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GIS-BASED URBAN GEOMORPHOLOGICAL ANALYSIS OF THE SULAIMANIA CITY, KURDISTAN REGION, NE IRAQ

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ABSTRACT

Sulaimania City, is located in, the northeastern part of Kurdistan Region of Iraq within the series of Zagros Mountains. It is situated within the High Folded and Imbricate zones, in an intermontane depression surrounded from the east by the Azmar Mountain and from the north by the Pira Migrun Mountain, and from the southwest by the Qaradagh Mountain range. This situation makes the Sulaimania City an excellent model for a big mountainous city in Iraq with geologic and geomorphologic environment greatly influencing the city growth modes. Digital Elevation Model (DEM), satellite images, different kinds of maps, in addition to field observations of the city and surrounding areas are used to investigate the impact of the geomorphologic factors on the city expansion pattern. A set of digital maps are constructed to show the interaction between the city urban growth pattern with: **i)** topography and geologic features, **ii)** geomorphic units and overall landscape style, **iii)** slope type and hazards, **iv)** lineaments density, **v)** flood hazards, and **(vi)** drainage system. All the maps are displayed in a GIS environment and some of them are made for different periods to show the city growth. Three basic stages of city growth were inferred and mapped to show the relation between city expansion and physical environment components and hazards. The results of this work show that the circular growth patterns of the Sulaimania City at early stages (1925 – 1973) prefer growth over areas covered by the fluvio-denudational landscape. Progressive stages of expansion move over flood-plains, alluvial fans margins as well as rolling hills areas. Growth at early stages avoids sloping or elevated areas with high drainage intensity and lineaments density, as well as, areas with high flooding risk. Recent explosive expansion pattern (after 1973) shows more irregular shapes with effective expansion over slopping areas, which are covered by Quaternary depression fills or soft sediments of the older geologic units. These areas are located along the northwest, northeast and southeastern directions over mountain's lower slopes, badlands, and rugged rocky terrains of the city-suburban areas are following major roads entering the city.

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التحليل الجيومورفولوجي الحضري لمدينة السليمانيه في اقليم كردستان، شمال شرق العراق باعتماد نظم المعلومات الجغرافية

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المستخلص

تقع مدينة السليمانية ضمن سلسلة جبال زاكروس في شمال شرق اقليم كردستان العراق وتمثل نموذج للمدن الجبليه المتوسطة الحجم. تتموضع المدينة فوق ارض شبه مستوية ومحاطة بمرتفعات جبلية اهمها من الشرق تراكيب ازمر وكويزه ومن الشمال بيره مكرون، ومن الجنوب الغربي سلسلة جبال قره داغ وتنحدر ارض المدينه نحو الجنوب بانفتاحها على السهل الفيضي لنهر تانجيرو الذي يصب في بحيرة دربندخان الى الجنوب الغربي من المدينة. لتقييم تاثير الخصائص الجيولوجية والجيومورفولوجية والمخاطر البيئية للمنطقة المحيطة بالمدينة على نمط واتجاهات وتطور التوسع العمراني لها استخدمت الدراسة تحليل وتفسير للصور الجوية الملونة والرقمية، بيانات الإرتفاعات الرقمية، وبيانات الأقمار الصناعية والخرائط الطبوغرافية المختلفة اضافة الى الدراسة الحقلية. تم تحليل المعطيات المدروسة والمستخدمة بطرق التفسير البصري والتفسير الرقمي وطبقت في بيئة نظم المعلومات الجغرافية. انتجت الدراسة مجموعة من الخرائط الرقمية التي توضح هذه العلاقة وتساهم في تفسيرها ومنها خرائط الخطوط التركيبية، خريطة الاشكال الارضية، خرائط المجاري النهرية، خريطة الانحدارات، وخريطة مخاطر الفيضانات وتوضح كل منها علاقة التوسع العمراني للمدينة بمراحلها الثلاثة الرئيسية بتلك المظاهر. بينت نتائج هذه الدراسة ان المدينة حافظت خلال مرحلة النمو الاولية (1925 – 1973) على الشكل الدائري التقليدي وضمن نطاق ضيق من اراضي التسوية النهرية على الجزء الاسفل من سفح جبل ازمر الغربي متجنبة منطقة المنحدرات الحاده ومنطقة الخطوط التكتونية الكثيفه لكثافة الشبكة النهرية فيها. ومع مرور الوقت اتجه النمو نحو الغرب والجنوب باتجاه السهل الفيضي لنهر التانجيرو لاستواء الارض وغطائها الرسوبي الهش. التوسع العمراني الانفجاري الحديث للمرحله الثانيه (1973 – 1990) والثالثة (ما بعد 1990) ولغرض سد الحاجة لاراضي الاستعمالات الحضرية المختلفة اتجه العمران اضافة الى الاتجاه الغربي شرقا وشمالا رغم المخاطر الطبيعية مثل انهيارات السفوح والفيضانات الموسمية والاراضي الوعرة وقساوة صخورها الجيرية.

INTRODUCTION

Urban geology or geomorphology is defined as the application of geological and geomorphological data to evaluate the planning and management of metropolitan areas. It is the surface component of the urban geology (Bathrellos, 2007). Urban geomorphology is a rapidly growing branch of applied geomorphology which links intra-city structure, municipal land use, and urban growth of the cities to landscape morphology and physical environments (Graf, 1996; and Downs and Booth, 2011). Urban geomorphology is described as the interdisciplinary field of geosciences and-socio-economic sciences, which deals with landscape problems in urbanized areas (Maria *et al.*, 2006). Geomorphological maps along with other relevant terra -related information such as slope, lithology, and geological structures can delineate a suitable area to facilities a specific type of urban development and planning (Pareta and Prasad, 2012).

The geological and geomorphological settings of city surroundings can influence pattern, style, and direction of city growth, as well as area, and type of land use within and around the city. Nature of landscape commonly controls the city master plan and distribution of different facilities. Geomorphologic processes, such as slope stability, flood hazards, and drainage network density, affect pattern and direction of city growth (Pareta and Prasad, 2012). Seismo-tectonic activities and lineaments distribution also have some impact on land use activities (Loczy, 2010). In that sense, understanding and evaluating the impact of the geomorphological processes and the physical environmental conditions of any given city (especially those with variable geomorphic terrains) would be very important to evaluate the future plans for the city expansion pattern within the land use framework.

This work aims to apply the above concepts on the Sulaimania City in Kurdistan Region, northern Iraq, for the first time as an attempt to demonstrate the influence of the geomorphological environment and related hazards on the urban growth pattern of the city. The Sulaimania City is chosen due to its outstanding geological and geomorphological setting. It is located within the Zagros Mountain range where relief contrast and folded strata overshadow most of the city urban aspects. The selection of the Sulaimania City for this study provides an excellent model to evaluate the interaction between cities urban development and the surrounding physical environment.

The Sulaimania City was founded in 1784 A.D. as the capital of the Kurdish Baban principality. It is now the major city of the Sulaimania Governorate, which represents the eastern wing of the Kurdistan Region. Its location represents a strategic link between the mountainous eastern and southern towns such as Ranyah, Chwarta, Penjwin, Said Sadiq, Arbat, Derbandikhan and Halabja. It is also well connected with the western rolling hills wing and towns such as Chem Chamal, Qaradagh, Zarayen, and Kirkuk city. The city now is representing a big metropolitan settlement center with a population currently, estimated around 1.7 million. The city went through a slow rate of growth until the turn of the Twentieth Century where urbanization became noticeable. In 1927, the Sulaimania City became the commercial and political capital of eastern Kurdistan and one of the 14 administrative divisions (Liwa'a) of the Government of Iraq. The city growth was irregular and slow similar to other cities of the Kurdistan Region and often interrupted by the political instability of the region. However, the growth of the cultural role of the city is always faster and remarkable, which is related to the cultural roots of the people of the area.

