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# Geology, Geomorphology, Tectonics and Geography of the Tigris Basin

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## Abstract

The geography, geomorphology, tectonics, stratigraphy and economic potentials of areas alongside the Tigris River and its tributaries are given with emphasis on Iraqi parts. The river runs mainly in the Mesopotamian Plain, whereas its tributaries run in different tectonic zones with different characters. Accordingly, the Quaternary sediments being dominated by alluvial plain sediments cover large parts of the river course, whereas the tributaries run through areas covered mainly by different rocks types of Neogene age. The main economic potential is the existing oil fields, sulphur and limestone deposits for cement industry.

**Keywords:** Tigris River, Quaternary sediments, Mesopotamian Plain, Economic potential.

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# 1. Introduction

The geology and topography along the paths of the Tigris River, and its tributaries are given with many satellite images and different maps for clarification purposes. However, the given details in Turkey, Syria and Iran are presented more briefly. This article is divided into three main parts, for the Tigris River and its tributaries.

## 1.1 Geography

The Tigris River inside Turkey flows mainly in mountainous areas, where it crosses many ridges; however, in small area it flows within flat and undulatory plains.

The Tigris River flows inside Iraqi territory from the extreme north-western part of Iraq (Figure 1) at Fish Khabour town in NW – SE trend. The landscape is gently rolling to flat plains with a wide flood plain of the river at an elevation of 338m above sea level (a.s.l.). There, the first tributary of the Tigris River merges with, it is called the Khabour River. The Tigris River continues flowing in the same landscape, locally following the trends of some mountains; such as Mashura; until it merges in Mosul Dam Reservoir at an elevation of about 258m (a.s.l.). The reservoir is surrounded by hilly terrain of Butmah East, and Ain Zala Mountains from the west and undulated plain in the east. After crossing Mosul Dam, the river continues flowing in an undulatory plains maintaining its general trend, with local bends and crossing some hilly terrains like Alan Mountain until reaching Mosul city at an elevation of 213m (a.s.l.). After crossing Mosul city, the river returns to its main NW – SE trend until near Al-Qayara town where the second tributary; called the Great Zab River merges in at an elevation of 195m (a.s.l.). There, the river changes its main trend to N – S, flowing in an undulatory landscape on the western side and almost flat plain to the east; until the third tributary; called Lesser Zab River merges in at an elevation of 163m (a.s.l.). There, the river flows following two main mountains called Khanooqah and Makhoul until it enters in the main gorge; called Al-Fatha at an elevation of 144m (a.s.l.) and with a trend of NE – SW, which is abnormal to its main trend. This is attributed to tectonic effect.

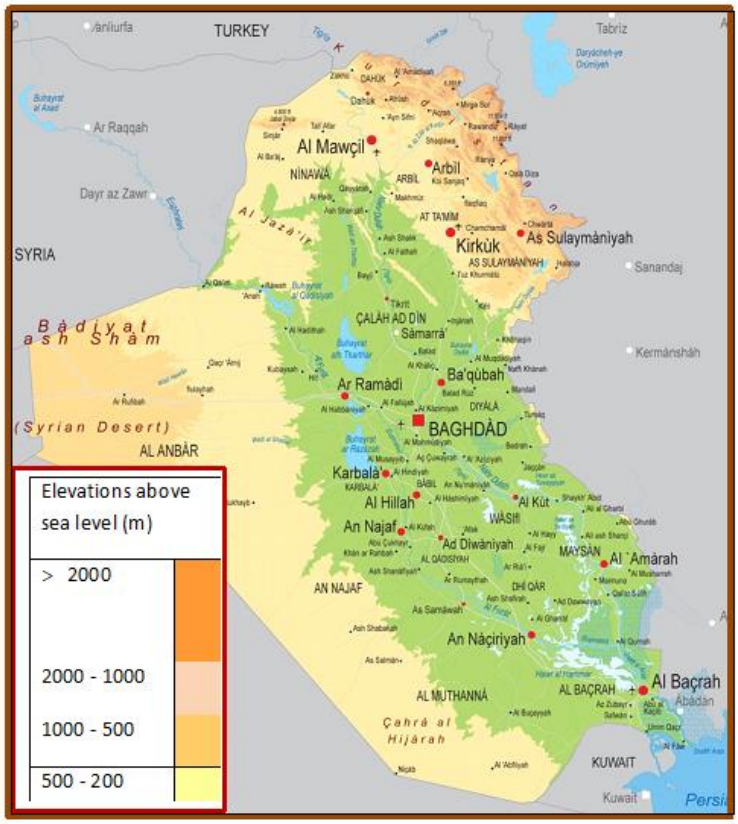


**Figure 1: Geographical map of Iraq showing the general relief and the main rivers and their tributaries and distributaries.**

After crossing Al-Fatha main gorge at an elevation of 140m (a.s.l.), the Tigris River flows in a gently rolling plain forming the Mesopotamia Plain [1] and particularly the giant alluvial fan called Al-Fatha Alluvial Fan, which was deposited by the Tigris River, its length is about 132km and the width is about 80km [2]. The main trend of the river is NW – SE until the river reaches Samarra town at an elevation of 68m (a.s.l.). In Samarra town, a barrage is constructed over the Tigris River to divert the excess water into Al-Tharthar Depression, a natural depression with the floor being 4m below the sea level [3].

At Samarra town, the river changes its main trend to NNW – SSE, near Al-Dhilooiyah town, the fourth tributary; called Adhaim River merges in at an elevation of 41m (a.s.l.). After Al-Dhilooiyah town by about 20km, the river changes its trend to almost N – S until it reaches the capital Baghdad at an elevation of about 42m (a.s.l.).

In Baghdad city, the Tigris River flows in many acute loops (Figure 2), indicating that the river started its mature stage. The river leaves Baghdad at an elevation of 35m (a.s.l.), there the fourth and the last tributary called the Diyala River merges in and the Tigris River continues its trend NW – SE until reaching Kut city at an elevation of 18m (a.s.l.). The river course between Baghdad and Kut cities is

characterized by many acute loops (Figure 3). Some of the loops are already abandoned forming ox bow lakes; others are still visible on satellite images and aerial photographs.

From Kut city downstream, the Tigris River starts exhibiting distributaries, the first one is Al-Gharraf River flow directly southwards and reaches almost the Euphrates River north of Nasiriyah city and the second is the Dujailah canal. The Tigris River continues flowing towards southeast until it reaches Amara city at an elevation of 8m (a.s.l.). There, the river has another two distributaries called Al-Khala'a and Al-Musharah which off take from the river upstream of Amara Barrage. Three more distributaries take off from the left and right banks of the river at locations downstream from Amara Barrage; the farthest of which is 33 kilometres south of Amara and upstream of Qalat Salih Barrage. These are Al-Majar Al-Kabir, Al-Majar Al-Saghir and Al-Mejaria canal.

