37° 00' 30.96"	1021	43° 09' 46.71"	36° 56' 42.31"	844	5542	5505	1.006	3.2	1025	931	94	Lineament + solution
20	Greater Zab	43° 34' 08.82"	37° 15' 22.05"	785	43° 33' 34.73"	37° 12' 17.23"	749	9475	8454	1.120	0.4	1590	771	819	Intense folding
21	Mateen	43° 10' 36.08"	37° 12' 08.13"	727	43° 05' 44.45"	37° 10' 04.71"	685	7718	8482	1.098	0.4	1100	770	330	Intense folding
22	Khabour	43° 10' 08.61"	37° 21' 27.23"	943	43° 10' 02.63"	37° 20' 02.94"	909	3123	2945	1.060	1.15	1551	922	629	Intense folding

The main characteristics (morphometry) of the studied gorges are shown in Table (1), these include: Longitude and Latitude of the inlet and outlet of each gorge, with their heights (m, a.s.l.). The highest and lowest points along the banks of the course; as measured perpendicularly from the highest point down to the adjacent lowest point along the stream level. The gradient of the stream along its course, as measured from the inlet to the outlet. The length of the gorge and the sinuosity (in the studied part of the stream). These data are acquired from Google Earth and Landsat images, beside the topographical maps and GIS applications.

The genesis of the gorges evolution is indicated from interpretation of Landsat and Google Earth images and the best available geological maps. When attributed to structural effect, then the data was checked and confirmed whether they do coincide with the acquired structural data. This was performed from the structural data, as reviewed from tectonic maps (Buday and Jassim, 1984 and Al-Kadhimi *et al*., 1996).

Unfortunately, there was no opportunity to visit all the studied gorges and to check the gathered data from Google Earth and Landsat images and other relevant data. Only 14 gorges were checked in the filed, during different occasions, these are gorges no. 1, 2, 3, 4, 6, 9, 10, 11, 13, 14, 17, 19, 20 and 22.

PREVIOUS WORKS

No much work was carried out, in Iraq; especially in the studied area, concerning the objectives of this work. However, the followings are the available published literature, which were reviewed by the authors:

- Al-Daghastani and Salih (1992) studied the behavior of Khazir River, in Mosul vicinity and found it reflects its adjustment to differential uplift and local tectonic activity during Quaternary, indicating antecedent stream origin.
- Al-Sakini (1993) studied the courses of the Tigris and Euphrates Rivers and concluded that the recent courses are greatly influenced by Neotectonic movements. Moreover, he concluded that the growth of some subsurface anticlines caused continuous shifting of the river courses that follow usually the anticline and not dissect it.
- Al-Daghastani and Al-Daghastani (1994) studied the drainage response of the tectonic activity and geomorphology of Jebel Ishkaft area, northwestern Iraq. They found that the Qabak Stream and its tributaries have evolved in close association with active folds. The clearest evidence of the tectonic effect shows significant changes of the pattern, gradient and valley morphology, indicating antecedent stream origin.
- Al-Naqash (2001) studied the courses of the Tigris River and its tributaries, concerning the crossing of the rivers to the anticlines, either from their plunge areas or perpendicularly to both limbs. He concluded that they all are older than Pre-Quaternary and that they all are antecedent type of rivers.
- Al-Kubaisi (2000) and Marouf and Al-Kubaisi (2002) studied the rivers and streams of North Iraq and concluded that the courses of the rivers and their later evolution are mainly controlled by the structural and tectonic history of the area.
- Al-Mosawi (2004) studied the Ishkaft and Sasan anticlines, in the northwestern part of Iraq and concluded that one of the main valleys in her studied area that crosses the Ishakaft anticline is of antecedent type.
- Al-Daghastani and Al-Banna (2006) carried out morphotectonic analysis of eight surface drainage basins, in Nainava Governorate, which varies in their basin geometry and concluded that the analysis of longitudinal valley profiles of the studied basins indicated

their effects by a group of morphotectonic variables, which characterized each distinct segment differentially.

CLIMATE

The current climate in the studied area, especially during the last few years, is almost semi-arid. However, concerning long term evaluation, it is characterized by Savanna climate. During Pleistocene and Holocene, the studied area had suffered from many wet periods that lasted for considerable times, providing the studied area by enormous amount of run-off water. From the existing literature, the glaciations were not reached the studied area, but from the authors' recognitions, in the field, a clear glacial form valley could be seen north of Sulaimaniyah, between Pera Magroon and Azmir Mountains. Therefore, the effect of the glaciation could not be ignored in partial evolution of some studied gorges. Freezing and snowing are very common during the winter; their influence in frost wedging is very common end affective, in acceleration of gorge's evolution. The following climatic data are gathered from the Iraqi Climatic Atlas (IMO, 2000) (Table 2):

Table 2: Climatic data of the studied area (1971 – 2000)

Month	Mean temperature (°C)	Mean monthly rainfall (mm)
November	12 – 14	60 – 100
December	6 – 8	80 – 120
January	4 – 8	100 – 150
February	6 – 10	80 – 120
March	8 – 12	80 – 100
April	14 – 16	
Mean amount of rainfall		(650 – 900) mm
Mean annual temperature		(16 – 20)° C
Annual number of days with frost		30 – 40
Annual number of days with snow		6 – 14

From reviewing the climatic data and imposing them in the morphogenetic diagram (Peltier, 1950 in Fookes *et al*., 1971) (Fig.2A), it is clear that the studied area is now under the influence of Savanna climate. The effect of chemical weathering and frost action is shown in Fig.

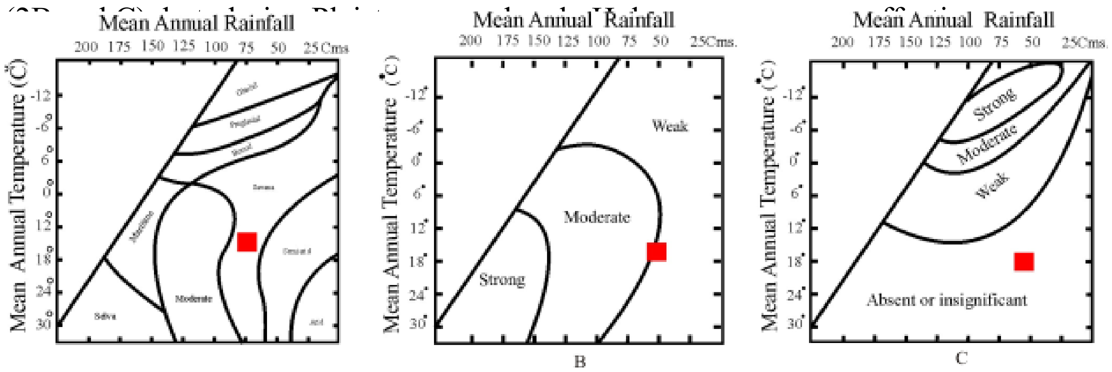


Fig.2A: Climatic boundaries of the morphogenetic regions (After Peltier in Fooks *et al*., 1971)

Fig.2B and C: Rainfall/ Temperature diagram (After Peltier, 1950 in Fooks *et al*., 1971) showing:
B- Intensity of chemical weathering (decomposition)
C- Intensity of frost weathering (disintegration)

GENESIS OF THE GOPRGES

The studied gorges are evolved almost perpendicularly (transversally) across anticlines or mountains; following the most difficult path, in carving few hundred meters of hard and massive limestones. Many of them have easier paths, which is (occasionally) not so far from the present path. The gorges are evolved after the rocks are folded, as it will be discussed later on; many evidences were recognized from Landsat and Google Earth images to confirm the genesis of the gorges.

The main factors and/ or agents that contributed in gorges evolution are:

■ Water

The main agent for the evolution of the gorges is the runoff water, as erosion agent. During Pleistocene and Holocene, many wet periods were recorded, during those wet periods the surface run off water had carved the massive limestones and the gorges were evolved. Freezing of the water in the joints, fractures and pores also played big role in disintegration of the rocks by splitting of the huge masses into smaller ones that were eroded more easily.

Each stream is enlarging due to lateral and head-ward erosion (Carpenter, 2008). The studied gorges have suffered from frost wedging (since Pleistocene until now) and from gravitational forces in form of mass movements that accelerate, indirectly, the evolution and enlargement of the gorges. Such factors are well known and common aspects in evolution of gorges and sinkholes (Travel West. Net, 2002; Lisenbee, 2003; White and White, 2005 and Desert Processes Working Group, 2005).

The rivers and streams gradually change their courses to follow belts of the most easily eroded rocks, avoiding resistant rocks that form highlands (Bloom, 1998 and Ritter *et al.,* 2002). In the studied gorges, however, the involved streams have ignored this rule and carved through huge masses of very hard massive limestones (few hundred meters thick). This is because they mainly have subsequently evolved in response to structural control, or partly due to solution effect.

■ Structural Elements

Faults, folds, plunge areas, lineaments and intense jointing; are contributed in evolution of the gorges. The stream may follow one or more of these elements and entrench deeply in the bedrock. Many of the studied gorges are parallel to lineaments or run parallel to plunges of the beds (nearby the plunge area), others are affected by surface or subsurface faults, along which the crossing of the huge rock masses is easier.