The city has historically played an important economic and political role in the life of Middle Eastern societies. It represents a middle-sizedcity, experiencing a very rapid growth triggered by the settled socio-political conditions of the region. The first master plan project to be endorsed for the city development was in 1958. It is considered as the basis for all development planning of the city. A German consortium of planners and engineers was commissioned in February 2006 for the new project of master planning. This project is finalized with maps and recommendations in 2009 as the master plan report (Master Plan Report (MPR), 2009), which is heavily relied in this study regarding urban developments. The pattern of the city urban growth and its stages have been discussed in detail by Al-Qayim *et al.* (in press) They had used different geographic and topographic maps and satellite images for different periods to define the variation in the city outer limits and expansion areas. They divide the growth of the city into three stages: Old Stage (1920 – 1973), Modernization Stage (1973 – 1990), and Stabilization Stage (post – 1990). Their maps, classification, and growth pattern are adopted in this study to show the interaction between geomorphological and environmental aspects with the city expansion pattern. This study is devoted to investigate the impact of the geomorphologic factors on the Sulaimania City expansion pattern using satellite images and different kinds of maps, in addition to field observations.

STUDY AREA

- **Location**

The city of Sulaimania is located in the northeastern part of the Kurdistan Region of Iraq, about 80 Km northeast of Kirkuk City and 35 Km west of the Iraqi – Iranian borders (Fig.1). The area covered by the master-plan project of the city is around 472 Km^2, located between longitude (45° 12' 00" and 45° 32' 00" E) and latitude (35° 25' 30" and 35° 40' 00" N). The city is located in an intermontane plain with elevation ranges between 1050 meter above sea level (m.a.s.l.) at the eastern part and about 800 m.a.s.l. at the western part. The elevation of the city center (Old City) is about 870 m.a.s.l. Approximately, 20% of the total study area is considered as a mountainous region with Azmar and Goizha mountains covering the eastern part of the area, whereas the height ranges between 1000 and 1650 m.a.s.l. Baranan Ridge of the Qaradagh Mountain bounds the city from the west, and the plunge of Sulaimania anticline (Extension from the big Pira Migrun Mountain) from the north (Fig.1), with height exceeds 2000 m.a.s.l. (Fig.2). Low areas are confined to major valleys such as the Tanjero valley where the elevation reaches 675 m.a.s.l.

Chaq Chaq and Kani-Ban are the major streams in the area. They flow from the north and the northwestern highs, with total lengths of 25.5 Km and 14.6 Km, respectively. Both of these streams meet southwestwards of the city (near Kani-Goma village, around 7.5 Km from the city center) to form the Tanjero River, with a total length of about 13 Km. The Tanjero River is one of the major recharge resources to the Darbandikhan reservoir, some 50 Km to the southwest of the Sulaimania city.

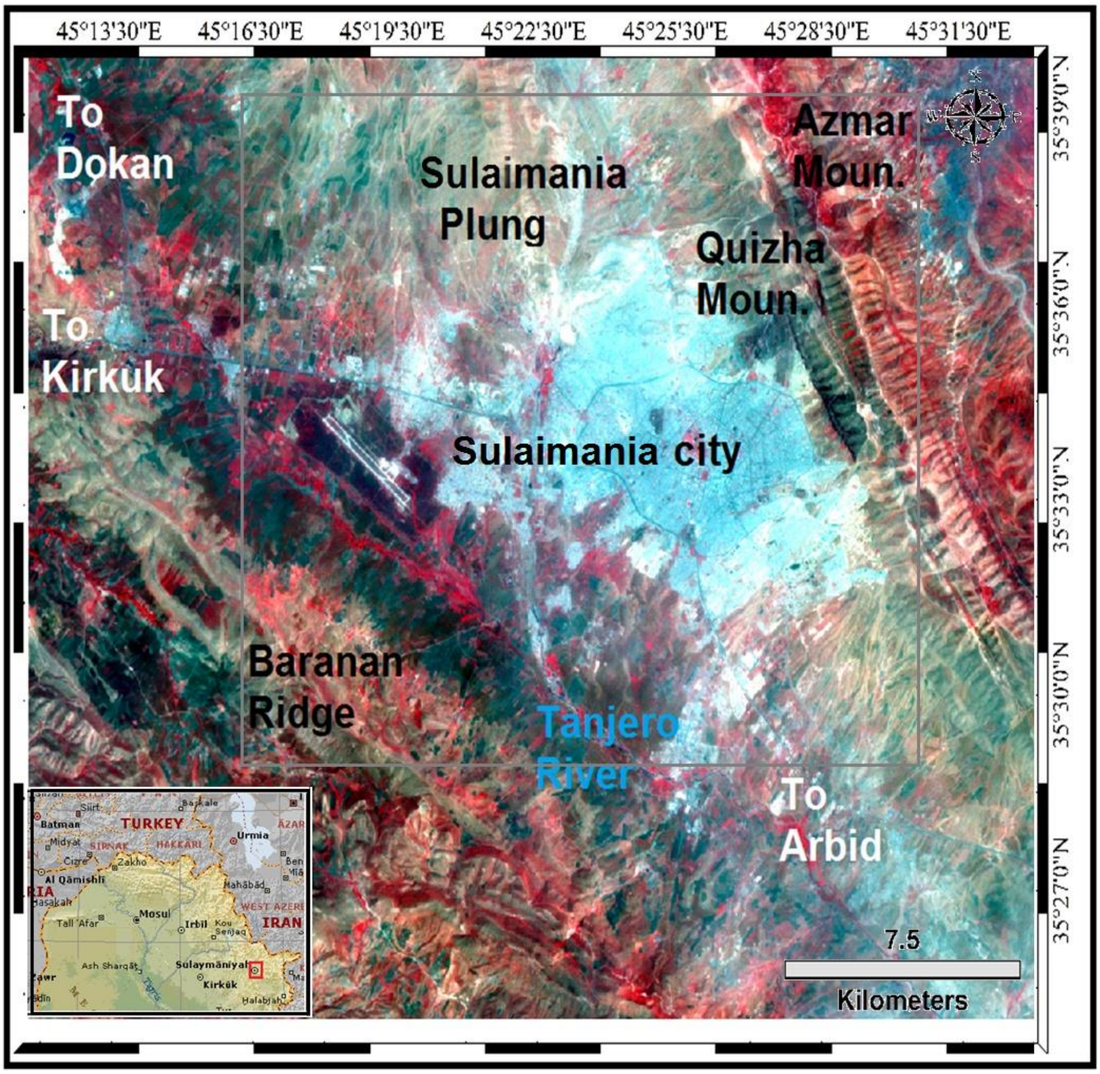

Fig.1: Land Sat satellite image (2011), showing the location of the study and the surrounding areas (RGB: Red: Band 4, Green: Band 3 and Blue: Band 2)