After about 50km south of Amara city, the Tigris River starts merging in a marsh system and continues until Al-Qurans town where both Tigris and Euphrates rivers merge together forming Shat Al-Arab (Figure 1) at an elevation of 5m (a.s.l.). Shat Al-Arab is about 190km long flowing in NW – SE trend and merges in the Arabian Gulf.

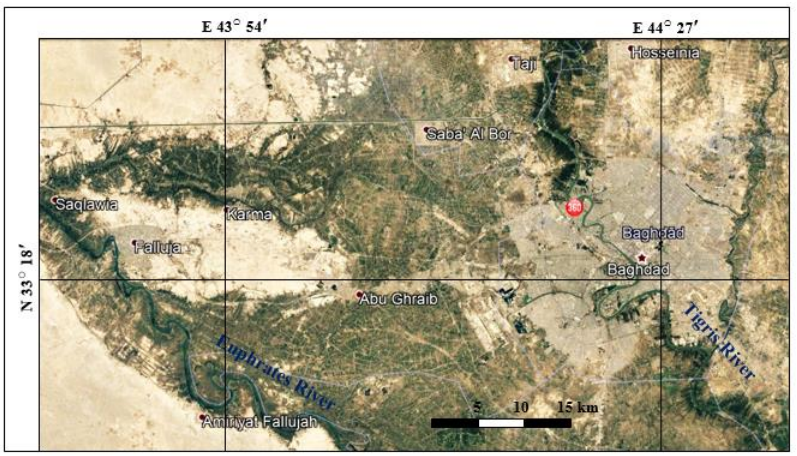


**Figure 2: Satellite image of the Tigris River crosses Baghdad, note the acute loops. Also note the loops in the Euphrates River.**

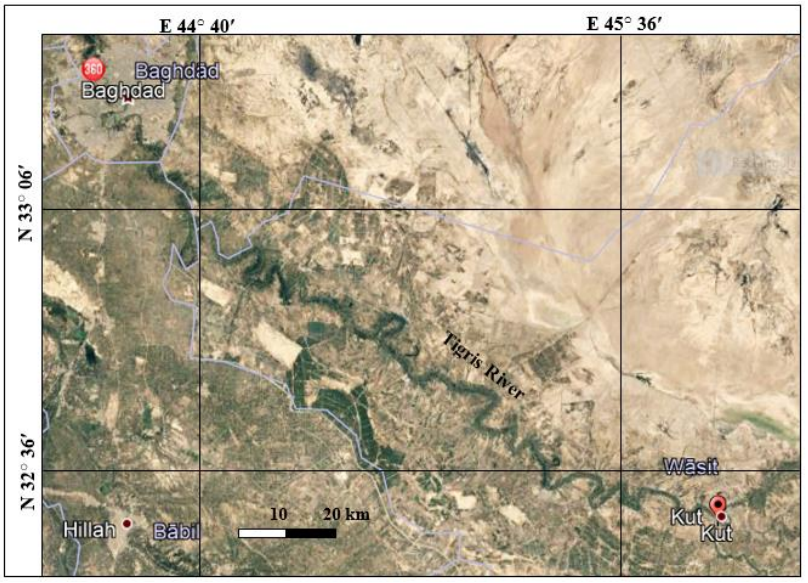


**Figure 3: Satellite image showing the acute loops along the course of the Tigris River, between Baghdad and Kut cities.**

The Tigris River flows in the Low Mountainous Province starting from its entrance into Iraqi territory from Turkey and continues in the same physiographic province until Al-Fatha Gorge. After crossing the gorge, it flows in the Mesopotamian Province and continues until it merges with the Euphrates River in Al-Qurna town; forming Shat Al-Arab, which flows in the Arabian Gulf [4].
The average gradient of the Tigris River from Iraqi Turkish borders until Al-Fatha gorge is 1.34%; whereas, from the gorge until the river merges with the Euphrates River at Al-Qurna is 0.22%. However, the average gradient of the river in the Iraqi territory is 0.25%, the height difference is 333m and the length is 1306km [5].

## 2. Geological Setting

The geological setting of the areas through which the Tigris River flows, is briefly reviewed using the best available data; mainly based on the geological maps of different scales and reports compiled by Iraq Geological Survey (GEOSURV) staff. However, in Turkey, Syria and Iran, published geological maps and satellite images are used to present; briefly the geological data. The geological setting includes three main aspects.

### 2.1 Geomorphology

The used data for describing the Geomorphological aspects inside Iraq are mainly acquired from the Geomorphological Map of Iraq [6] and the Geological Map of Iraq [4].

The main geomorphological units along the course of the Tigris River and its tributaries are the terraces, anticlinal ridges, fault ridges, flat irons and erosional pediments.

The Geomorphological units and forms of the course of the Tigris River are briefly described; hereinafter. The main Geomorphological fluvial units of the river are the terraces and flood plain. [7] mentioned that ten levels of terraces occur in the upper reaches of the Tigris River [8]. However, are not in accordance with the mentioned data and believe that maximum four level of terraces occurs along the course of the Tigris River. Another aspect is the flood plain of the river, usually, two levels are present. Among the other Geomorphological units which exist along the course of the Tigris River are the anticlinal ridges, as in Mashura, Ani Zala, Butma, Alan, Khanooqa and Makhoul anticlines. These are developed when hard and soft rock is alternated together; like in the rocks of the Fatha Formation. Flat irons and erosional sediments are also present along the course of the river.

After Al-Fatha gorge, the Tigris River flows in the Mesopotamian Plain. Two levels of terraces are developed along the course of the river; until Al-Niba'ai town, southwards, no more terraces are developed. The river course runs in a wide flood plain, then in the wide Mesopotamian Plain, which is characterized by depressions of different sizes, crevasse splays, sheet run off, marshes (both active and dry), and estuarine sabkhas (salty) sediments. In the extreme southern part of the Shat Al-Arab course, tidal flat and inland sabkha sediments occur [1].

### 2.2 Tectonics and Structural Geology

The main tectonic zones through which the Tigris River flows are described, besides the main structural features, such as anticlines, faults, subsurface anticlines (Figure 4). However, the tectonic units inside Turkey and Iran alongside the Tigris River with its tributaries are briefly mentioned. Moreover, the Neotectonic activities inside Iraq are also briefly described for the Tigris River; emphasizing on the Mesopotamian Plain, which is a very mobile subsiding trough.

The Tigris River inside Turkey flows mainly in the Anatolide – Turoside Block, and crosses Bitlis – Zagros Suture Zone. In its upper and western reaches, the river crosses the North and Eastern Anatolian faults, respectively. It also crosses many anticlines and other minor faults.

