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Geomorphology of the northwestern Kurdistan Region of Iraq: landscapes of the Zagros Mountains drained by the Tigris and Great Zab Rivers

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ABSTRACT

We present the geomorphological map of the northwestern part of the Kurdistan Region of Iraq, where the landscape expresses the tectonic activity associated with the Arabia-Eurasia convergence and Neogene climate change. These processes influenced the evolution of landforms and fluvial pathways, where major rivers Tigris, Khabor, and Great Zab incise the landscape of Northeastern Mesopotamia. Anticlinal ridges and syncline trough compose the Zagros orogen. The development of water and wind gaps, slope, and karsts processes in the highlands and the tilting of fluvial terraces in the flat areas are the main evidence of the relationship between tectonics, climate variations and geomorphological processes. During the Quaternary, especially after the Last Glacial Maximum, fluctuating arid and wet periods also influenced local landforms and fluvial patterns of the area. Finally, the intensified Holocene human occupation and agricultural activities during the passage to more complex societies over time impacted the evolution of the landscape in this part of Mesopotamia.

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1. Introduction

The interplay between endogenous and exogenous processes produces various landscapes on Earth (Burbank & Anderson, 2011; Burbank & Pinter, 1999). In tectonically active regions like the Kurdistan Region of Iraq (KRI), vertical and lateral movements of faults and surface processes influenced the distribution and formation of landforms. Folding, stretching, shearing and faulting of rocks exert major control over the evolution of the region's hydrographic networks (Bishop, 2007; Burbank & Anderson, 2011; Hasan et al., 2019; Kirby & Whipple, 2012; Nicoll, 2010; Oberlander, 1965, 1985). In arid and semi-arid regions, where climatic factors appear to be dominant, local water availability affects the intensity of surface and sub-surface processes. This is ultimately related to present-day climatic settings and Quaternary rainfall variations (Goudie, 2013). By contrast, in tectonically dynamic regions like the KRI, the evolution of surface processes is often controlled by the interplay between climate changes and tectonic influence, namely uplift, faulting and folding (Hüneburg et al., 2019; Zerboni et al., 2020).

The KRI is a semi-arid, arid to Mediterranean climate region where the interaction between thrust

and fold processes, climate and rate of weathering-erosional-depositional processes is dramatically evident in the present-day landscape (Alwan et al., 2019; Fouad, 2015; Jassim & Goff, 2006). At the same time, the role of fluvial dynamics, slope, karst and anthropogenic processes significantly impacted the developing mountain and lowland physiography. The KRI has been the scene for many milestones in human evolution: among others, the 'Out of Africa' dispersion of *Homo*, the earliest onset of agriculture, the creation of the first complex societies and the emergence of ancient urban centers (Van de Mierop, 2015). Understanding the timing and steps of landscape evolution of the KRI is thus vital for explaining the adaptive strategies of its ancient human dwellers (Pomeroy et al., 2017). The interpretation of such a palimpsest landscape where geologic processes and climatic fluctuations have interacted for a long time requires a detailed geomorphological investigation.

Therefore, we developed a geomorphological map (Main Map) of the KRI in order to (i) map the distribution of fundamental geomorphological features, (ii) recognise the different contribution of both endogenous and exogenous processes on shaping landforms in

order to (iii) correlate them with human subsistence strategies adopted during the Late Quaternary in response to climate fluctuations and environment changes. This work illustrates the geomorphology of the northern KRI, a landscape that includes the Zagros Mountains and the drainage basins of the Tigris and Great Zab Rivers, as the first map contribution toward a further regional interpretation.