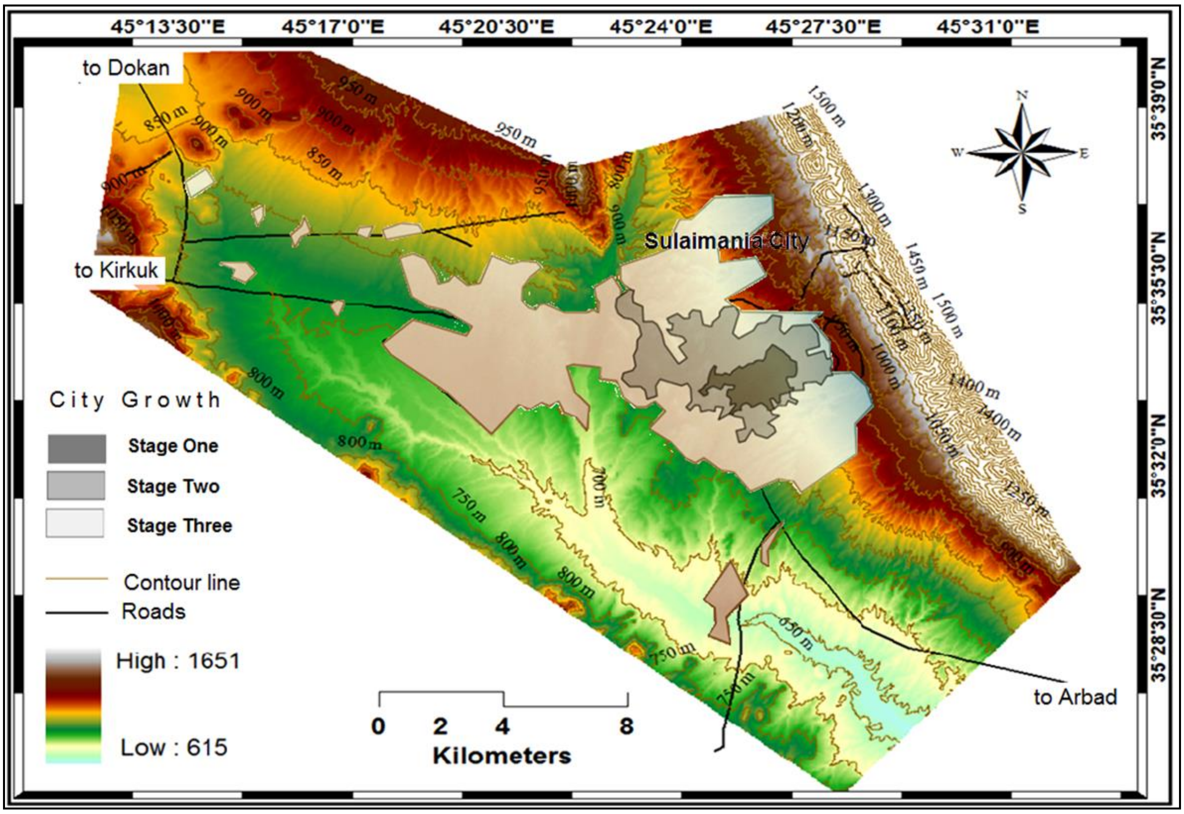

Fig.2: DEM colored map of the study area showing variation in topography and urban growth stages of Sulaimania City

- **City Physical Environment**

In this part attention will be given to the physical conditions, which have important influence on the development of landscape surrounding the Sulaimania City and affect its urban growth. The following aspects are found influential to understand the relation between the physical environment and the urban growth of the Sulaimania City.

– ***Topography*:** The topographical setting is inferred from the DEM of Fig. (2), in addition to other topographic maps. The city is located in an intermontane depression, which is filled by Quaternary sediments derived from the surrounding heights (Fig.2). The margin of this depression is covered by the soft sediment of older geological units. The landscape of this depression is generally characterized by rolling hills terrain intersected by relatively shallow and low density drainage network. The depression is bounded from the eastern side by the NW – SE trending Azmar Mountain range with an elevation reaches 1590 m.a.s.l.

Adjacent to Azmar Mountain, two distinctive smaller mountains are recognized: on the eastern side, Azmar Bichkola (1400 m.a.s.l.), and to the western side the Goizah Mountain (1500 m.a.s.l.). The northern margin of the depression is defined by the plunging noses of (from east to west) Surdash, Sulaimania and Pira Migrun mountains. The peak of the Pira Migrun Mountain is about 2500 m.a.s.l. To the west, the depression extends for about 10 Km with an almost flat area of the Tanjero River flood plain. The western side of that depression is limited by an elongated, NW – SE trending, about 1000 m.a.s.l. high ridge of Baranan Mountain. The southern limit of the depression is open to the southward sloping flood plain of the Tanjero River, which reaches 600 m.a.s.l. in elevation near its influence with Sirwan River near Derbandikhan Lake.

– ***Geology*:**

- ***Structural and Tectonic Setting*:** The Sulaimania City is located at the northeastern margin of the High Folded Zone and close to the Imbricate Zone of northeast Iraq. Both zones form the Foreland Fold- Thrust Belt of the Zagros orogeny (Fig.3). This regional orogenic belt extends in a NW – SE trend and is believed to have resulted from long and active convergence history between Arabia and Eurasian plates (Jassim and Goff, 2006; Emami, 2008; and Al-Qayim *et al*., 2012). Deformation intensity decreases southwestwards. Structures to the northeast of the Sulaimania City is characterized by tight, overturned high-amplitude, dense folds intersected by intense faulting (Al-Hakari, 2011). These folds were associated by thrusting, mostly semi-parallel to their fold axis (Al-Fadhli *et al*., 1980). Azmar and Goizha anticlines, located NE of Sulaimania City are disrupted by axial and dense net of reverse faults; each often dislocates the axis of anticlines southwestwards, manifesting typical imbricate structureand morphology (Buday and Jassim, 1987). Recent studies, such as Ma'ala *et al*. (2004); Ibrahim (2009); and Al-Hakari (2011) considered the Azmar anticline as a convex, and asymmetrical fold. According to Numan (1997); and Jassim and Goff (2006), it is considered as an anticlinorium and one of the huge structures within the Imbricate Zone (Fig.4). Beds at the western limb have the maximum inclination, especially, in the Balambo Formation.

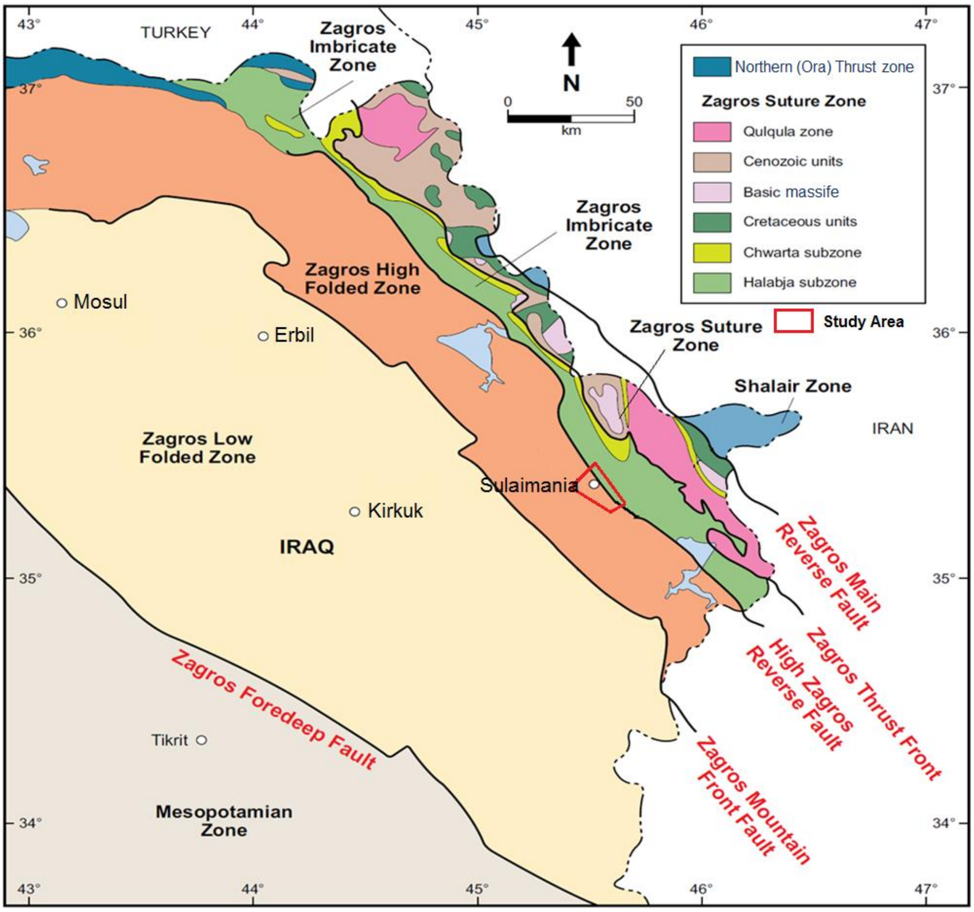

Fig.3: Regional tectonic map of northeast Iraq showing major tectonic divisions with bounding faults (written in red), and location of the study area (after Al-Qayim *et al*., 2012)