The Tigris River inside Iraq flows within the Low Folded Zone, Outer Platform of the Arabian Plate. The zone is part of Zagros Thrust – Fold Belt [9]. The river runs parallel to many anticlines and never cross one, it passes through the plunge areas of the anticlines, such as Mashiura, Butmah East, Alan, Khanouqa and Makhoul. This is a good indication that the incision rate of the river was less than the growth rate of the anticlines. All those anticlines are on the right side (west) of the Tigris River. However, south of Mosul city, the river crosses Mishraq anticline in its eastern part; not from the plunge area.

After Al-Fatha gorge, the Tigris River flows in the Mesopotamia Zone, Outer Platform of the Arabian Plate [9]. Although there is no any surface anticline along

the course of the river, there are many subsurface anticlines.

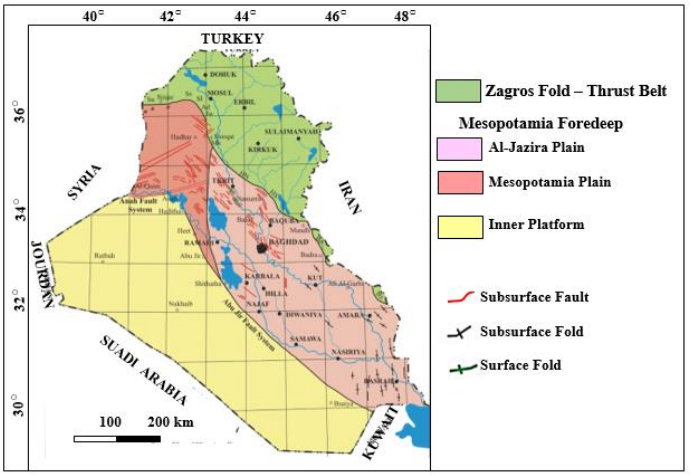


**Figure 4: Structural Map of Iraq, showing the Mesopotamia Foredeep. (After [10]).**

All those subsurface anticlines, which are along the course of the Tigris River, are dislocated from their original locations due to Neotectonic activities [10].
After Amara city and southwards (between latitude 31° and 32°) the Tigris River changes its trend to almost N – S; influenced by the regional trend of the subsurface anticlines (Figure 4).

## 2.3 Stratigraphy

The type, age and geological formations along which the course of the Tigris River flows inside Iraq are described here depending on [10,11]. The geological map of the river course is shown in Figure 5. However, the exposed rocks alongside the course of the river and its tributaries inside Turkey, Syria and Iran are very briefly mentioned too.
The Tigris River inside Turkey flows in its upper reaches within Mesozoic metamorphic and Tertiary volcano – sedimentary rocks. North of Diyar Bakir city, it flows between Plio – Quaternary basalts and Plio – Quaternary alluvial basin. From Diyar Bakir city and east wards for about 100km, the river flows between Eocene limestone and Plio - Quaternary alluvial basin. More southeast wards, the river flows between Eocene limestone, Mesozoic metamorphic and Tertiary volcano – sedimentary rocks. Before entering the Iraqi territory, the river flows in Plio – Quaternary alluvial basin.

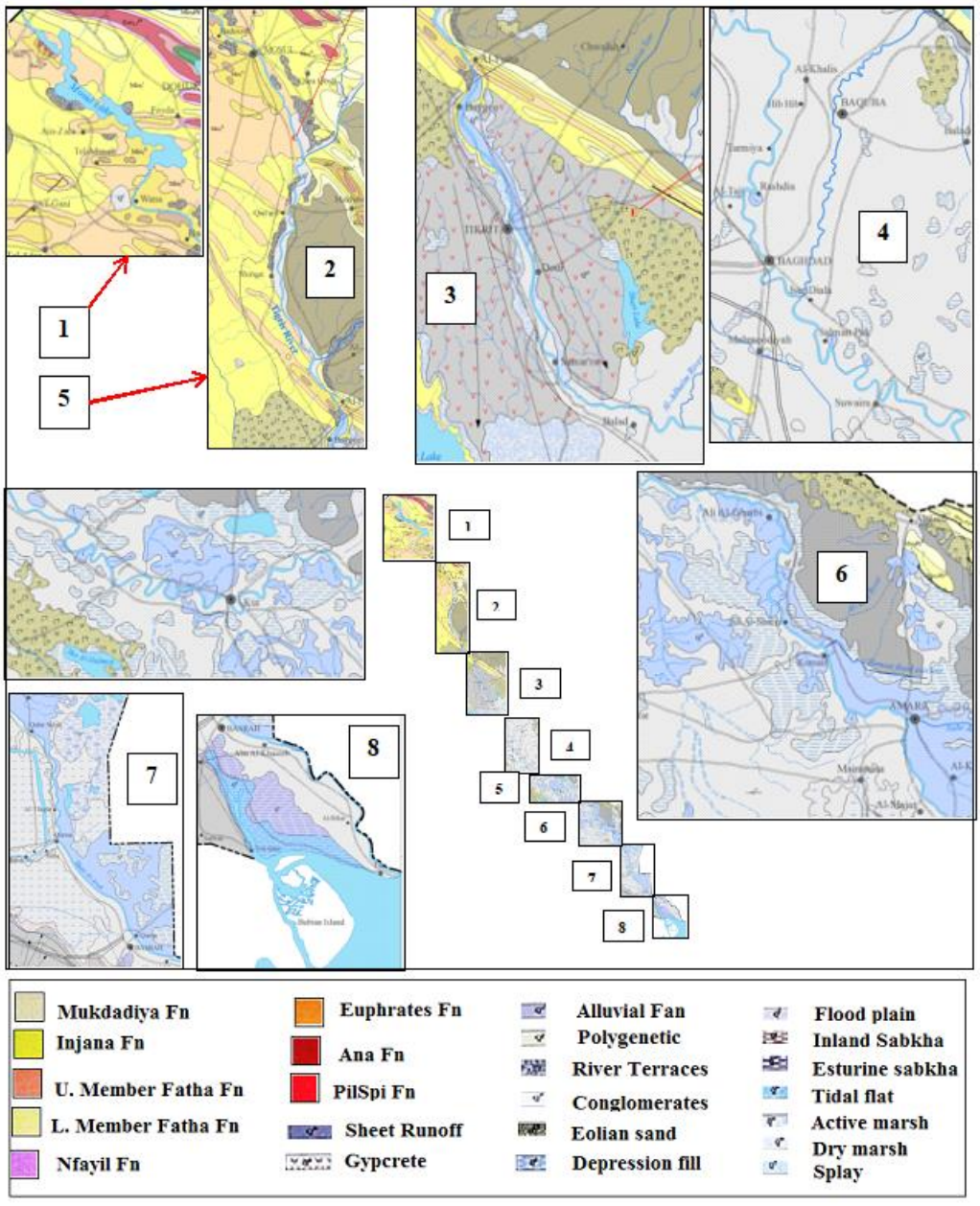


**Figure 5: Geological map of the Tigris River's course. The small portions show the geographic relation between the eight parts of the geological map (After [10]).**

The Tigris River when enters to the Iraqi territory from Turkey runs in greyish pebbly sandstones alternated with claystone of Upper Miocene – Pliocene in age (11.6 – 3.6Ma), which belong to the Mukdadiya (ex-Lower Bakhtiari) Formation (Figure 5).