■ Solution

Limestones are dissolved inform of karst features forming sinkholes. The majority of the studied gorges are found in limestones. By enlarging of the sinkholes and their conjunction together; the whole rock mass is disintegrated and the water entrenched in more easily, crossing the barrier and the gorge is evolved.

■ Mass Movements and Alluvial Fans

Sliding, flow and rock fall, are the most common mass movements phenomena in the studied area. Many alluvial fans are developed in different areas, some of them are very large, up to many square kilometers, and some are still active. Both processes could help, indirectly, in the evolution of the gorges by blocking (damming) of the stream and/ or river course, consequently causing the stream to shift its course to a new one that might be across an anticline or a mountain. The new course might be much more difficult than the pre-existing path.

MORPHOMETRY OF THE STUDIED GORGES

The studied gorges are systematically described hereinafter. The mentioned characters with the structural effect represent the morphometry of the studied gorges. The details of the location and morphometric characteristics are given in Table (1). Figure (1), shows the locations of the studied gorges; with their serial numbers. Each gorge is presented by a Landsat image that shows the details of the gorge. Moreover, a topographic map showing the main drainage is enclosed too. These are acquired from GIS applications. Those gorges, which have been visited by the authors, are described in more details; including the shape of the cliffs, locally forming "Hoodoos", size of the fallen blocks and other characters are mentioned too.

Although the watershed basin is a basic unit in morphometric analysis, because all hydrologic and geomorphic processes occur within the watershed (Singh, 1992), but in this study, it is not considered, because studying the basins of 22 streams is behind the scope of this study, moreover the basins of many streams extend off the Iraqi international boundaries. Therefore, the morphometric study of the streams is restricted from the inlet to the outlet part.

– **No.1: Sartak** (Fig.3A and B)
Location: South of Darbandi Khan town.
Formation: Pila Spi, well thickly bedded, jointed and very hard limestone.
Morphology: Very narrow gorge (locally) with very steep walls, the Sartak Bamu Stream is flowing westwards in meandering (S) form.
Structure: Golan anticline with NW – SE trend and steeper southwestern limb.
Genesis: Solution, as it is clear from the smooth and curved surfaces along the steep walls of the very narrow and irregular gorge (Fig.3A) that indicates the effect of the solution by vertically moving water. Originally, it was a group of sinkholes that are enlarged due to their conjunction and then the walls collapsed down and the present gorge is developed.

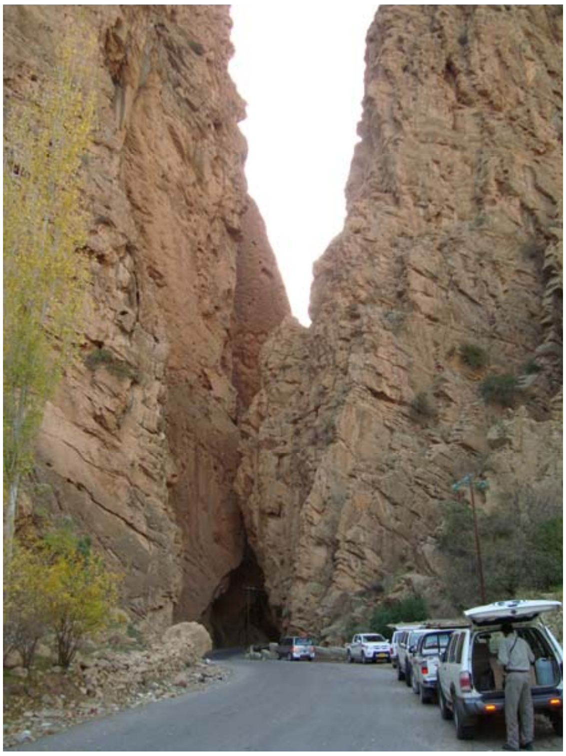


Fig.3A: Sartak Gorge, note the effect of the solution on the vertical walls of very hard limestone of the Pila Spi Formation

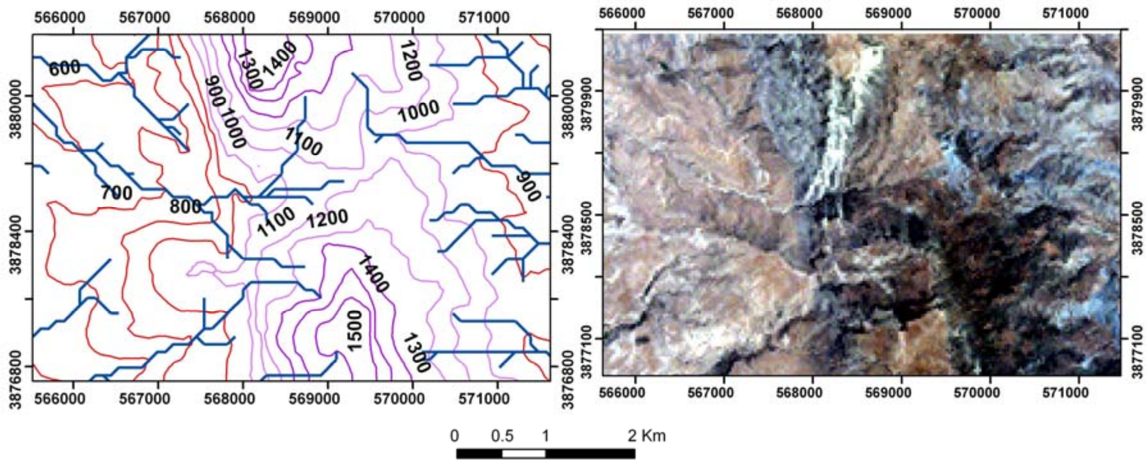


Fig.3B: Topographic map and Landsat image of Sartak Gorge (No.1)

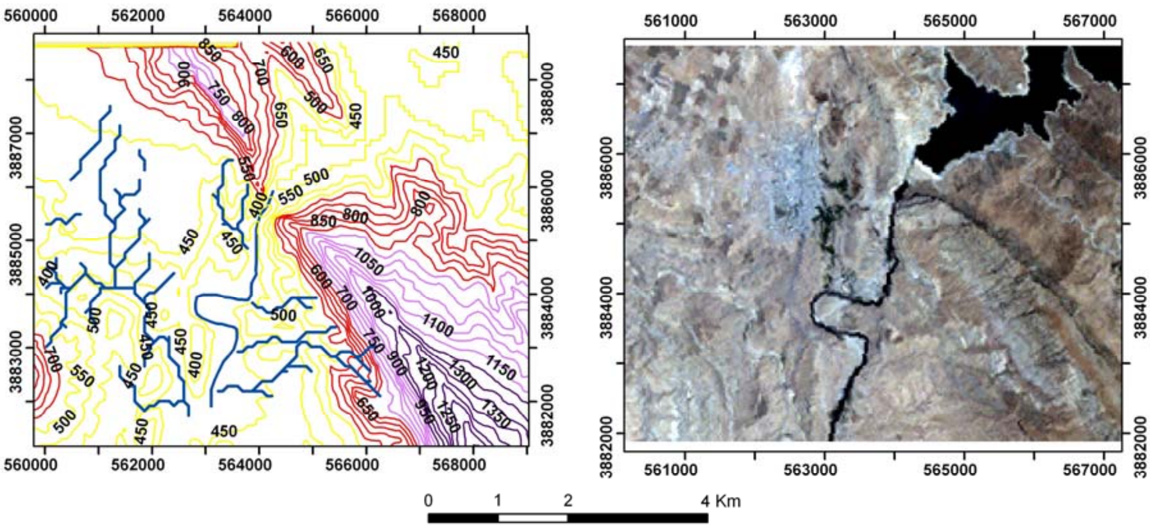
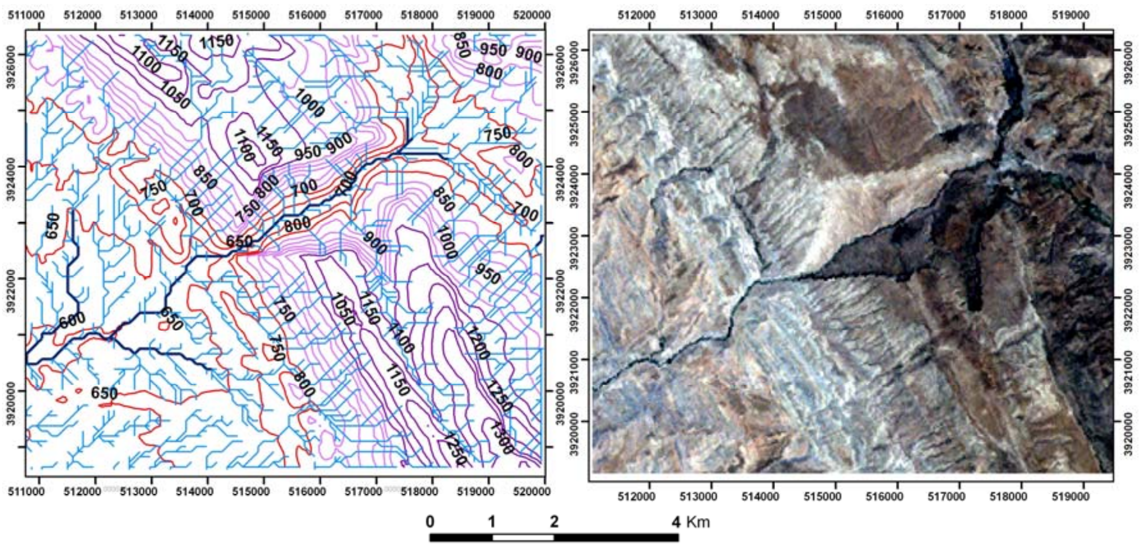


Fig.4: Topographic map and Landsat image of Darbandi Khan Gorge (No.2)



Fhg.5: Topographic map and Landsat image of Deleza Gorge (No.3)

– **No.2: Darbandi Khan** (Fig.4)
Location: South of Sulaimaniyah; in Darbandi Khan town.
Formation: Pila Spi, well thickly bedded, jointed and very hard limestone.
Morphology: Narrow gorge with steep walls (canyon like), the Diyala (Serwan) River is flowing southwards with deeply incised channel in bedrock.
Structure: Darbandi Khan anticline with NW – SE trend; almost symmetrical, near the southeastern plunge, the southwestern limb is highly deformed due to local intense folding.
Genesis: Structurally controlled, near to the southeastern plunge area.