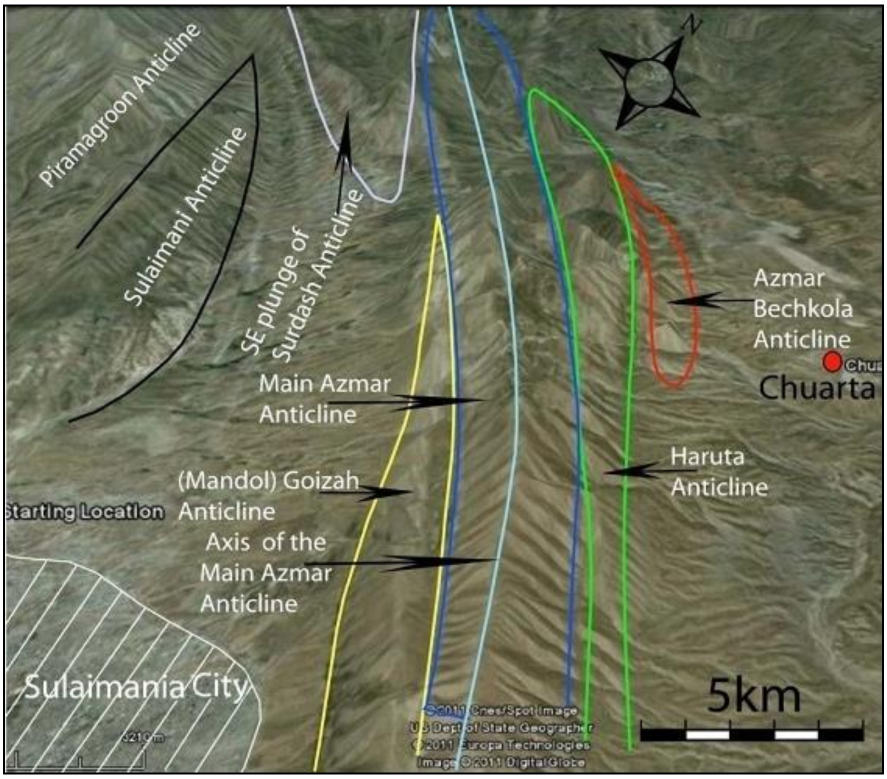

Fig.4: Google Earth image showing the folds of NE Sulaimania City (after Al-Hakari, 2011)

The Goizah anticline is about 45 Km long and appears to be concealed somewhere along the strike due to the thrusting of main Azmar anticline, which makes it seems like a part of the main Azmar anticline. The Goizha anticline protects the city from major mass wasting activities that comes from higher Azmar anticline. In addition to these structures, other major anticlines of the northwest and the western areas such as Pira Migrun, Sulaimania, and Baranan belong to the High Folded Zone. Major lineaments in the study area are associated with the major structural features (Bety *et al*., 2016). However, intensive lineaments population was found to be associated with harder limestone ridges and outcrops as compared to soft clastic sediments of the central part of the study area.

– ***Stratigraphy*****:** The lithologic variability of the stratigraphic units, which are exposed the study area in addition to the effect of major structures and lineaments are significantly controlling the general pattern of drainage network and landscape of the city surroundings. Rocks are ranging from hard massive limestone of the Balambo Formation to soft shale of the Kolosh and Tanjero formations (Fig.5). The exposed units from older to younger includes: Balambo, Kometan, Shiranish, and Tanjero formations and the Tertiary units of Kolosh and Sinjar formations in addition to the Quaternary sediments. Below is a brief review of lithologic characters of these units, based on Bellen *et al*. (1959) and Al-Hakari (2011) reviews, in addition to field observations of the authors.

- **Balambo Formation:** The formation in the study area represents the oldest exposed rocks at the core of Azmar anticline. It is intensively deformed and consists of medium to thickly bedded light gray limestone at the top, and greenish gray marly limestone with marlstone interlayers at the bottom (Fig.6a). The exposed thickness of the formation in the study area is about 400 m.

- **Kometan Formation:** Generally, the formation in the study area crops out at the flanks of Azmar and Pira Migrun anticlines, with few patches within the city forming local hills. It is characterized by a well and medium-bedded, dense, and fine-grained light gray limestone (Fig.6b). Bedding planes are well marked by stylolite lines. The limestone is intensively cut crossed by different sets of joints with occasional occurrence of chert nodules. These rocks are tight and hard, and are widely used as a building stone in the city constructions. The average thickness of the formation in the study area is about 70 m.

- **Shiranish Formation:** The thickness of the formation varies from place to other and ranges from 50 to 150 m. The formation is composed of alternations of greenish gray marl and light gray limestone (Fig.6c). The formation is well exposed as a continuous belt along the limbs of the Azmar and Pira Migrun anticlines as well as small patches within the city. The soft nature of its sediments makes it often, concealed under Quaternary cover.

- **Tanjero Formation:** It is composed mainly of alternation of medium to thinly bedded green sandstones with claystone, shale thicker interlayers. Conglomerate units are infrequent. The formation thickness is estimated to be around 1000 m. The depression area is located over the Tanjero Formation outcrop due to its soft and easily erodible sediments. Leveling of that depression is related to the Quaternary sedimentary fill. Most of the Sulaimania City urban structures were constructed over the Tanjero Formation (Fig.6d, Table 1). In areas of thick sandstone horizons, it stands out as prominent ridges or isolated hills within the rolling topography of the intermontane depression.

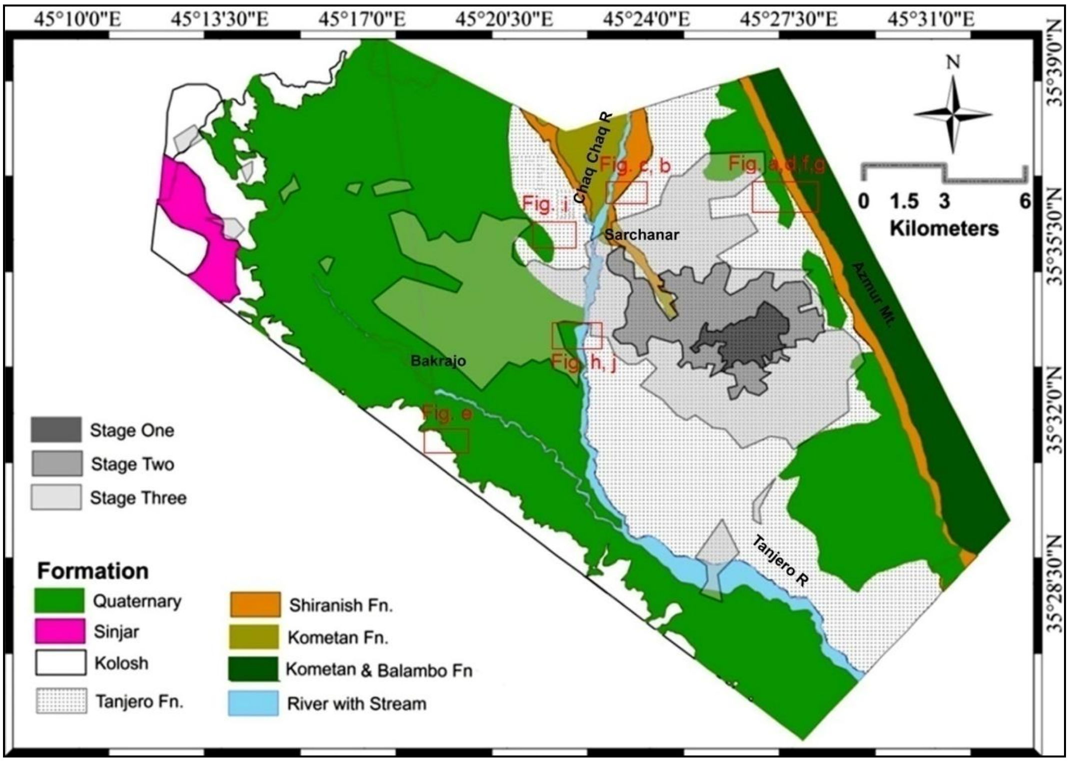

Fig.5: Geological map of Sulaimania City and surroundings. Field photos location of Figure (6) are shown in red rectangles (Geology from Al-Hakari, 2011)