After that, the Tigris River continues flowing alternatively in two main formations; the Injana (ex-Upper Fars) and Fatha (ex-Lower Fars). The former consists of reddish-brown sandstone and claystone, the age is Upper Miocene (11.6Ma), whereas the latter consists of cyclic deposits of green marl, reddish brown claystone, limestone and gypsum, the age is Middle Miocene (15.97Ma). In a very short distance of the Tigris River course, near Mashorah Mountain; before merging with the Mosul Reservoir, the river flows within the rocks of the Pila Spi Formation, it consists of well-bedded limestone, the age is Eocene (56.0Ma). The Tigris River continues flowing between the rocks of the Fatha and Injana formations until crossing Al-Fatha gorge. This is attributed to the presence of tens of anticlines and synclines in which the mentioned two formations are exposed.

The Tigris River, locally flows within the sediments of its flood plain, which are mainly silt, clay with rare sand. These sediments are Holocene in age (11.7Ka). Moreover, along the bank's terraces of Pleistocene age (2.58Ma) are present; they consist of pebbles of different shapes and sizes, mainly of silicates, carbonates and different types of igneous and metamorphic rocks, cemented by gypsiferous and sandy materials.

Passing Al-Fatha Gorge, the Tigris River flows in the sediments of Al-Fatha Alluvial Fan; deposited by the river. The sediments are almost the same as those of the river terraces, with the same age. However, the top is covered by gypsiferous soil (Gypcrete).

At Balad town, the Tigris River starts flowing in the sediments of the Mesopotamian Plain and continues until it merges with the Euphrates River near Al-Qurnah town. The sediments of the plain consist of silt and clay; however, locally some depressions occur. They may have some organic soil with silt and clay. After Qalat Salih town; south of Al-Amara city, the Tigris River flows in marshy areas (Figure 5). The sediments are Holocene in age (11.7Ka); highly contaminated with organic materials.

# 3. Mineral Resources

The Tigris River course from Mosul city until Al-Fatha gorge is considered as sulphur district [13]. Many sulphur deposits are developed in this district; due to anaerobic bacteria that acts with the gypsum rocks and the presence of water; consequently, native sulphur is deposited, as the following equation:

$$\underset{\text{(Anhydrite)}}{CaSO_4} + \underset{\text{(Dilute)}}{CH_4} + \underset{\text{(Anaerobic)}}{\text{Bacteria}} \xrightarrow[\text{conditions}]{\text{Reducing}} H_2S + S + CaCO_3 + H_2O + \text{Energy}$$

Among the main deposits in the Sulphur District along the Tigris River is Al-Mishraq Sulphur Mine.

**Al-Mishraq Sulphur Mine:** Al-Mishraq native sulphur deposit is about 40km southeast of Mosul and 315km north of Baghdad. This deposit is the largest known occurrence of stratiform bioepigenetic sulphur, containing at least 1000 million tons of sulphur [14]. It is the largest deposit in the word. Sulphur is mined from Al-Mishraq Mine using Frasch Process, which includes pumping of boiled water in drilled wells supplied by special pipes; accordingly, the boiled water dissolves the sulphur and flows out as liquid.

## 3.1 Oil

Although "oil" is not a mineral; but, it is mentioned as "Mineral resources". On the other hand, a "mineral resource" is anything that is economically valuable which are extracted from the earth. Many oil fields with different annual production and different oil types are located along the course of the Tigris River (Figure 6). Parts of the oil fields are on the surface; i.e. with surface expression, these are north of Al-Fatha Gorge; such as Mashura, Ain Zala, Butmah, Qayarah. Others are subsurface oil fields; i.e. no any expression occurs on the surface, such as Balad, Baghdad East, Abu Amoud, Ahdab, Amara, Kumait, Halfaya, Rifae, and Majnoon.

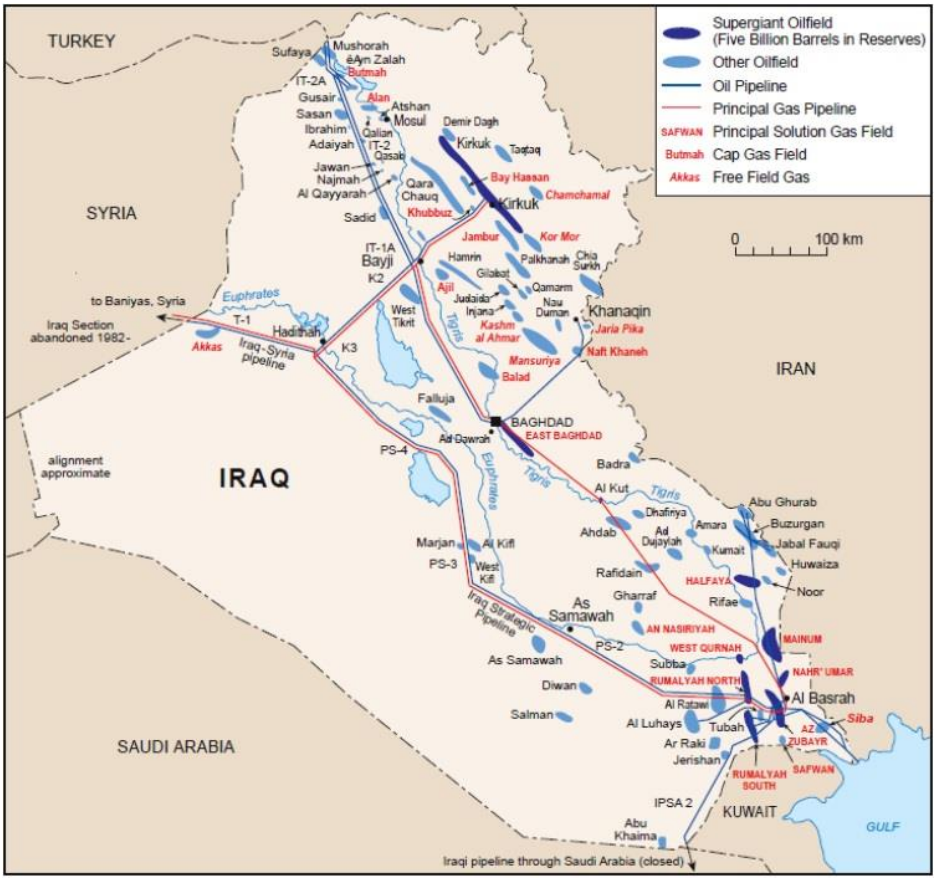


**Figure 6: Distribution of oil fields along the courses of the Tigris and Euphrates rivers**

In reviewing the oil fields map of Iraq (Figure 6), it is clear that tens of oil fields occur slightly far from the course of the Tigris River. Moreover, after merging of the Tigris and Euphrates rivers; forming Shat Al-Arab, two giant oil fields are located along its course, they are Nahr Umr and Zubair and Siba (Figure 6).