– **No.3: Deleza** (Fig.5)
Location: South of Sulaimaniyah city.
Formation: Pila Spi, well thickly bedded, jointed and very hard limestone.
Morphology: Narrow gorge (canyon like) with steep walls (both banks); the uppermost part is vertical, forming Hoodoos , the Deleza Stream (a branch of Daqooq Chai that merges to Adh'aim River) is almost straight, flowing southwards and deeply incised channel in bedrock.
Structure: Qara Dagh anticline with NW – SE trend and steeper southwestern limb
Genesis: Structurally controlled, as evidenced by a transversal lineament and accelerated by rock fall; large fallen blocks of well bedded massive and very hard limestone up to 10 m^3 could be seen in and alongside the course.

– **No.4: Pira Magroon** (Fig.6)
Location: Northwest of Sulaimaniyah city.
Formations: Sarmord, interbedding of shale, marl and marly limestone. Qamchuqa, well thickly bedded, jointed and very hard limestone.
Morphology: The gorge is canyon like, with steep walls on both banks; the stream, which is a branch of Lesser Zab River, is flowing southwestwards with deeply incised channel in the bedrock.
Structure: Pira Magroon anticline with NW – SE trend.
Genesis: Structurally controlled, locally affected by the northwestern plunge of Pira Magroon anticline that is about 1.5 Km northwestwards of the gorge. The main stream that was most probably running more towards northwest, to cross Pira Magroon anticline from its northwestern plunge area is shifted towards south, due to blockage of the stream course by tens of alluvial fans sediments that attain more than 30 m in thickness. The alluvial fans are developed northwestwards, along the southwestern flank of Khalikan Mountain, they blocked (dammed) the course of the stream, due to their southwestern flow direction, and consequently the stream was shifted to cross the mountain diagonally.

– **No.5: Sitak** (Fig.7)
Location: South of Dokan, northwest of Sulaimaniyah city.
Formation: Pila Spi, well thickly bedded, jointed and very hard limestone.
Morphology: Narrow gorge with steep western wall, the Lesser Zab River is flowing southwestwards with deeply incised channel in the bedrock.
Structure: Tasloojah anticline with NW – SE trend; almost symmetrical.
Genesis: Structurally controlled, partly effected by the northwestern plunge.

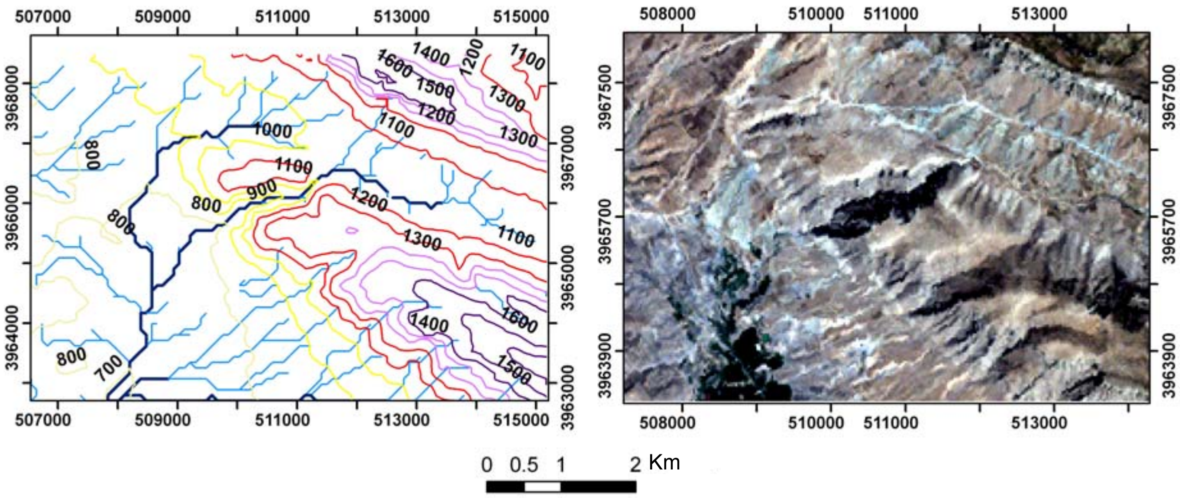


Fig.6: Topographic map and Landsat image of Pira Magroon Gorge (No.4)

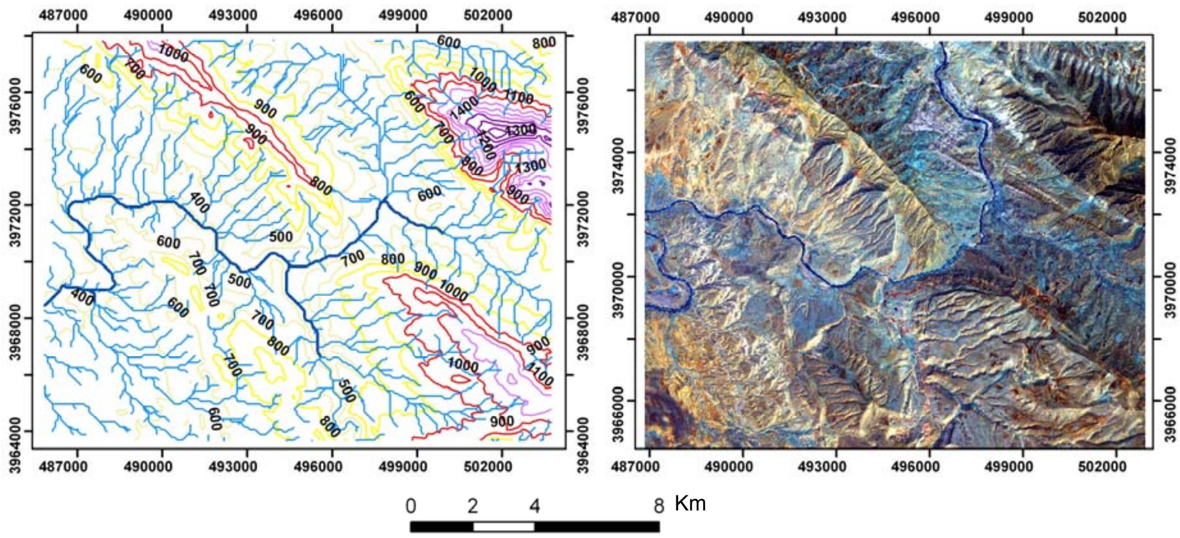


Fig.7: Topographic map and Landsat image of Sitak Gorge (No.5)

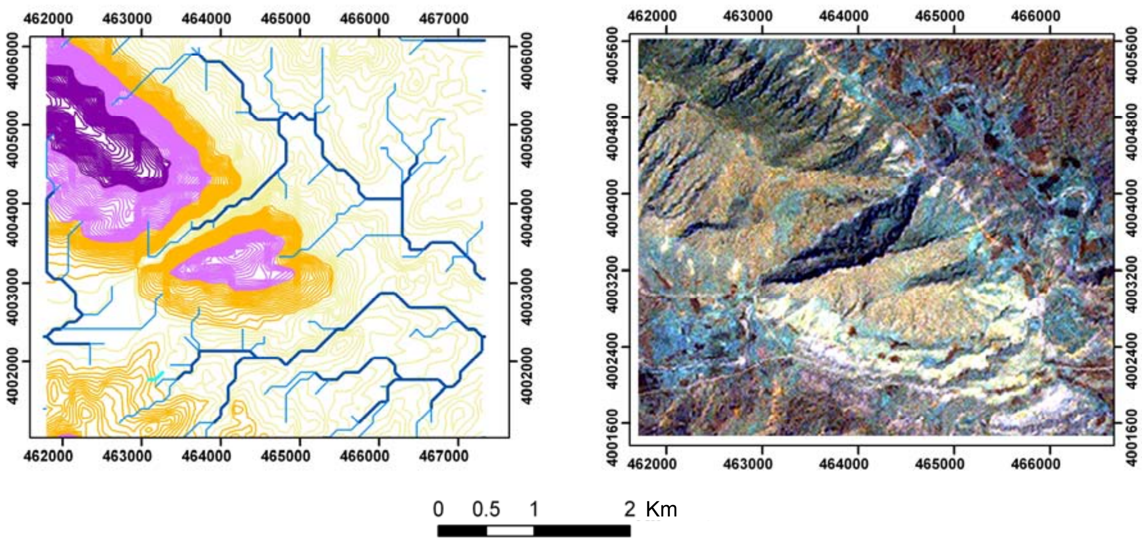


Fig.8: Topographic map and Landsat image of Samaquli Gorge (No.6)

– **No.6: Samaquli** (Fig.8)
Location: East of Erbil city
Formations: Qamchuqa and Aqra – Bekhme; well thickly bedded and very hard limestone.
Morphology: Very narrow gorge (canyon like) with very steep walls almost vertical, Samaquli stream is flowing northeastwards with deeply incised channel in bedrock.
Structure: Safin anticline with NW – SE trend and steeper southwestern limb.
Genesis: Structurally controlled, as evidenced from a lineament and accelerated by rock fall and land slides, large fallen blocks (3 – 8 m^3) of well bedded massive and very hard limestone could be seen in and alongside the course.