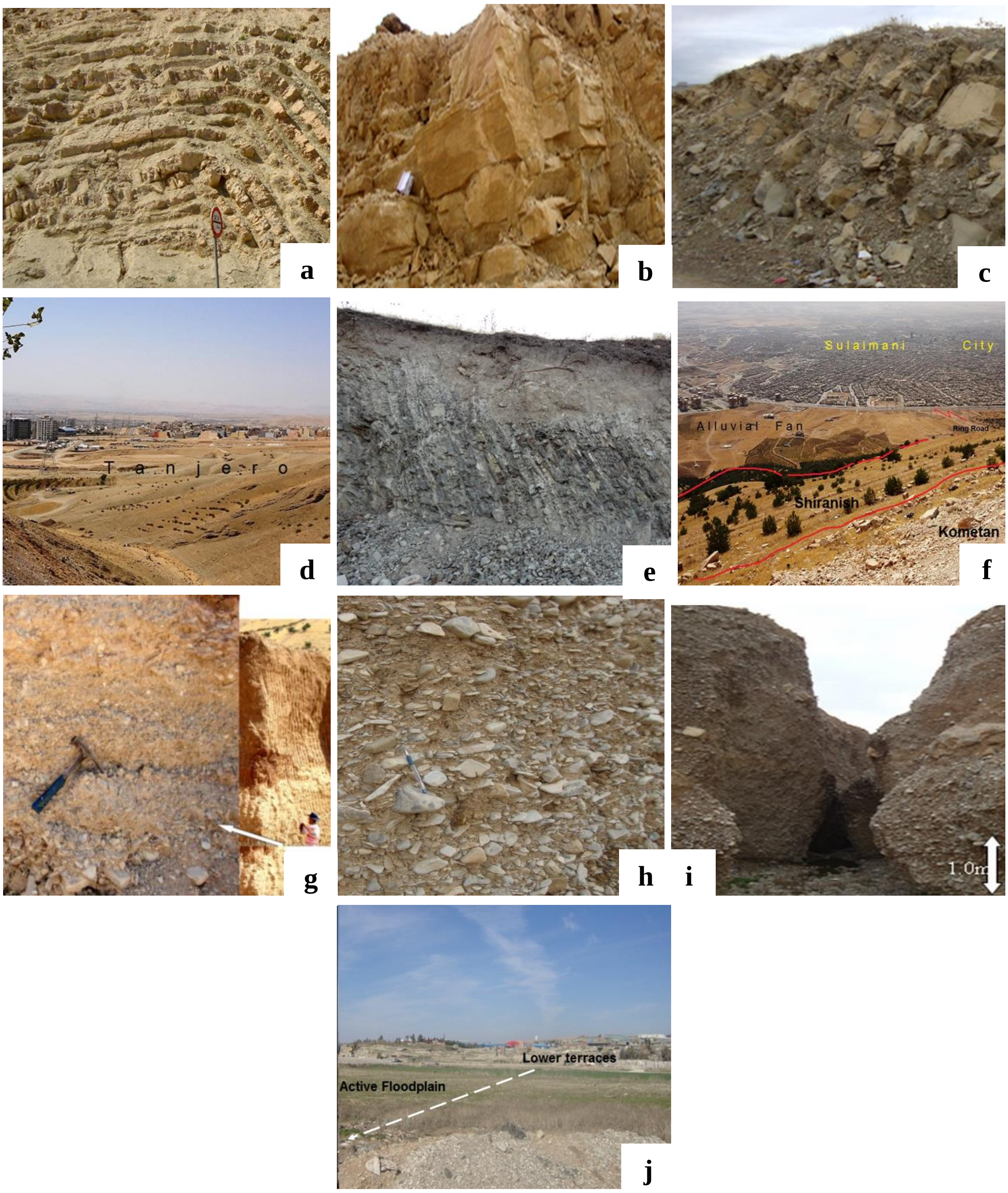

Fig.6: Field photos of the stratigraphic units and geomorphic features of the Sulaimania area. **a)** Local folding of limestone and marlstone beds of the Balambo Formation at Azmar Anticline. **b)** Thick, hard limestone beds of the Kometan Formation near Sarchanar. **c)** Gray marly limestone beds of the Shiranish Formation along Chaq Chaq Stream valley. **d)** Soft sediments of the Tanjero Formation crop out at the northeastern outskirt of Sulaimania City. **e)** Gray thinly bedded clastic sediments of the Kolosh Formation near Bakrago. **f)** Alluvial fan deposits are located at the foot of Azmar Mountain on the eastern side of the city. **g)** Mixed, limestone-gravel sediments of the alluvial fan to the east of the city. **h)** Fluvial angular and imbricate gravel Quaternary sediments of the Tanjero River. **i)** Incision of a small stream into Chaq Chaq valley sediments. **j)** Floodplain and river terraces of the Tanjero River. For photos location, see Figure 5

Table 1: Area and percentage of the formations crop out at Sulaimania city and surroundings calculated from the DEM, aerial photograph, and geological map

Formation Name	Area Km^2	Total of area %
Balambo and Kometan	37	7.86
Shiranish	13	2.75
Tanjero	127	26.85
Kolosh	43	9.1
Sinjar	7.5	1.58
Quaternary sediments	234	49.47
Stream Channel	11	2.3

- **Kolosh Formation:** It consists of about 600 m thick dark grayish green siliciclastic strata of calcareous shale, siltstone, sandstone, and sandy limestone. It is usually exposed in the slopes, below the cliffs of the Sinjar Formation at Baranan ridge and downwards to the plain area of the western side of the city (Fig.6e). The generally thick and soft sediments of the formation are responsible for the low topography of its distribution area. However, at areas where thick sandstone units occur prominent ridges or hills can be seen.

- **Sinjar Formation:** It crops at Baranan ridge forming its prominent feature. It ranges in thickness between 100 and 80 m and consists of massive and thick bedded, hard, and gray fossiliferous limestone. The lower part becomes argillaceous and intercalated with the greenish gray calcareous and sandy shale of the upper part of the Kolosh Formation. Because it forms a gently dipping attitude, it displays active slumping and landslides in front of the Baranan ridge (Karim and Ali, 2005).

- **Quaternary Sediments:** They cover about 50% of the whole study area (Table 1) particularly to the west, north and south of the city. It occupies valleys, depressions, and lowland regions. Alluvial fans with fluvial sediments are the most common types of the Quaternary sediments in the study area, showing variable morphology and extent due to variation in local base levels (Al-Daghastani, 1989). Alluvial fans can be clearly seen on the eastern side of the city flowing down the Azmar anticline range (Fig.6f). Sediments are mixed and poorly sorted with angular fragments of carbonate rocks derived from the Balambo, Kometan, and Shiranish formations (Fig.6g). Alluvial fans occur in small size in front of the Goizha Mountain, usually dissected by parallel or subparallel valleys flowing down into the city area. In some parts, small alluvial fans are coalesced together to form medium to large scale alluvial fan belt (bajada). They are less dissected and consist of gravel, sand, and mud. The thickness of the Quaternary sediments at the margin of the fan reaches about 25 m.

Fluvial sediments, which are common basically within major river valleys and streams (Fig.6h), are represented by gravel, sand, and mud of channel sediments, flood plains, and river terraces sediments. Channel sediments are developed as a narrow elongated belt following the Tanjero River course and its distributaries (Fig.6i). Other types of Quaternary sediments are surface flow and flood sediments, which are represented by mixed, poorly sorted, usually muddy sediments filling low areas and depressions (Fig.6j).

– *Geomorphology*: Detailed geomorphological description and mapping following the classification system of the Faculty of Geo-Information Science and Earth Observation-The Netherland (ITC) for the Sulaimania area is reviewed by Al-Daghastani *et al*. (2020) and adopted here in brief. The study area is subdivided into three basic geomorphological landform groups with several subgroups:

- ***Units of Structural Origin***
  - *a. Central ridge of Goizha Structure on the Kometan Formation.*
  - *b. Dissected central structure ridge of the Goizha structure.*
  - *c. Inner core of Sulamania structure on the Kometan Formation.*
  - *d. Homoclinal structure ridge on the Kolosh Formation.*
  - *e. Dissected outer homoclinal ridge on the Tanjero Formation.*

- ***Units of Fluvial Origin***
  - *a. Active flood plain and valley fills.*
  - *b. Active incised valley.*
  - *c. High river terraces.*
  - *d. Single and Multiple stage alluvial fans.*

- ***Units of Denudational Origin***
  - *a. Pediment (associated with alluvial fan area to the east of study area).*
  - *b. Badlands (the Tanjero Formation outcrop to the north and south of study area).*

METHODOLOGY

Basic sets of data collected for this research relied on analysis of different sets of maps, aerial photographs and satellite imagery of different types and scales in addition to field survey and land checking. These data include:

1. Thirteen digital (one layer) aerial photographs mosaic with a scale unit equal to (1cm = 76.2 m) taken in 2009, are used for visual interpretation using principle points of interpretation according to the ITC system (Verstappen *et al*., 1978) to be integrated with other geological, geomorphological and topographic maps.
2. The DEM of 15 m resolution is used to evaluate topographic features of the area, and to assist in the interpretation of geomorphological characteristics, lineament analysis, and slope evaluation. The basic raster information includes columns and rows (15950, 13500), number of the bands (1), cell size (2, 2), uncompressed size (821.4 MB), pixel type (floating point), and pixel depth (32 bit).
3. ASTER (2009) in multi-bands with 15 m special resolution and SPOT panchromatic images with 5 m resolution are used for digital analysis.
4. Different scales of topographic maps to support the geological and the geomorphic interpretation.
5. Geological (Ma'ala *et al*., 2004) and geomorphological (Al-Daghastani *et al*., 2020) maps are used to show the distribution and the spatial relations between different geologic units and landforms.