## 3.2 Limestone and Dolostone

Limestone and dolostone form main constituent of the Euphrates and Fatha formations, especially the former. The limestone is widely used in different purposes; such as cement production, building and as a decorative stone. The main uses are mentioned hereinafter; briefly.

a) Cement Production: The main use of the limestone is in cement production. Eleven cement factories exist along the Tigris River and its tributaries (Figure 7). The factories use limestone from different geological formations. The total production is over 15 million tons/year.

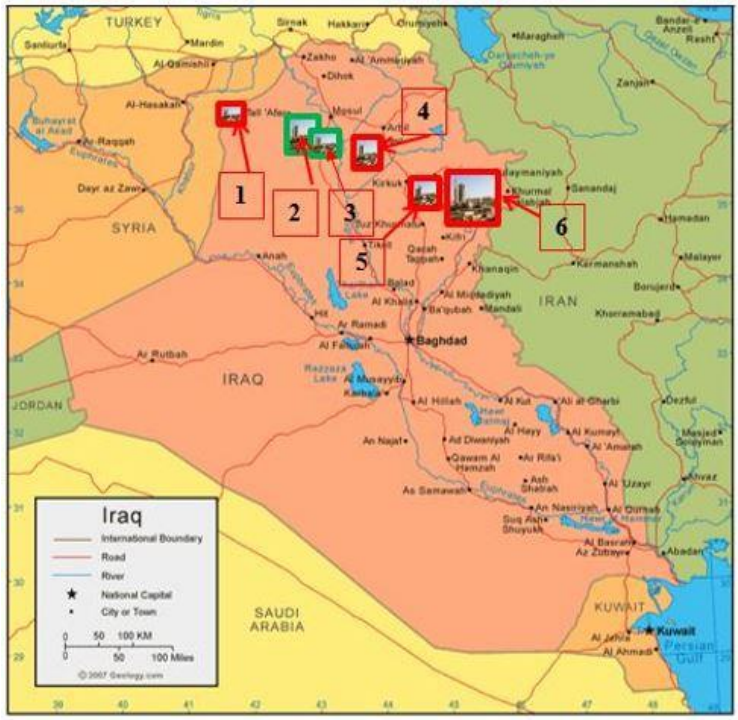


**Figure 7: Cement plants in Iraq. In green are those located along the Tigris River, in red are plants far from the river course.**
**Cement plants: 1= Sinjar, 2 = Badush 1 & 2, 3= Hamam Al-Aleel, 4= Kar, 5= Al-Ta'meem and 6= Five plants (Tasluja, Mass, Lafarge, Delta, and Gasin).**

b) Building Stone: Tens of local quarries occur along the Tigris River in different locations; from the entrance of the river inside the Iraqi territory until Al-Fatha Gorge. All quarries are small and private; the owners have quarrying licenses from the Ministry of the Industry and Minerals with cooperation of Mosul Governorate. The quarried limestone and dolostone are transferred to local small rock slabbing factories. There they are cut in different dimensions and supplied to many governorates for building and decorations purposes. Locally, the used rock is called "Hillan".
c) Aggregates: The flood plain sediments of the Tigris River are excellent source for aggregates; used in different construction purposes. Moreover, the terrace sediments are also good source for construction purposes. However, the latter should be washed to be free from $SO_3$. It is worth to mention that after construction of Mosul Dam; the amount of the flood plain sediments is drastically reduced due to non- replacement by floods.

The flood plain sediments are quarried along the course of the Tigris River from small quarries by local people. All quarries are small and private; the owners have quarrying licenses from the Ministry of the Industry and Minerals with cooperation of the involved governorates.

### 3.3 Gypsum

Gypsum is one of the main constituents of the Fatha Formation, which is exposed in wide areas alongside the Tigris River from the entrance of the river into the Iraqi territory until Al-Fatha Gorge (Figure 5). Gypsum is used in different purposes; such as cement production and building.

a) **Cement Production:** Gypsum is used in cement production as the last stage; after production of the clinker in different ratios depending on the used raw mix in cement production. Gypsum is quarried from the exposures of the Fatha Formation. The quarries are usually nearby to the cement plants along the Tigris River; however, in cement plants of Sulaimaniyah Governorate (Figure 7), the quarries are located near Derbandi Bazian vicinity about 20km SW of Sulaimaniyah city.
b) **Building and Decorative Stone:** Gypsum is used as a decorative stone after being quarried, slabbed in different sizes. It is also burnt and crushed into powder size in local furnaces called "Koora". The product is used as thin plaster in the inner walls. Locally, it is used in production of gypsum board, which is also used in decoration of the inner walls.

### 3.4 Claystone

Claystone is one of the main constituents of the Fatha and Injana formations and Mesopotamian Plain sediments [1, 4, 11]. The main industrial use is in cement and brick productions.

a) **Cement Production:** Clay is mixed with the limestone as one of the main raw materials used in cement production. The percentage of the used claystone may reach 45% of the raw mix for cement production [15]. The claystone is quarried from the Fatha Formation and/ or Injana Formation for cement production.
b) **Brick Production:** Clay is the main constituent of the brick production. Enormous amounts of clay from the Mesopotamian Plain sediments are quarried for brick production. The main complex of brick plants is located SE of Baghdad; it is called Al-Nahrawan Complex. Downwards from Al-Nahrawan, many other brick plants are located along the course of the Tigris River; the clay is quarried from the Mesopotamian Plain. All the plants are using crude oil in their furnaces and are considered as a pollution source [16].