– **No.7: Rayat** (Fig.9)
Location: Northeast of Rawandooz and Erbil cities.
Formations: Walash and Naopurdan Groups. Sarmord, interbedding of shale, marl and marly limestone. Qamchuqa and Aqra – Bekhme; both are well thickly bedded, jointed and very hard limestone.
Morphology: The gorge locally is canyon like, with steep eastern walls; the stream, which is a branch of Rawandooz River, is flowing southwestwards with deeply incised channel in the bedrock.
Structure: Part of the main thrust, within the Zagros Suture Zone**.** It is the southwards extension of Hasarost Mountain.
Genesis: Structurally controlled, as evidenced from a lineament along which the stream flows.

– **No.8: Galala** (Fig.10)
Location: Northeast of Rawandooz and Erbil cities.
Formations: Walash and Naopurdan Groups. Sarmord, interbedding of shale, marl and marly limestone. Qamchuqa and Aqra – Bekhme; both are well thickly bedded, jointed and very hard limestone.
Morphology: The gorge locally is canyon like, with steep eastern walls; the stream, which is a branch of Rawandooz River, is flowing southwestwards with deeply incised channel in the bedrock.
Structure: Part of the main thrust, within the Zagros Suture Zone**.** The southwards extension of Hasarost Mountain.
Genesis: Structurally controlled, parallel to the deep seated Ba'aj – Mosul – Rawandooz Fault (Al-Kadhimi *et al.*, 1996).

– **No.9: Barsarin** (Fig.10)
Location: Northeast of Rawandooz and Erbil cities.
Formations: Jurassic formations, interbedding of soft shale, marl with hard dolomite. Sarmord, interbedding of shale, marl and marly limestone. Qamchuqa and Aqra – Bekhme; both are well thickly bedded, jointed and very hard limestone.
Morphology: The gorge locally is canyon like, with steep western walls; the stream, which is a branch of Rawandooz River, is flowing southwards with deeply incised channel in the bedrock.
Structure: Tanoon anticline with NW – SE trend, with steeper southwestern limb, which is thrusted over the Zozek Anticline, towards southwest.
Genesis: Structurally controlled, parallel to the deep seated Ba'aj – Mosul – Rawandooz Fault (Al-Kadhimi *et al.,* 1996).

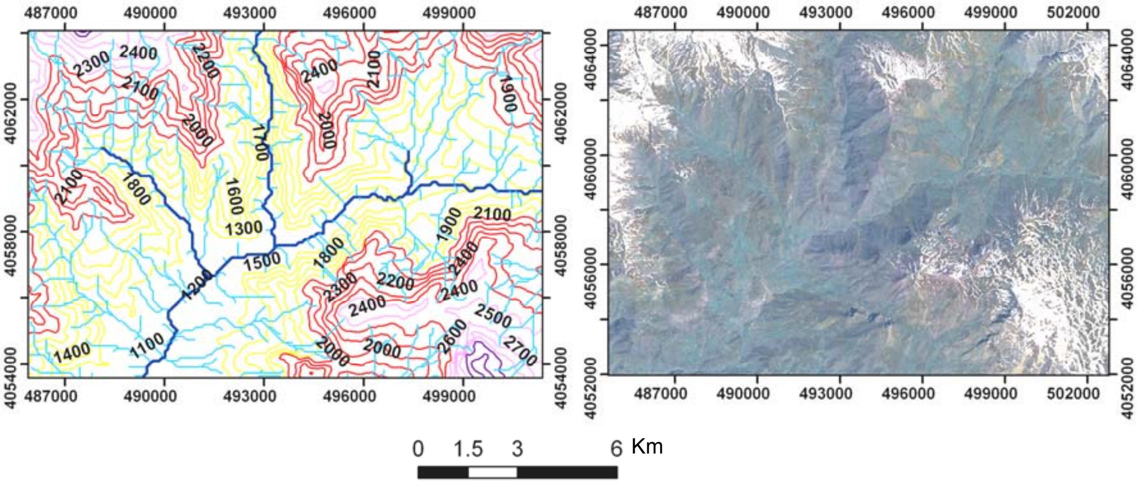


Fig.9: Topographic map and Landsat image of Rayat Gorge (No.7)

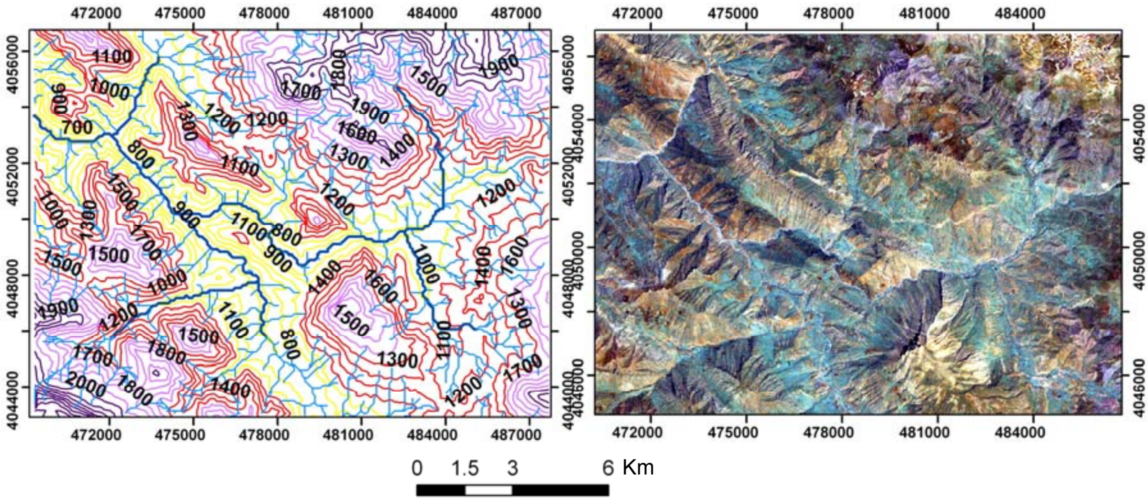


Fig.10: Topographic map and Landsat image of Galala and Barsarin Gorges (Nos. 8&9)

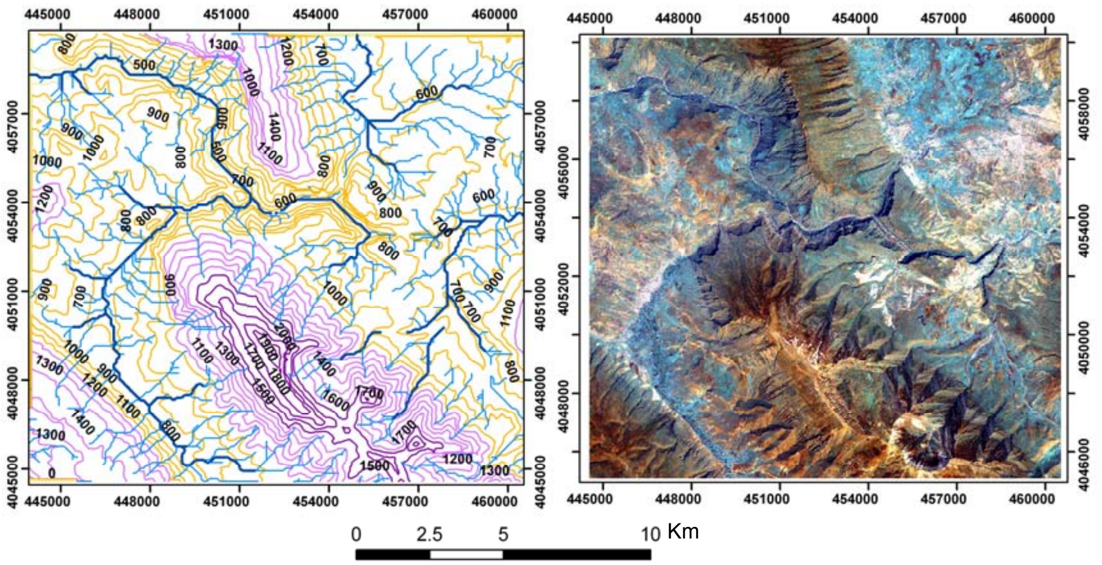


Fig.11: Topographic map and Landsat image of Gali Ali Beg 1 and 2 Gorges (Nos.10 &11)

– **No.10: Gali Ali Beg 1** (Fig.11)
Location: Northeast of Erbil city
Formations: Sarmord; interbedding of shale, marl and marly limestone. Qamchuqa and Aqra – Bekhme; both are well thickly bedded, jointed and very hard limestone.
Morphology: Very narrow gorge with very steep walls (canyon like), the uppermost part is vertical, forming Hoodoos; the Rawandooz River (that merges to the Greater Zab River) is flowing southwestwards with deeply incised channel in the bedrock.
Structure: The southwestern limb of Bradost anticline and the northeastern limb of Korak anticline, both have NW – SE trend and dissected by NW – SE trending reverse fault with the northeastern block being thrusted.
Genesis: Structurally controlled, partly effected by the aforementioned reverse fault, accelerated by rock fall and land slides, large fallen blocks of well bedded massive and very hard limestone up to 10 m^3 could be seen in and along the course.