All these data are put together to finally produce a set of maps of the city expansion stages for the examined periods. The urban expansion maps are overlaid on: topographic, geologic, geomorphologic, slope type, drainage density, land use, flood risk, and lineament density maps to demonstrate and interpret the influence of these effective environmental conditions and hazards on the urban expansion pattern of the city. Different soft wares are used in the analysis and the treatment of the data, which includes:

- Arc GIS, V9.3,
- ERDAS image V.9.1, and
- Global Mapper V.8.

RESULTS

▪ Environmental Hazards and Urban Growth

This part is intended to evaluate important environmental and geomorphological hazards responsible for landscape development of the Sulaimania City, and their impact on the urban growth of the city. These factors include; topography, outcrop distribution of geological units, distribution of geomorphological units, degree and distribution of slopes, and drainage density of the major streams of the area, and slopes and slopes-associated processes such as mass wasting and flood hazards. The influence of these factors on the city growth pattern is discussed individually below, through a set of maps constructed for each factor.

▪ Geology and Lineaments Impact

The distribution of the soft and mainly siliciclastic sediments of the Shiranish, Tanjero and partly Kolosh formations, as well as the loose Quaternary sedimentary cover, played an important role in the development of city site. Erosion and re-deposition of sediments from these formations have assisted in leveling the area of the so-called depression in between the Azmar Mountain ridge and the Branan ridge, which bound the city area (Fig.5). During recent years of city expansion, even some of the Kometan Formation hard limestone outcrops and ridges were integrated into the suburban parts of the city. After 1990 and during the stabilization stage of the city growth, urbanization was expanded towards the west and over areas mainly covered by Quaternary sediments of the pediment plains. On the other hand, eastward expansion during this stage was very limited and grew over the Quaternary sediment of the alluvial fans developed at the foot of Azmar-Goizha anticline (Fig.7).

The city growth pattern with respect to lineament density shows that urbanization has expanded over areas of very low, low, and medium lineaments density as demonstrated in (Fig.8). As stated, before these areas are consisting of soft clastic sediments of the Shiranish, Tanjero, and Kolosh formations, which absorbs stress and are less deformed compared to the brittle limestone of the underlying units. Less lineament density would provide stability and firm ground for construction, which encouraged city growth over these areas.

▪ Impact of Topography and Geomorphology

The high altitude of the Azmur – Goizha anticlines from north and eastern sides, which exceeds 1600 m.a.s.l. strongly controls the expansion of the city from that side. Urbanization towards that direction was limited due to high slopes, rugged terrain, dense network of deep galleys and grooves, frequent flooding, and hard rocky substrate of the mountain region (Fig.7). The rolling hill topography and the leveled area towards the south and west permit a better chance for growth and urbanization (Fig.2).

Since its establishment and during different growth stages most of the city area had being spread over a land surface developed by the alluvial and fluvial activities and the resulted landforms (Fig.7). The Quaternary soft sediments of these areas permit a better ground for construction and leveling works. Landforms dominated by different stages of alluvial fans developments at the fore slopes of the mountains occur to the northern and eastern parts of the city. The central part of the city area is covered by the low altitude area of the mountain pediment (Fig.8). This part is intersected by a network of frequently flooding valleys. Other fluvial landforms, which have a negative impact on urbanization, include badlands to the north of the city developed by the alternating hard and soft clastic strata of the Tanjero Formation, and those in the southern part of the city where it is covered by thick pebbly clastics of the Tanjero River.

During early stages of the city growth, expansion confined to the east of Chaq Chaq valley, and over drainage network of low order streams i.e., order two and three (Fig.7). During late stages of the city growth, urbanization encroached areas of higher drainage orders including Chaq Chaq valley of the fifth order, which became part of the city urban plan.

- **Slopes Influence**

Most of the city area during stage one and two of the city growths were constructed over a gently-sloping to sloping terrain (Fig.9). However, during the last stage, the city urban area shows great expansion over the western side and partly to the southern parts (Qarga district), because it is flat to gently-sloping class areas. Besides, the northern and northeastern part of the city expanded during this stage, whereby city growth went beyond these low sloping areas to higher slopping classes (sloping and moderately steep classes; (Fig.9). Many residential complexes and recreational facilities, such as the "Chavi Land" park, were constructed. The reasons behind the expansion over these relatively slopping areas lie in their higher altitude, rigid rocky ground, quiet neighborhood, clean air and the beautiful scenery which overlooks the Sulaimania City. The environmental problems associated with the expansion over these relatively sloping areas are the potential mass wasting activities, especially rock fall and toppling, soil creep and flush flooding.

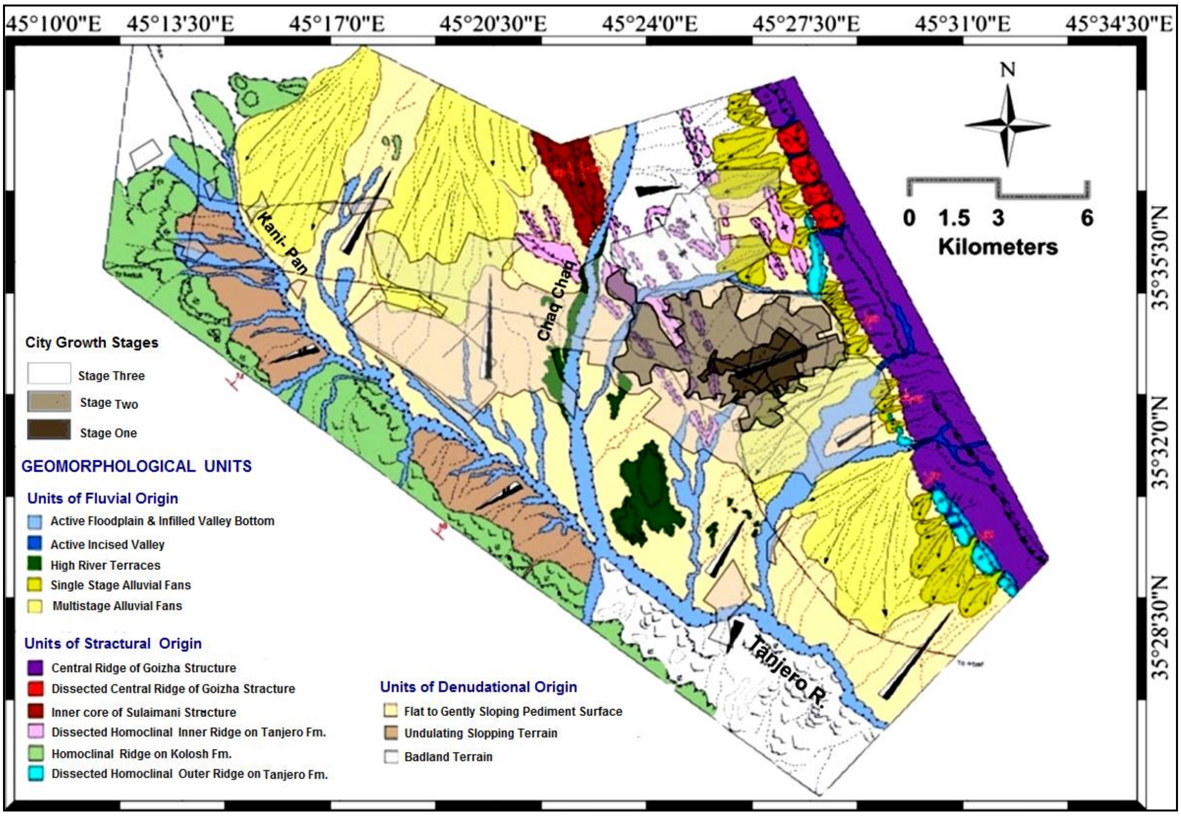

Fig.7: Geomorphological map of the Sulaimania City and surroundings (after Al-Daghastani *et al*., 2020)