## 4. Sea Level Changes and course of the Tigris River

There are some discrepancies in the assumptions between researchers as the shore line of the gulf and the course of the Euphrates River is concerned, even in the works of the same authors. For example, [17] assumes that the shoreline was near Hit; along the Euphrates River and at Samarra; along the Tigris River during 8000 – 6000B.C., which are about 600km northwest and north of the present shoreline. Moreover, he assumes that the Tigris and Euphrates rivers were flowing directly into the gulf without being merged together during 325B.C. This means that the shoreline was more northwards than the present shoreline; otherwise, the two rivers couldn't flow separately into the Gulf. But, he didn't mention how far the shoreline was. It is worth to mention that before 8000 years the Ubaid settlements were close to the location of Ur which was very near from the shoreline (Carter and Philip, 2010).

The time of reaching the present shoreline location is again quite different from the mentioned assumptions by different authors. For example, [18] claimed the present shoreline location was 6000B.C. Whereas, during 6000 B.C. the shoreline was 360 km north of the present location according to [19], and between Nasiriya and Amara [20, 21, 22]. Moreover, Lambeck (1996) claimed that before reaching to the present shoreline, the whole Gulf was dry and the Tigris and Euphrates River were flowing into the Gulf directly. This assumption was confirmed only by Tanoli (2013). However, this agrees with the theory that the early Sumerians had crossed the Gulf which was dry at that time coming from a place in Baluchistan and they settled in Bahrain (Dilmun) before moving to Mesopotamia [23]. Later on, the sea started forward movement which is exactly the opposite of all other reconstructed scenarios of different authors.

[24] mentioned that the shoreline of the Gulf was 1440km southeast of Baghdad before 10500B.C., and it was 250km southeast of Baghdad along the Tigris River (near Amara city) and 60km southwest of Baghdad along the Euphrates River (near Hilla city). Although they use palynological evidences like their colleagues [21] but they reached to very different results as the shoreline of the Gulf is concerned.

Another abnormal assumption is presented by [21]. They constructed the shoreline during different time spans depending on the present ostracods and palynology. The abnormal presentation is that they extended the shoreline only along the Tigris River; not along the Euphrates River. This means the course of the Euphrates River was higher than that of the Tigris River, therefore, the gulf extended only towards the Tigris River. Moreover, this means that the ancient city of Ur was never been located along a shoreline, which is not in accordance with the majority of carried out archeological and geological studies.

Another significant issue which needs discussion is the changing of the river courses during the Pleistocene and Holocene. There is a big difference between the considered reasons between the archeological and geological studies. The archeological studied assume that all the happened changes in the river courses are related to major floods and/ or constructed irrigation canals (Ellison, 1978).

Whereas, geological studies assume that the main reason for changing of the river courses is the Neotectonic activities which are mainly related to the growth of the subsurface anticlines [10, 25, 26, 27]. The influence of major floods and the mechanism of river hydraulics, especially during large floods are also considered in majority of geological studies. The presence of main irrigation canals which were constructed during early civilizations are also considered too in geological studies as main factor which had contributed in shifting of the river courses [28, 29]. The humid conditions associated with very heavy rain showers during wet stages of the Pleistocene and even early Holocene also had contributed in changing the river courses. This is attributed to the erosional forces and the weight of the carried sediments in entrenching the courses of the rivers into more straight courses, especially when acute meanders had existed in the river courses, where the irrigation canals were constructed perpendicularly on large meanders. This is called rapidly varied flow [30].

# 5. Tributaries of the Tigris River

The tributaries of the Tigris River are described briefly; including the main geological aspects along their courses. In Turkey, the tributaries are already mentioned within the main course of both rivers.

In Iraq, the Tigris River has five main tributaries, the first two originate from Turkey, the third one is originating inside Iraq whereas, the remaining two are originating from Iran. They are described hereinafter briefly.

## 5.1 Khabour River

The Khabour River flows inside Turkey in vey rugged mountainous area, where Mesozoic metamorphic rocks and Tertiary sedimentary – volcanic rocks are exposed.

Inside Iraq, the Khabour River runs in a very rugged mountainous area; in its upper reaches, and in undulatory plains in its lower reaches. The elevation of the river bed in the entrance point inside Iraq is 933m (a.s.l.), and 676m (a.s.l.) when the river leaves the mountainous areas and 392m (a.s.l.), when it merges with the Tigris River. Accordingly, the gradient of the river in the mountainous areas is 7.47% and 3.97% within the undulatory plains. The river; in its upper reaches flows in the oldest exposed rocks in Iraq called the Khabour Quartzite of Ordovician age (485.4Ma). It continues flowing southwards crossing rocks of Different ages (Ordovician – Eocene); mainly of carbonate rocks; within the Imbricate and High Folded Zones. After crossing the ridge of the main thrust fault, the river flows west wards in rocks of Neogene age; mainly of clastics within the Low Folded Zone.

## 5.2 Greater Zab River

The Greater Zab River flows inside Turkey in Mesozoic metamorphic rocks and Tertiary sedimentary – volcanic rocks forming very rugged mountainous area.

Inside Iraq, the Greater Zab River flows southwards in rugged mountainous areas

crossing many mountains in form of gorges and/ or canyon like valleys; until it flows out of Bekhme gorge; after that the river flows in undulatory plains; there the river flows in a wide flood plain with tens of meanders indicating the maturity of the river. The elevation of the river bed in the entrance point inside Iraq is 785m (a.s.l.), and 399m (a.s.l.) where the river leaves the mountainous areas at Bekhme gorge, and 185m (a.s.l.), where it merges with the Tigris River. Accordingly, the gradient of the river in the mountainous areas is 3.6% and 1.77% within the undulatory plains,

The course of the Greater Zab river flows in areas built up by rocks of different ages, Triassic – Eocene; in the mountainous areas. Whereas, in the undulatory plains, the river flows mainly in clastic rocks of Miocene – Pliocene age with different types of Quaternary sediments; among them are the river terraces and flood plain sediments [4, 11]. Tectonically, the mountainous areas belong to the Imbricate and High Folded Zones. After crossing Bekhme gorge, the river flows in NE – SW trend; crossing many anticlines in the Low Folded Zone [9]. The straight course of the river is controlled tectonically [31], however, among the straight course of the river, many meanders are developed. The meandering is attributed to structural forms, mass movements and growth of alluvial fans [32].

The Greater Zab River has many tributaries, among them are: Rawandouz River, Shamdinan River, Haji Beg River and Amadia River, they all have the same characters of the upper reaches of the Greta Zab River. The basin is tectonically active [26]. In the lower reaches of the river, a main tributary called Khazir – Goml River merges with the Greater Zab River, before it meets the Tigris River by about 30km.

### 5.3 Lesser Zab River

The Lesser Zab River flows inside Iran sedimentary rocks of Tertiary age forming rugged mountainous area; crossing many anticlines within the Zagros Thrust – Fold Belt.