– **No.11: Gali Ali Beg 2** (Fig.11)
Location: Northeast of Erbil city
Formations: Sarmord; interbedding of shale, marl and marly limestone. Qamchuqa and Aqra – Bekhme; both are well thickly bedded, jointed and very hard limestone.
Morphology: Very narrow gorge with very steep walls (canyon like), the uppermost part is vertical, forming Hoodoos; the stream, which is a branch of Rawandooz River is flowing northeastwards with deeply incised channel in the bedrock
Structure: Korak anticline with NW – SE trend and steeper southwestern limb.
Genesis: Structurally controlled, near to the southeastern plunge of Aqra anticline and affected by NW – SE trending reverse fault with the northeastern block being thrusted, accelerated by rock fall and land slides, large fallen blocks of well bedded massive and very hard limestone up to 15 m^3 could be seen in and alongside the course.
Note: Both aforementioned gorges merge together, almost in the middle part of the main gorge and have one outlet, along which the Rawandooz River flows eastwards to merge with Greater Zab River. It is the longest, deepest and most narrow gorge in Iraq.

– **No.12: Diyana** (Fig.12)
Location: Northwest of Rawandooz city and northeast of Erbil city.
Formations: Sarmord, interbedding of shale, marl and marly limestone. Qamchuqa and Aqra – Bekhme; both are well thickly bedded, jointed and very hard limestone.
Morphology: The gorge locally is canyon like, with steep eastern walls; the stream, which is a branch of Rawandooz River, is flowing southwestwards, almost in straight line, with deeply incised channel in the bedrock.
Structure: Bradost anticline with NW – SE trend, with steeper northeastern limb.
Genesis: Structurally controlled; nearby to the southeastern plunge of a local dome. Although this gorge does not cross the whole anticline, but it is included within this study. The authors believe that the stream was originally crossing the Bradost anticline. Now, the inlet is blocked (dammed) by two large masses that have flowed down from both sides of the inlet, causing the blockage of the inlet. This also is evidenced from the size of the gorge and the stream that crosses the Bradost anticline. If originally it was not flowing through the blocked inlet; then the gorge wouldn't be in its present size, because the remaining part of the stream is unable to erode and carve such a large gorge within the very hard limestones of Qamchuqa and Aqra – Bekhme formations.

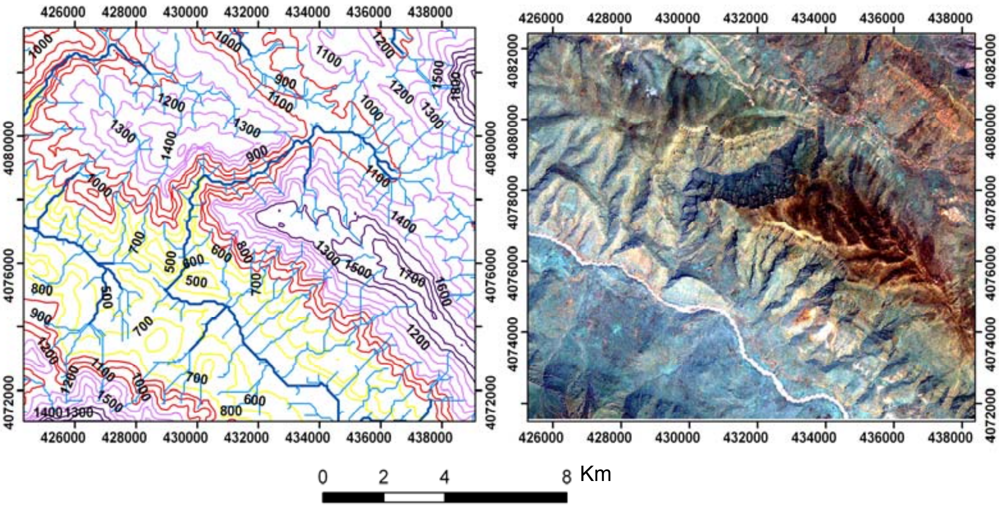


Fig.12: Topographic map and Landsat image of Diyana Gorge (No.12)

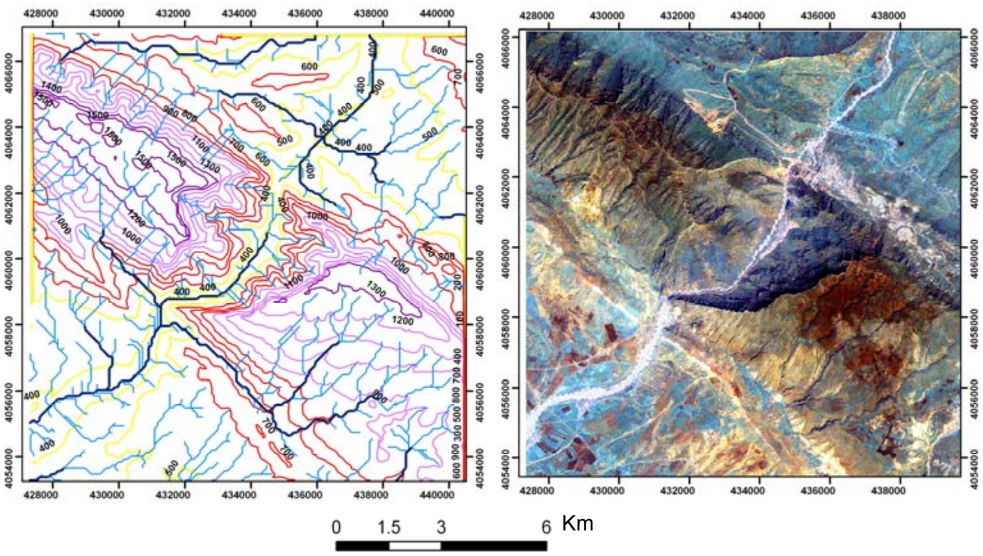


Fig.13: Topographic map and Landsat image of Bekhme Gorge (13)

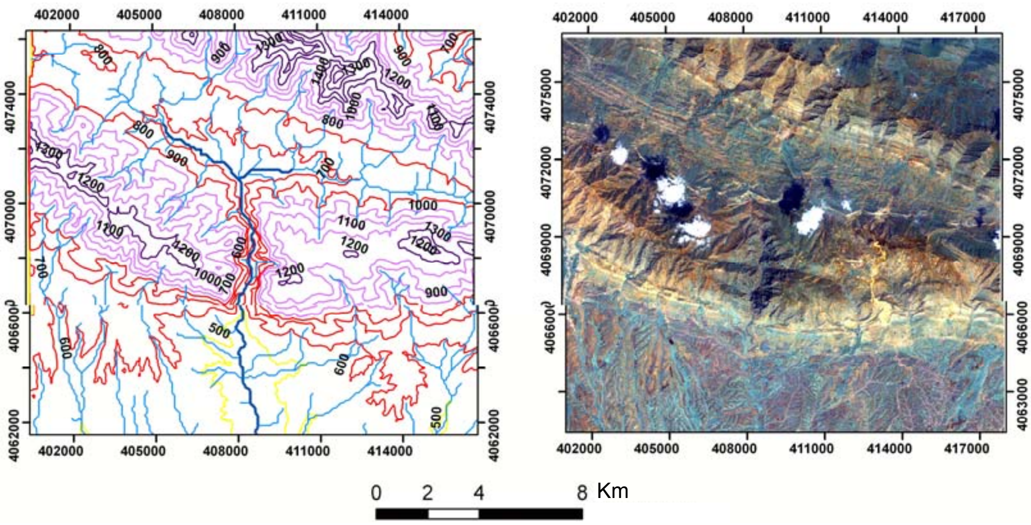


Fig.14: Topographic map and Landsat image of Galley Zanta Gorge (No.14)

– **No.13: Bekhme** (Fig.13)
Location: North – Northeast of Erbil city
Formations: Sarmord; interbedding of shale, marl and marly limestone. Qamchuqa and Aqra – Bekhme; both are well thickly bedded, jointed and very hard limestone
Morphology: Narrow gorge with steep eastern walls (canyon like), the uppermost part is vertical, forming Hoodoos; the Greater Zab River is flowing southwestwards with deeply incised channel in the bedrock.
Structure: Peris anticline with NW – SE trend and steeper southwestern limb.
Genesis: Structurally controlled, coincides with the deep seated Ba'aj – Mosul – Rawandooz Fault (Al-Kadhimi *et al.,* 1996).