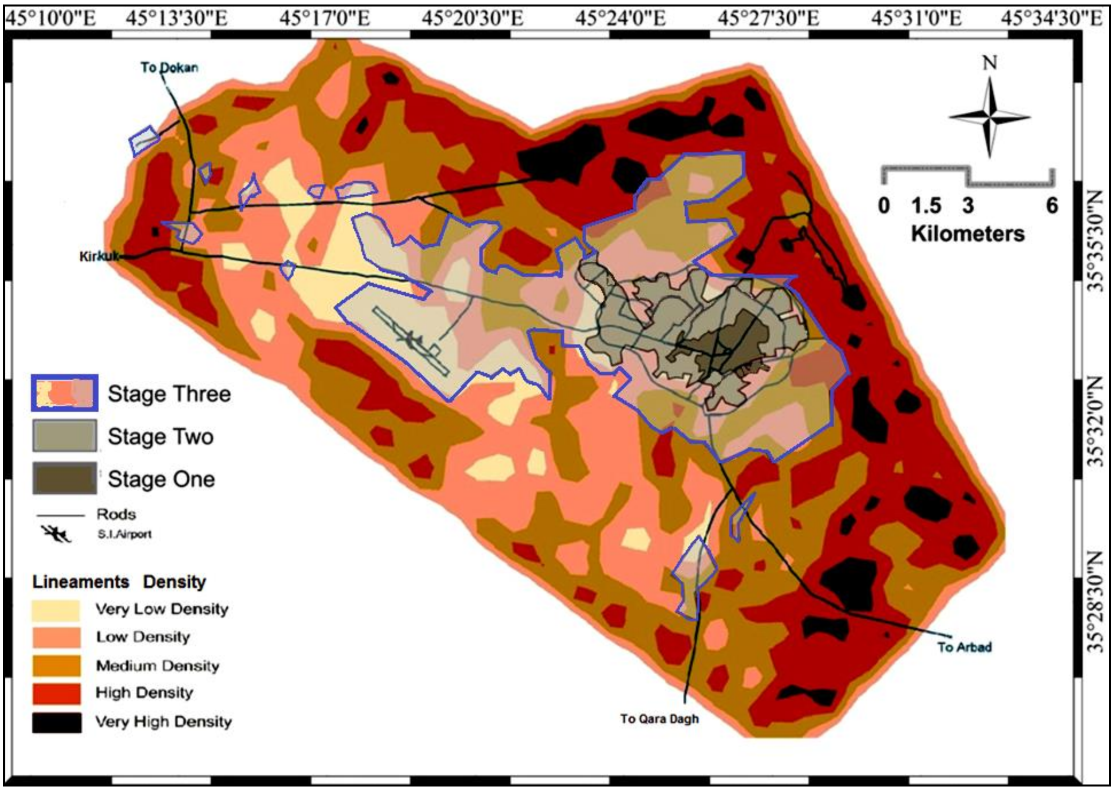

Fig.8: Lineament density map of the study area showing the three stages of Sulaimania City urban growth

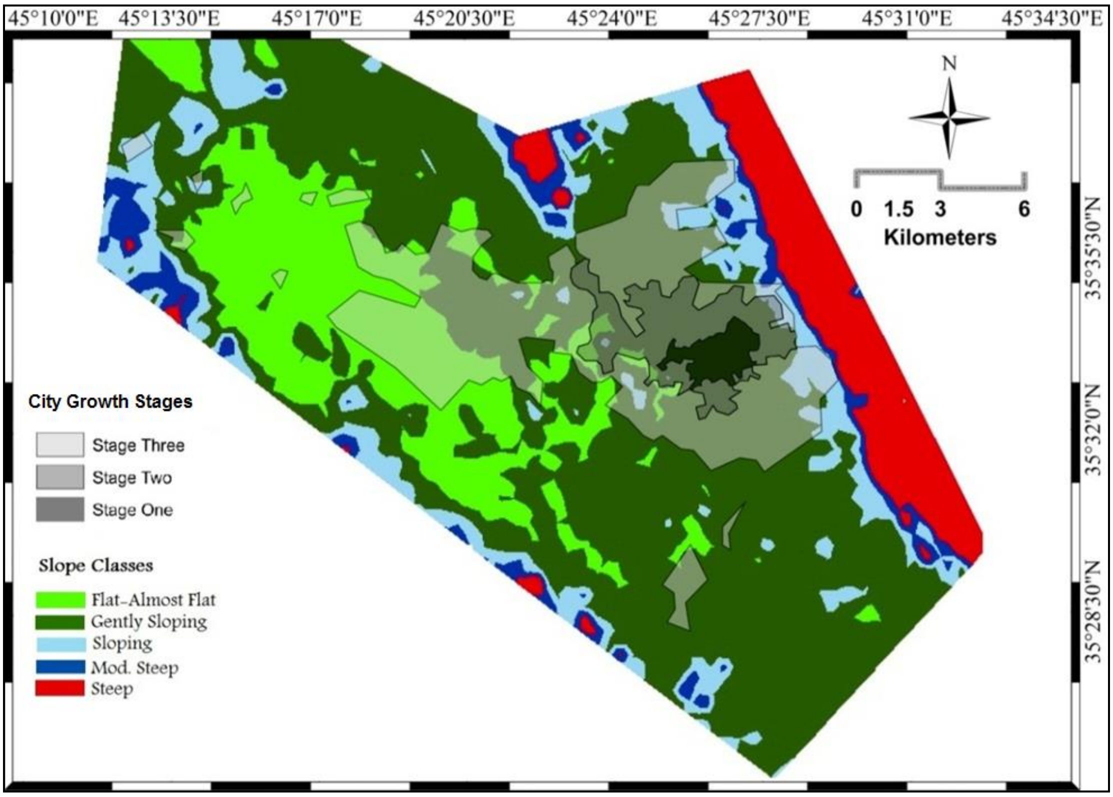

Fig.9: Slope classes map of the study area showing the three stages of the urban growth of the Sulaimania City

- **Flooding Risk Impact**

The drainage network map of the area is created from DEM with ArcMap 9.3 to produce a flooding risk map. This was done by processing the previous shapefile of the main watershed of the area (Tanjero Basin), which is extracted digitally from the DEM and plotted in GIS environment (Fig.10). This map shows the areas of potential surface flow, which usually lead to gully erosion (Tanaka and Agata, 2002). According to the density of drainage network, the area is classified into four risk classes; low, medium, high and very high risk flooded areas. This map is used to evaluate the impact of flooding risk on the city growth. Area and coverage percentage for each flood-risk class was calculated and the results are shown in the Table (2).