Inside Iraq, the Lesser Zab River flows west wards in rugged mountainous areas crossing many mountains in form of gorges and/or canyon like valleys; until it flows out of the mountainous area south of Dukan; however, between Qalat Diza and Ranya towns, the river flows in very large alluvial fans, which consists mainly of gravels of different sized capped by thick reddish-brown soils. All those areas are cultivated as agricultural lands due to very fertile soil. After crossing Dukan Dam, the river flows in undulatory plains crossing many anticlines; there the river flows in a wide flood plain with tens of meanders indicating the maturity of the river. The elevation of the river bed in the entrance point inside Iraq is 640m (a.s.l.), and 500m (a.s.l.) where the river enters Dukan Reservoir, 430m (a.s.l.), where it leaves the mountainous areas south of Dukan Dam, and 126m (a.s.l.), where it merges with the Tigris River. Accordingly, the gradient of the river before entering Dukan Reservoir is 3.78% and 1.64% within the undulatory plains.

The course of the Lesser Zab river flows in areas built up by igneous and

metamorphic rocks of Cretaceous age; along the Iraqi – Iranian borders and sedimentary rocks of Cretaceous age too. Whereas, in the undulatory plains, the river flows mainly in clastic rocks of Miocene – Pliocene age with different types of Quaternary sediments; among them are the river terraces and flood plain sediments [4, 11]. In the undulatory plains, the course of the river is almost in a straight-line trending NE – SW. The straight course of the river is controlled tectonically [31]; however, among the straight course of the river, many meanders are developed. The meandering is attributed to structural forms, mass movements and growth of alluvial fans [32]. It is worth mentioning that the river has no tributary; however, some large valleys and/ or streams merge with; such as wadi Al-Ahmar and Taq stream.

Tectonically, the mountainous areas belong to the Zagros Suture, Imbricate and High Folded Zones. After crossing Bekhme gorge, the river flows in NE – SW trend; crossing many anticlines in the Low Folded Zone [9].

### 5.4 Al-Adhaim River

Al-Udhaim River is the only tributary of the Tigris River that originates inside Iraq. The river includes three main tributaries called Khassa Chai, Tawooq Chai and Tuz Chai (all are local names indicating the term river and/ or stream), all these are intermittent streams; but during the heavy rainy showers, high floods are formed in three of them supplying Al-Adhaim River by considerable quantities of water.

The Khassa Chai tributary is 143km passing through Kirkuk City. It starts west of Cham Chamal town at elevation of 722m (a.s.l.), at Kirkuk city the elevation of the river bed is 358m (a.s.l.), and at the merge point with Al-Adhaim Reservoir is 163m (a.s.l.). Accordingly, the gradient of the river is 3.9%. The exposed rocks in the basin of the river are mainly of clastics with very rare limestone and gypsum of the Fatha Formation. The age of the exposed rocks ranges from Middle Miocene up to Pliocene; with different types of Quaternary sediments; such as river terraces, flood plain and valley fill sediments [4, 11]. The latter is very well developed and considered as excellent source for aggregates. Tectonically, the whole river flows within the Low Folded Zone. All existing anticlines trend in NW – SE direction and the northeastern limb is thrusted over the north southern limb, the main one is Kirkuk Structure [9].

The Tawooq Chai tributary is 178km passing through Daqooq town. It starts north of Bazian gorge at elevation of 955m (a.s.l.), at Basara gorge; where it crosses Qara Dagh Mountain the elevation of the river bed is 677m (a.s.l.), at Daqooq town the elevation of the river bed is 258m (a.s.l.), and at the merge point with Al-Adhaim Reservoir is 136m (a.s.l.). Accordingly, the gradient of the river until Daqooq town is 5.16% and downward until it merges with Al-Adhaim Reservoir where it is 2.83. The exposed rocks in the upper reaches of the river are clastics of the Gercus Formation (Eocene age) and limestone of the Pila Spi Formation (Upper Eocene age). After Basara gorge, the exposed rocks are mainly clastics; with very rare limestone and gypsum of the Fatha Formation. The age of the exposed rocks ranges

from Middle Miocene up to Pliocene; with different types of Quaternary sediments; such as river terraces, flood plain and valley fill sediments [4, 11].
The latter is very well developed and considered as excellent source for aggregates. Tectonically, the upper reaches of the river until Basara gorge is within the High Folded Zone. Southwards of Basara gorge, the river flows within the Low Folded Zone. All existing anticlines trend in NW – SE direction and the northeastern limb is thrusted over the north southern limb, the main one is Kirkuk Structure, Jambour and Pulkana anticlines [9].
The Tuz Chai tributary is 138km passing through Tuz Khurnatu City. It starts from the southern limb of Qara Dagh Mountain at elevation of 1334m (a.s.l.), at Tuz Khurmatu the elevation of the river bed is 248m (a.s.l.), and at the merge point with Al-Adhaim Reservoir is 116m (a.s.l.). Accordingly, the gradient of the river until Tuz Khurmatu town is 8.37% and until the merge point with Al-Adhaim Reservoir is 3.59%.
The exposed rocks in the basin of the river are mainly of clastics with very rare limestone and gypsum of the Fatha Formation. The age of the exposed rocks ranges from Middle Miocene up to Pliocene; with different types of Quaternary sediments; such as river terraces, flood plain and valley fill sediments [4, 11]. The latter is very well developed and considered as excellent source for aggregates. Tectonically, the whole river flows within the Low Folded Zone. All existing anticlines trend in NW – SE direction and the northeastern limb is thrusted over the north southern limb, the main one is Pulkhana anticline [9].
Al-Adhaim River starts from the junction point of its three main tributaries. However, after construction of Al-Adhaim Dam, the junction point is inundated by the reservoir's water. After the dam site, at an elevation of 114m (a.s.l.), the river flows out of Himreen North Mountain in a flat area, which is part of the Mesopotamia Plain and continues southwards until it merges with the Tigris River at an elevation of 43m (a.s.l.) near Al-Dhlooiyah town. The gradient of the river from the crossing point of Himreen North Mountain until merging with the Tigris River is 0.98%. The river course is within the sediments of the Mesopotamia Plain, which consists mainly of silt and clay with some aeolian sand. Tectonically, Al-Adhaim River crosses Himreen North anticline, which is considered as the boundary between the Low Folded Zone and the Mesopotamia Plain. Himreen North anticline is NW – SE trending anticline with the northeastern limb being thrusted over the northwestern limb [9].
It is worth mentioning the Al-Adhaim River and its three main tributaries are flowing almost in straight courses, usually NE – SW trending. The straight course of the river is controlled tectonically [31]; however, among the straight course of the river, many meanders are developed. The meandering is attributed to structural forms, mass movements and growth of alluvial fans [32].