– **No.14: Galley Zanta** (Fig.14)
Location: North of Erbil city
Formations: Qamchuqa and Aqra – Bekhme; both are well thickly bedded, jointed and very hard limestone
Morphology: Very narrow gorge (canyon like) with very steep walls, the uppermost part is vertical, forming Hoodoos; the Zanta Stream is flowing southwards with deeply incised channel in the bedrock.
Structure: Aqra anticline with NW – SE trend and steeper southwestern limb, locally overturned.
Genesis: Structurally controlled, parallel to the southeastern plunge that is few hundred meters far and coincides with a local lineament of N – S direction.

– **No.15: Bakirman** (Fig.15)
Location: Northeast of Erbil city and west of Aqra city
Formations: Qamchuqa and Aqra – Bekhm; both are well thickly bedded, jointed and very hard limestone; Kolosh, soft black clastics; Pila Spi, well thickly bedded, jointed and very hard limestone.
Morphology: Very narrow gorge (canyon like) with steep walls, the uppermost part is vertical, forming Hoodoos; the Bakirman Stream (Khazir River) is flowing southwards with deeply incised channel in the bedrock.
Structure: Aqra anticline with NW – SE trend and steeper southwestern limb, locally overturned.
Genesis: Structurally controlled, parallel to the southeastern plunge of a local dome.

– **No.16: Zibar** (Fig.16)
Location: North of Erbil city.
Formations: Sarmord, interbedding of shale, marl and marly limestone. Qamchuqa and Aqra – Bekhme; both are well thickly bedded, jointed and very hard limestone.
Morphology: The gorge locally is canyon like, with steep walls; the Haj'ji Beg Stream that merges to Greater Zab River is flowing southeastwards with a meandering **S** form. The deeply incised channel in the bedrock is far from the river bed, indicating very intensive erosion and incision.
Structure: Matin and Shereen anticlines with NW – SE trend that changes westwards to E – W trend, with steeper southwestern limbs, locally the gorge runs through horizontal beds giving it step landscape.
Genesis: Structurally controlled, locally affected by NW – SE trending thrust fault.

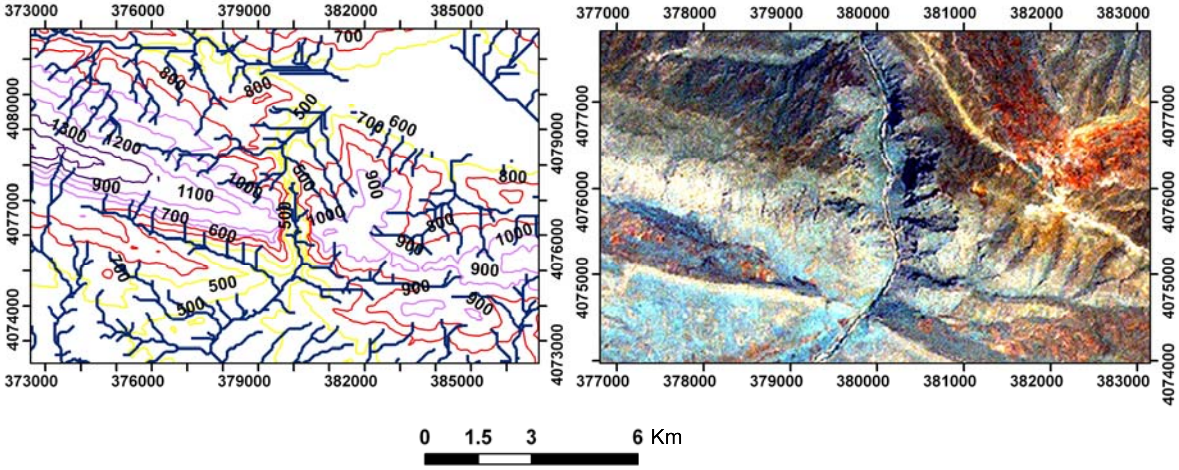


Fig. 15: Topographic map and Landsat image of Bakirman Gorge (No.15)

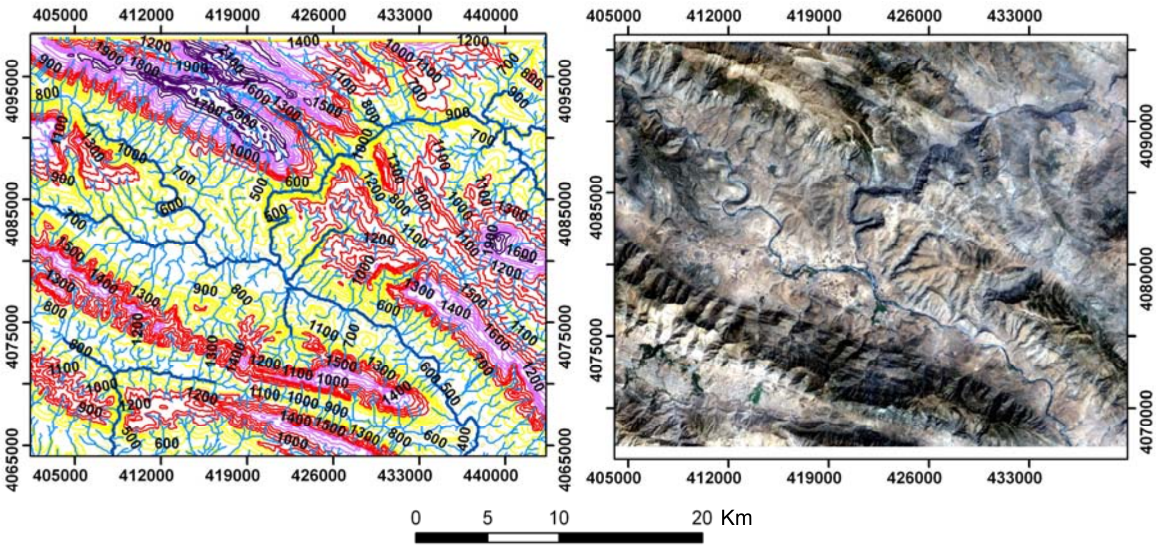


Fig. 16: Topographic map and Landsat image of Zibar Gorge (No.16)

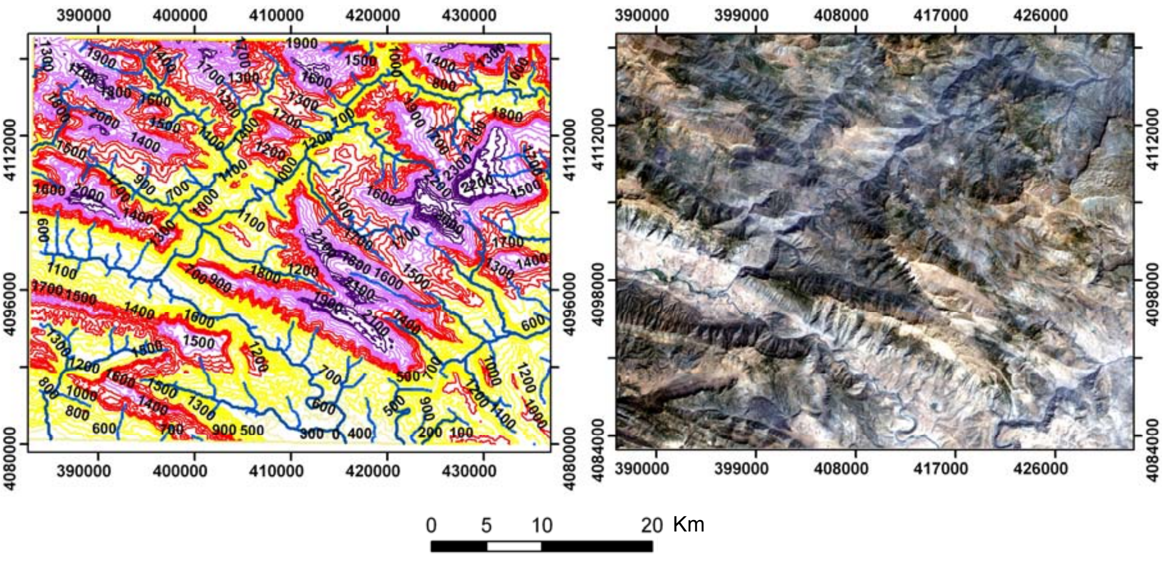


Fig.17: Topographic map and Landsat image of Shamdinan Gorge (No.17)

– **No.17: Shamdinan** (Fig.17)
Location: East of Amadiyah city and northeast of Dohuk city.
Formations: Jurassic formations, interbedding of soft shale, marl with hard dolomite. Sarmord, interbedding of shale, marl and marly limestone. Qamchuqa and Aqra – Bekhme; both are well thickly bedded, jointed and very hard limestone.
Morphology: Narrow gorge with steep walls, the uppermost part is vertical, forming Hoodoos; Shamdinan Stream is flowing southwestwards in meandering form, due to highly deformed rocks and crossing three anticlines.
Structure: Shamdinan, Matin and Shereen anticlines with NW – SE trend that changes westwards to E – W trend.
Genesis: Structurally controlled, very highly disturbed beds due to intense folding and over thrusting.

– **No.18: Galley Dera Luke** (Fig.18)
Location: Near Amadiyah city and northeast of Dohuk city.
Formations: Qamchuqa and Aqra – Bekhme; both are well thickly bedded, jointed and very hard limestone.
Morphology: Narrow gorge with steep walls, the uppermost part is vertical, forming Hoodoos; the Greater Zab River is flowing southwards in very straight trend with deeply incised channel in the bedrock.
Structure: Matin anticline with E – W trend and steeper southern limb.
Genesis: Structurally controlled with clear very straight lineament.