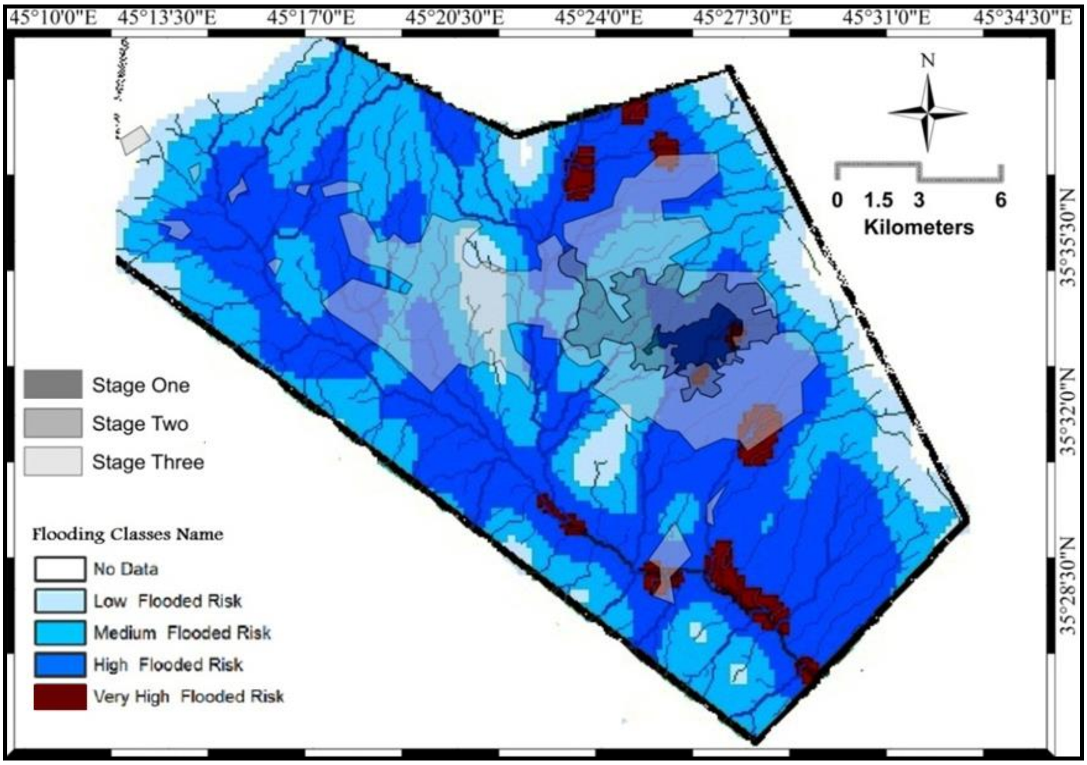

Fig.10: Flood risk map of the study area showing the three stages of urban growth in the Sulaimania City (modified after Bety, 2013)

Table 2: Flood-risk classes and their area coverage percentage in the study area

Flood Risk Class	Area in Km^2	Percentage (%)
Low Flooding Risk	68	14.37
Medium Flooding Risk	192	40.59
High Flooding Risk	198	41.86
Very High Flooding Risk	15	3.17
Total Area	473	100

According to Table (2), about 82% of the study area is subjected to medium to high flooding risk. These areas are often associated with the lower reaches of the drainage network. Similar areas are usually characterized by active flooding induced by lowland morphology, gentle slopes, exposures of impermeable formations, and intense urbanization (Bathrellos *et al.*, 2016). The low-risk flooding areas cover only 15% of the total city area, and only 3% of the area is characterized by a very high risk of flooding. Areas of very high flooding risk are associated with upper reaches and flood plains of the major streams, such as Chaq Chaq River. Small dams were constructed to control these floorings as that on Chaq Chaq River, but unfortunately failed due to strong flooding capacity during rainy seasons. The old city was established over an area of medium to low flooding risk. However, during the last stage of the city growth, and due to the growing needs for new residential area, expansion went over areas of high flooding risk, especially, to the northern, western, and southern parts of the city (Fig.10).

DISCUSSION

The major ridges of the Azmar-Guoizha Mountain from the east, the Baranan Mountain ridge from the west, and the occurrence of Sulaimania and Pira Migrun Mountains from the northwest, isolate an intermontane small depression in between. This depression is filled by recent sediments to form a pediment surface of rolling to flat-laying topography. This topographic setting provides a suitable location for settlement as well as protection from severe winter climatic conditions. Soft recent sediments of the depression encourage the cultivation of original settlers of the city, especially in the suburban parts (Fig.8). The selection of the city site at the margin of the multistage alluvial fans along the slope-foot of the Azmar – Goizha mountains reduces the influences of sever slope processes hazard (mass wasting and flooding). Furthermore, positioning of the city in a relatively higher place from the frequently flooded low areas at the central part of the intermountain plain, protect the city from the active stream flooding at the central part of the depression.

The general shaping of the particular topographic and geomorphic setting of the city surroundings is mainly controlled by the tectonic build up and geologic components of the area. The intensive folding of the Zagros range exposes deep, older, and hard limestone of the Balambo – Kometan formations at Azmar – Goizha and Pira Migrum anticlinal cores from the eastern and the northern parts. Other hard limestones of the Sinjar and Pila Spi formations form the wings of the anticlines and form the bounding ridge of Baranan Mountain form the west. The broad syncline in between provides the low area for recent sediment accumulation from the surrounding highs. The soft and easily-eroded clastic sediments of the Shiranish, Tanjero, and Kolosh formations, which are exposed around the depression margin, provide the filling material to level up the depression. The seasonal streams and groundwater are the essential water resources to make the intermontane plain suitable spot for settlement and cultivation. All these geologic and geomorphic elements contribute to give the Sulaimania City its unique location, which helped in the socio-economic development and triggered urban expansion, despite some physical and environmental limitations

The major high feature of Azmar – Goizha Mountain to the east play an important role in limiting the expansion of the city in that direction at least during the early and middle stages of the city growth (Fig.2). The high degree of slopes, the hard and highly fractured rock substrate and the active mass wasting processes of that part discourage construction and land use there. The high-risk flooding of mountain flank (alluvial fan belt) and the deeply incised valley, as well as the rugged and undulating topography, prevent urbanization and constructions to reach up to the margin of the alluvial fans plain. However, during the last stage of city growth, and due to the increasing demand for favorable sites for urbanization, especially tourism and recreational constructions, expansion pressured to move in that direction.

Most of the city expanded during the early stages, thus growing to the west of the city encouraged by the flat to sub flat topography, the soft substrate of the Tanjero and Kolosh formations, in addition to the fluvially-derived recent sediments and soil cover. The only obstacles are the remains of the dissected outer sandstone homoclinal ridges of the Tanjero Formation and the Chaq Chaq valley. During the late growth stage, the city went westwards far beyond the Chaq Chaq valley by more than 5 Km over the Quaternary cover of the depression plain. During this late stage and upon growth in the residential sector investments, and to comply with the increasing demand for housing and residential areas, expansion went northward into the badland area (Fig.7). This is an undulated area, intensively intersected by the occurrence of the sandstone homoclinal ridges. Therefore, active peneplanation and cut and fill works were required to overcome the nature of this rugged topography. The same thing happened southwards as the expansion went beyond the 60 meters circular road, over the incised multi-stages alluvial fan (badland area).

SUMMARY AND CONCLUSIONS

An integrated approach of GIS-based environmental and geomorphological analyses linked with the urban growth pattern is applied to the Sulaimania City. This study reveals interesting points regarding the growth pattern and its interaction with geological-geomorphological as well as environmental hazards affecting the city and its surroundings. These points include:

1. The three stages of Sulaimania City growth history were developed under the combined influence of political history and socioeconomic conditions of the area and significantly controlled by the geological-geomorphological settings and effective environmental hazards of the city surroundings.
2. The city site is selected as favorable topographic and geomorphic situation which is characterized by an intermontane plain covered mainly by the soft clastic sediments of the Kolosh, Tanjero and Shiranish formations as well as the soft Quaternary sediments.
3. The marginal limits of the city along the alluvial fan series at the foot of Azmar-Goizha Mountain gave it an intermediate position between a relatively elevated area above the frequently flooded parts of the plain, and far enough from the high sloping area of mass wasting hazards.
4. The urban growth in the northeastern direction was effectively hampered by the topographically high Azmar-Goizha Mountain and its steep slopes. This had developed an active and high risk of mass-wasting processes and frequently flooded slops over the city area. The rocky ground and rugged terrain of that part discourage urbanization in that direction.

Most of the city expansion moved in the western direction during all city growth stages. An active urban growth of the city in that direction is encouraged by simple low relief topography, soft sediment ground, and the running of the major connecting road to Kirkuk Governorate. Expansion to the northern and southern parts of the city began in the later stages and upon increasing demand for residential and housing areas, and to maintain the ideal circular form of the city. Landscape modifications' were required to accommodate expansion to the north over the badland terrain and to the south over part of the incised multi-stages alluvial fan areas.

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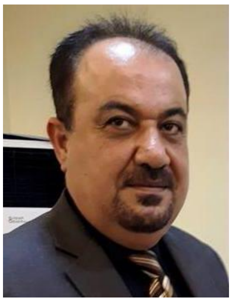

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