### 5.5 Diyala (Sirwan) River

This is the last tributary of the Tigris River origination from Iran. In the upper reaches of the river it is called as Sirwan River, downstream; south of Derbandikhan Dam it is called as Diyala River.

Inside Iran, the Sirwan River flows in mountainous area built up by carbonates of Cretaceous age within Zagros Thrust and Zagros Fold Zones.

Inside Iraq, the Diyala Zab River flows south wards in rugged mountainous areas crossing many mountains in form of gorges and/ or canyon like valleys; until it flows out of the mountainous area south of Derbendikhan town; after that the river flows in undulatory plains crossing many anticlines; there the river flows in a wide flood plain with tens of meanders indicating the maturity of the river. The elevation of the river bed in the entrance point inside Iraq is 569 m (a.s.l.), and 488m (a.s.l.) where the river enters Derbendikhan Reservoir, 431m (a.s.l.), after Derbendikhan Dam, 96m (a.s.l.) where it enters into Himreen Reservoir, 89m (a.s.l.) after Himreen Dam, 49m (a.s.l.) at Ba'quba City, and 36m (a.s.l.), where it merges with the Tigris River. Accordingly, the gradient of the river before entering Derbendikhan Reservoir is 6.1% and 0.2% within the undulatory plains.

The course of the Diyala (Sirwan) River flows in its upper reaches in areas built up by carbonates of Cretaceous age; along the Iraqi – Iranian borders and until it enters in Derbendikhan Reservoir, which is surrounded by rocks from Cretaceous up to Pliocene ages of different rock types. Whereas, in the undulatory plains, the river flows mainly in clastic rocks of Miocene – Pliocene age with different types of Quaternary sediments; among them are the river terraces and flood plain sediments [4, 11]. Tectonically, the upper reaches of the river course belong to the Imbricate Zone, near Halabja town, the river flows within the High Folded Zone. After crossing Derbendikhan Dam, the river flows in N – S trend; crossing many anticlines in the Low Folded Zone, until Himreen North anticline, after that the river flows in the Mesopotamia Zone [9]. The straight course of the river is controlled tectonically [31]; however, among the straight course of the river, many meanders are developed. The meandering is attributed to structural forms, mass movements and growth of alluvial fans [32].

It is worth mentioning that the Diyala (Sirwan) River has many tributaries, among them are the Tanjeru and Al-Wind rivers, which are the main two tributaries. However, others are Dewana stream, south of Derbendikhan town, Kifri Chai and Nareen chai. Moreover, the Diyala River after crossing Himreen North Mountain and more exactly 8km downstream of Himreen Dam at the Diyala weir structure, feeds two large main canals to irrigate the Diyala Irrigation project system and the Khalis irrigation project system; which are two of the largest irrigation systems in Iraq. It is believed that some of them are historical artificial irrigation channels.

# 6. Mineral Resources Along the Tributaries of Tigris River

The existing mineral resources along the tributaries of the Tigris River are briefly described hereinafter.

## 6.1 Oil

Many oil fields with different annual production and different oil types are located along the courses of the tributaries of the Tigris River (Figure 6). The main and largest one is Kirkuk Structure with its three domes; Baba and Avana, the Lesser Zab River and Khassa chai River cross the structure. Other oil fields, which are located along the course of the Lesser Zab River are; Bai Hassan, Qara Chough and Chamchamal. Along Al-Adhaim River and its tributaries, many oil fields are located, although some of them are not productive hitherto. Among them are: Cahmchamal, Jambour, Pulkana, Khor Mor, Qumar, Gillabat and Injana. Along the course of the Greater Zab River and its tributaries, the following oil fields are located: Damir Dagh, Barda Rash and Quwair. Along the course of the Diyala (Sirwan) River and its tributaries, the following oil fields are located: Naft Khana, Chia Surkh, Nao Duman, Mansouriya. The last one is most probably a gas field rather than to be oil field.

## 6.2 Limestone and Dolostone

Excellent types of limestone suitable for cement industry with enormous reserves are located along the tributaries of the Tigris River and their tributaries. Among them are Sinjar, Ana and Euphrates formations. The Sinjar Formation is exposed south of Sulaimaniya City and is exposed along the Tawooq chai; the tributary of Al-Adhaim River, and along the eastern course of the Lesser Zab River [4]. The Ana and Euphrates formations are exposed in Qara Chough anticline, which is crossed by the Lesser Zab River. Moreover, limestone and dolostone are used in constructions; as crushed aggregates and as decorative stones.

## 6.3 Gypsum

Gypsum is one of the main constituent of the Fatha Formation. It is exposed along the courses of the Greater Zab, Lesser Zab, Al-Adhaim and Diyala (Sirwan) rivers. The main use of the gypsum is in cement production and for plaster production; however, locally it is used as building stone. It is worth mentioning that near Kifri town the maximum exposed thickness of gypsum beds occurs; with thickness of 40m [33].

## 6.4 Claystone

Claystone is one of the main constituents in Bai Hassan, Mukdadiya and Injana formations, beside the Fatha Formation. All of them are exposed along the courses of the Greater Zab, Lesser Zab, Al-Adhaim and Diyala (Sirwan) rivers. The main use of the claystone is in cement production and brick construction, although it is used in very limited amounts.

### 6.5 Bentonite

Bentonite is exposed within the Mukdadiya Formation along Pulkhana and Himreen North anticlines. Locally, it is quarried and very rarely mined in very primitive methods; such as in Qara Tappa town; along Nareen chai (tributary of Diyala River) and near Na Salih village, west of Kifri town [33].

### 6.6 Bitumen

Different types of bitumen and/ or heavy oil are exposed within the Fatha, Injana and Mukdadiya formations, which are exposed along the course of the Diyala River and its tributaries. Locally, bitumen is mined in very primitive methods; such as near Na Salih village, west of Kifri town, it is used as fuel for daily consumptions, especially during winter for heating of houses [33].

### 6.7 Gravel and Sand

Gravel and sand occur in enormous amounts along the courses of the tributaries of the Tigris River and their tributaries, beside the main valleys, which drain inside those tributaries. The gravel and sand are mainly present as valley-fill sediments, in form of pebbles (for the gravels) of different sizes, forms, shapes and lithology. They are quarried in enormous amounts and used for different constructional purposes.

## 7. Conclusions

Since this article is a review article; therefore, the main conclusions are related to the changes in the river course. The authors believe that the main reason for that is the growing up of the subsurface anticlines. However, the role of the large floods and construction of historical irrigation cannels cannot be ignored. Moreover, the Tigris River basin including the tributaries has a very significant economic potential, especially oil and Sulphur.

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