– **No.19: Zawita** (Fig.19)
Location: Northeast of Dohuk city.
Formations: Pila Spi, well thickly bedded, jointed and very hard limestone.
Morphology: Narrow gorge (locally) with steep walls, the Zawita Stream is floiwng southwards with deeply incised channel in the bedrock.
Structure: Kiri Rabatki anticline with NW – SE trend that changes westwards to E – W trend.
Genesis: Structurally controlled, partly affected by solution, as it is clear from the smooth surfaces along the steep walls that indicate the effect of the solution by vertically moving water.

– **No.20: Greater Zab** (Fig.20)
Location: North of Amadiyah city.
Formations: Many formations ranging from Cretaceous to Eocene, consisting of different rock types, clastics, shale, well thickly bedded, jointed and very hard limestone.
Morphology: Narrow gorge (locally) with steep walls, the Greater Zab River is flowing southwards with deeply incised channel in the bedrock.
Structure: Part of the Thrust Zone, the Cretaceous rocks being thrusted over Triassic and Jurassic rocks, causing highly disturbed and crushed rocks.
Genesis: Structurally controlled, very highly disturbed beds due to intense folding and over thrusting.

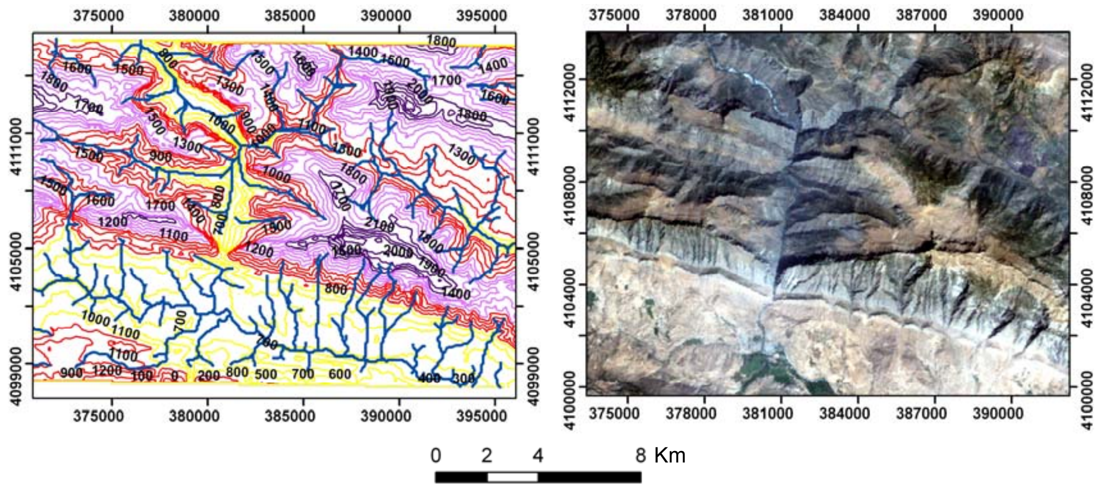


Fig.18: Topographic map and Landsat image of Dera Luke Gorge (No.18)

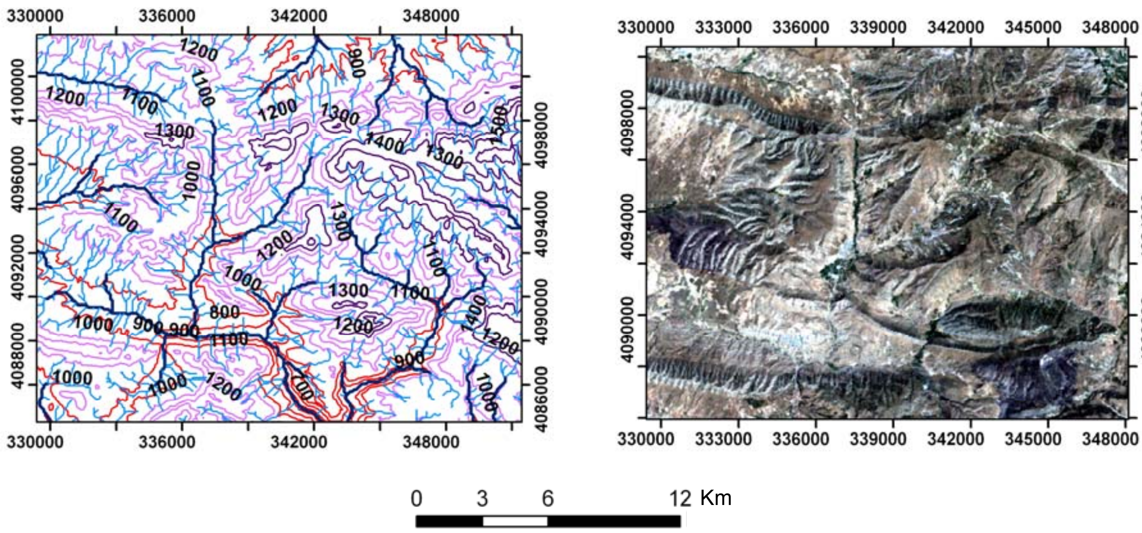


Fig.19: Topographic map and Landsat image of Zawita Gorge (No.19)

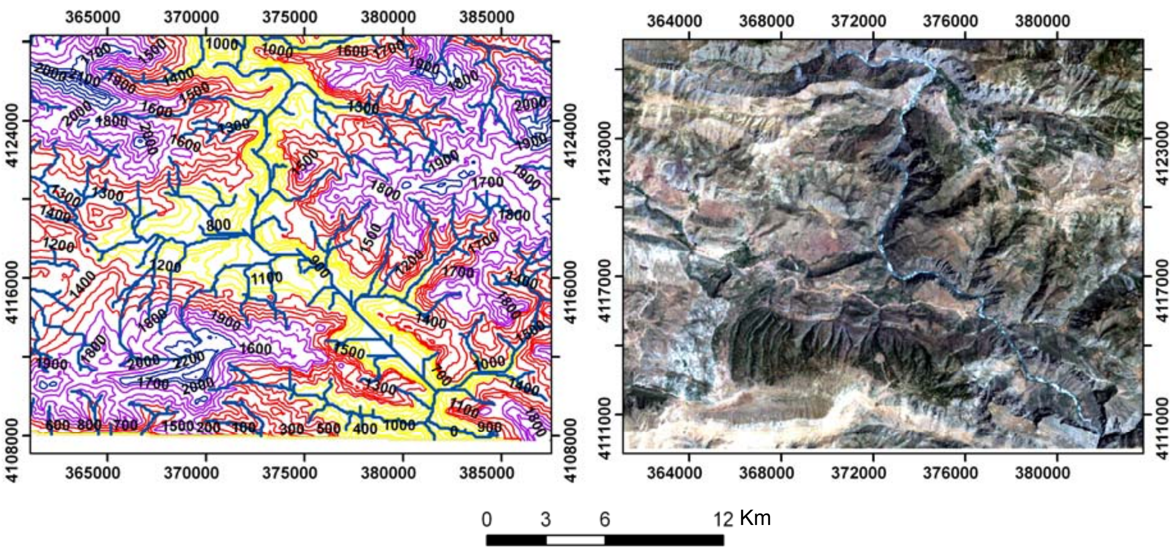


Fig.20: Topographic map and Landsat image of Greater Zab Gorge (No.20)

– **No.21: Mateen** (Fig.21)
Location: Northeast of Amadiyah city.
Formations: Many formations ranging from Cretaceous to Eocene, consisting of different rock types, clastics, shale, well thickly bedded, jointed and very hard limestone.
Morphology: Narrow gorge (locally) with steep walls, Khabour River is flowing southwards with deeply incised channel in the bedrock.
Structure: Almost parallel to the northwestern plunge of Mateen anticline. Originally the river course was straight, but many meanders are developed due to mass movements.
Genesis: Structurally controlled, very highly disturbed beds due to intense folding and over thrusting.

– **No.22: Khabour** (Fig.22)
Location: Northeast of Amadiyah city.
Formations: Many formations ranging from Paleozoic to Eocene, consisting of different rock types, clastics, shale, well thickly bedded, jointed and very hard limestone.
Morphology: Narrow gorge (locally) with steep walls, the Khabour River is flowing southwards with deeply incised channel in the bedrock.
Structure: Ora anticline with E – W trend and steeper southern limb. The Paleozoic, Triassic, Jurassic and Cretaceous rocks being thrusted over Tertiary rocks, causing highly disturbed and crushed rocks.
Genesis: Structurally controlled, very highly disturbed beds due to intense folding and over thrusting.

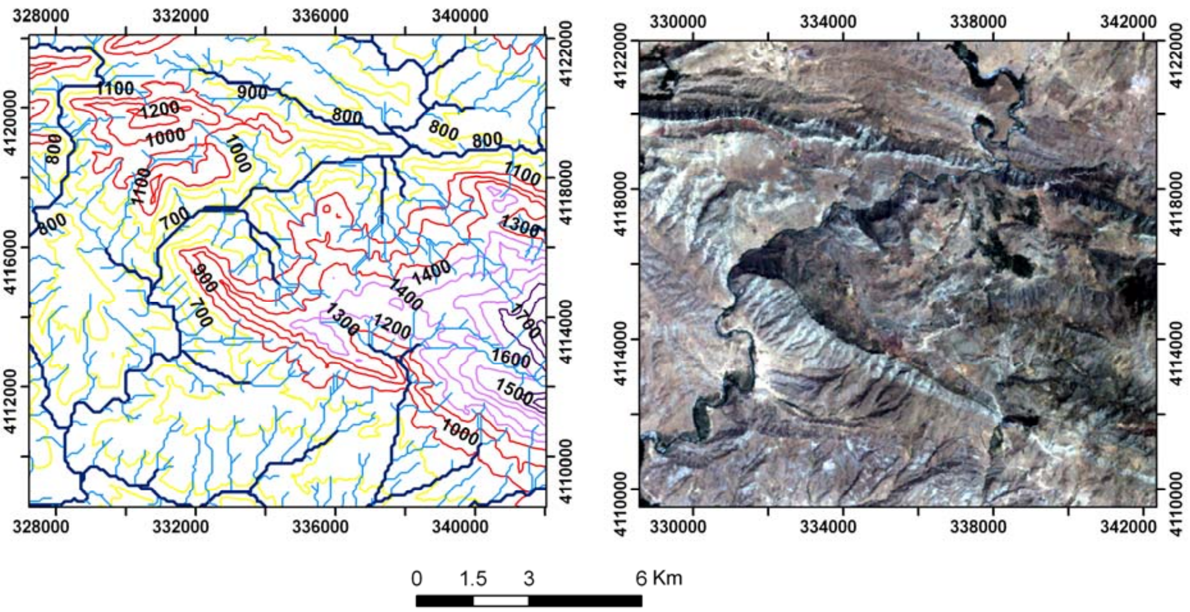


Fig.21: Topographic map and Landsat image of Mateen Gorge (No.21)

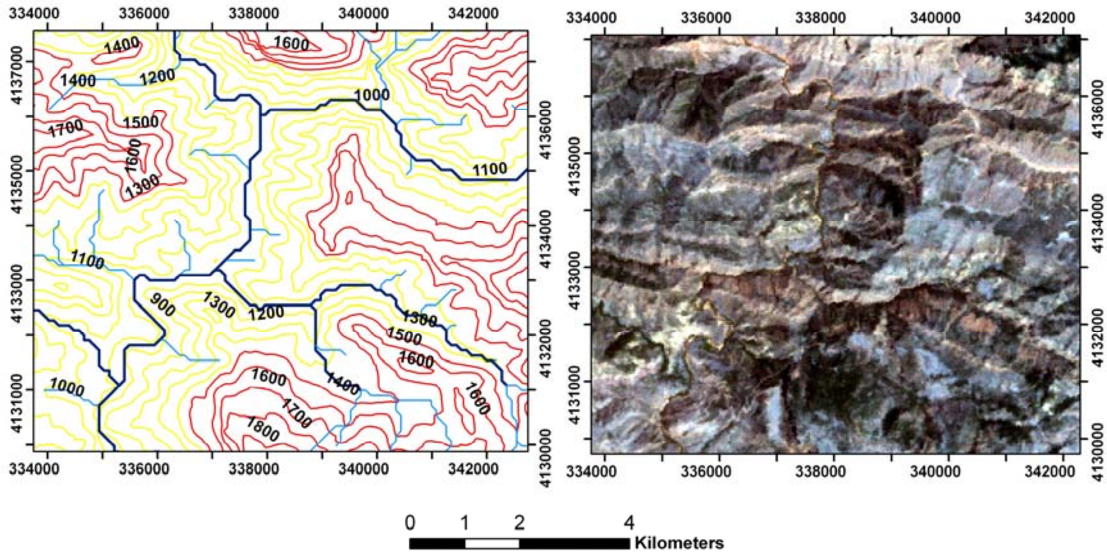


Fig.22: Topographic map and Landsat image of Khabour Gorge (No.22)

DISCUSSION

The studied gorges are located, tectonically, in the High Folded Zone and few of them within the Zagros Suture Zone (Al-Kadhimi *et al*., 1996 and Fouad, 2010). The exposed rocks in which the streams have carved their courses and evolved the studied gorges are mainly of Cretaceous – Eocene rocks, very locally Paleozoic, Triassic and Jurassic rocks are exposed too. Therefore, the rocks were continuously folded since Late Cretaceous to the Late Alpine Orogeny, although locally they are still active. The authors believe that the present landscape is formed during Quaternary; therefore, all studied gorges are evolved starting from early Pleistocene and are still under evolution, superimposed – posterior type of streams.

The concept of Mazzanti and Trevisan (1978) in Alvarez (1999) that invokes combination of antecedence and superposition for development of transversal gorges; when this concept is adopted, then the sedimentation break in Oligocene and Early Miocene, which prevailed over the whole study area, contradicts with the antecedence theory for the evolution of the studied gorges, because any previously existing stream wouldn't be able to exist during the Oligocene – Early Miocene break time.

The supposed mechanism for transverse drainage in folded areas has been classified by Oberlander (1965 and 1985) and Thornbury (1965), but the suggested mechanisms are: **1)** antecedence, **2)** superposition, **3)** headward erosion and **4)** modification of original consequent drainage by captures. Oberlander (1965 and 1985) however, studied gorges in Zagros Mountains Fold-thrust Belt and offered a new mechanism for generating the transverse gorges; he considered them a variant of superposition.

Majority of the studied transversal gorges are controlled structurally; this is another prove that the gorges are not antecedent. They flow through lineament, fault or near to plunge areas.

Solution is another factor that contributed in the evolution of gorges. Only one gorge (No.1, Sartak) was found to be evolved due to karstification (Fig.3A and B). In Zawita gorge (No.19), the solution partly contributed in evolution of the gorge.

In Pira Magroon Gorge (No.4, Fig.23), the alluvial fans contributed in evolution of the gorge, besides to the structural factor, being affected by its closeness to the plunge area. In Diyana Gorge (No.12, Fig.24), two large mass movements had blocked the stream, in the inlet; therefore the stream is now discontinuous through the anticline (Fig.24), it starts just after the original inlet.

Fig.23: Pira Magroon Gorge, note the alluvial fans in the north and northwestern parts (middle and lower right corner) that have dumped the original stream course

Fig.24: Diyana Gorge, note the two mass movements phenomena that have blocked the inlet of the gorge, in the northeastern part (left lower corner)

The studied gorges revealed that all the involved streams are not antecedent, but they are superimposed type, as majority of them have paths that are not the easiest in crossing the anticlines or mountains. Moreover, the streams are neither braided nor meandering. This could be confirmed from the following evidences:

- Majority of the streams have almost very straight courses (Figs.25 and 26), or segmented straight course (Gorges No.3, 6, 7, 9, 12, 13, 14, 15, 18, 19, 20, 21 and 22), although locally show small snake curves due to mass movements (Fig.25).
- The sinuosity of the streams, as measured from the inlet to the outlet portion ranges from 1.006 – 1.186, but the majority are far from the maximum recorded value (Table 1).
- In some streams, horse-shoe bend occur, but these are not related to the original stream morphology. Most of them are due to mass movements, usually flow or sliding, like in Diyana (No.12, Fig.24), Shamdinan (No.17, Fig.17) and Galley Dera Luke Gorges (No.18, Fig.25). In Zibar Gorge (No.16, Fig.16), the horse-shoe bend is attributed to horizontal bedding. In Pera Magroon Gorge (No.6, Fig.23) the small meandering is attributed to the presence of hard rocks alternated with soft rocks with steep dip. The hard rocks stand steeply in the course of the stream, forming barriers, so the stream swings after crossing each hard rocks unit.

Fig.25: Galley Dera Luke Gorge, note the straight line of the stream course
(The small meanders are due to mass movements)

Fig.26: Zawita Gorge, note the straight line of the stream course

It is worth to mention that Al-Daghastani and Salih (1992) and Al-Daghistani (2007) reveled that the Khazir River is an antecedent river; it is the down-stream continuation of Bakirman stream (Gorge No.15), after leaving the High Folded Zone and interring the Foothills Zone. When comparing the morphology of the river in its two parts, a clear difference could be seen, especially the meandering system (sinuosity index) and related features. The authors believe that the main reason for this difference is that the Khazir River is located within the Foothills Zone, which had not suffered from tectonic forces as the High Folded Zone; moreover, the folding in the latter zone started before the former zone. Therefore, it is more difficult to keep a river course, prior to intense folding, as it is the case in Khazir River. The intense meandering of the Khazir River indicates continuous growing of the anticline with continuous eroding of the rocks that are much softer, as compared to the hard limestones through which Bakirman stream entrenched its gorge.

CONCLUSIONS

The followings could be concluded from this study:

- A lot of streams in the north and northeastern parts of Iraq have carved their courses along very hard rocks, but not all of them had crossed a topographic barrier.
- Only 22 streams were found to have crossed an anticline or a mountain forming gorge along their courses, which locally are of canyon type.
- Almost all of the studied gorges are related to tectonic affect, only one was found to be of solution origin.
- Majority of the gorges have straight lines in their courses, although some of them exhibit small meanderings, due to mass movements, which was not existing, during evolution of the gorge.
- The sinuosity of 14 streams, among 22 studied streams, varies from 1.006 – 1.098, while the maximum recorded sinuosity is 1.186.
- The studied transversal gorges are of superimposed – posterior type.

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