2. The study area: geographic, geological, climatic and archaeological background

The study area covers 12,000 km² in the northwestern KRI inside the governorates of Dohuk, Nineveh, and Erbil. The main topographic elements are: (i) the mountain belt of Zagros in the North that merges with its southern foreland expressed as (ii) several wide plains bordered by the Tigris River in the Southwest and the Great Zab River in the East. In the whole area, fluvial patterns are influenced by the tectonic activity related to the propagation of the Zagros structures: some rivers flow from WNW–ESE to N–S (Gomel Su, Nahr al-Kazir and Great Zab Rivers), others from N–S to W (Khabur River and its tributaries). Regional, long-term climatic data are scanty; the only reliable data series comes from the meteorological station in the city of Mosul, also known as ancient Nineveh, and located 20 km towards South outside the Main Map. The available models suggest a semi-arid to temperate-warm climate for the lowlands, with an average annual rainfall around 380 mm and temperatures ranging from –0.6 to 37.3°C with wide variations due to orographic effects and mountain air circulation patterns (Wilkinson, 2003; Wilkinson & Tucker, 1995). Winters are moderate to cold, while summers are dry and hot to extremely hot. Roughly, 90% of the annual rainfall occurs in the winter months between December and March. In the mountainous foothills, the climate is classified as the Mediterranean, with precipitation up to 1000 mm/yr. and a long wet season (November–April) (Al-Zuhairi et al., 2016; Eklund & Seaquist, 2015). Most rivers and tributaries are active during the rainy period (Othman & Gloaguen, 2013) and ephemeral or inactive in the dry season. The Tigris, Great Zab, Nahr al-Khazir and Khabur are perennially active rivers.

The KRI region is part of the Zagros-Fold Thrust Belt (ZFTB), resulting from the continental collision between the Arabian and Eurasia plates that started in the Early Miocene and still actively progressing today (Csontos et al., 2012; Dewey et al., 1973; Der-court et al., 1986; Fouad, 2015; Mouthereau et al., 2012). The Zagros deformation has propagated over the NE margin of the Arabian Plate toward the Mesopotamian Foreland Basin and the Persian Gulf (Blanc et al., 2003; Csontos et al., 2012; Vergés et al., 2011). In

the KRI, tectonic deformation along the ZFTB is organized into four different zones from the inner part of the orogeny (Imbricated and High Fold zones) to its foreland (Foothills zone and Mesopotamian Foreland Basin) (Berberian, 1995; Fouad, 2015; Frizon de Lamotte et al., 2011; Jassim & Goff, 2006). The deformation is expressed by formation of a series of anticline folds that comprise the main structural pattern within the regional landscape. Some scholars suggest that a strike-slip fault with dextral shear shifted the orientation of anticline relief and related synclinal valleys with different uplift and exhumation rates (Csontos et al., 2012; Reilinger et al., 2006). Anticlines are W–E trending in the Dohuk area, while in the eastern and southern sector of the mountain belt, the orientation of anticlines changes into NW–SE. The folded and deformed sedimentary succession exposed in the area includes Upper Triassic/Lower Cretaceous to Pliocene units.

Within the Imbricated and the High Folded zone, the anticlinal ridges mainly consist of reefal limestone, dolomitic limestone with bedded marls and shales of Upper Triassic–Upper Cretaceous ages. At the border with Turkey, there are outcrops of Ordovician sandstones and Carboniferous–Permian limestones and shale; while to the North and East of the Dohuk City, the Eocene carbonates form the ridges of anticlines (Sissakian, 2014; Zebari et al., 2019). Along the Foothill Zone, sequences of limestone, dolostone and sandstone from the Upper Paleocene to the Lower Miocene are exposed. Middle to Late Miocene mudstones and sandstones form the substrate of lowlands. Finally, Plio-Pleistocene conglomerates outcrop close to the Great Zab River and Mosul Dam Lake (Al-Dabbagh & Al-Naqib, 1991; Fouad, 2014; Sissakian, 2014). Fluvial, floodplain, alluvial fan, colluvial and anthropogenic deposits characterize the Quaternary sequences in the hillslope of anticlines and in the low relief areas (Fouad, 2014; Jassim & Goff, 2006). The anticlines within the foothills are widely spaced and the synclines between them create swales and plains filled by various Quaternary sediments, including alluvial fans and floodplain deposits. As a consequence of recent tectonic activity, fluvial terraces and part of the alluvial plain are tilted following the deformation pattern of the main orogen (Figure 1).

The KRI and adjoining regions have been inhabited since at least the Middle Palaeolithic (Morandi Bonacossi, 2017), as confirmed by various occurrences such as the archaeological site of Shanidar Cave, where nine Neanderthals were buried (Solecki, 1971). Since the late Upper Pleistocene, hunter-gatherer communities began to intensively exploit plants, especially wild cereals and legumes (Conati Barbaro et al., 2016, 2019). However, the agricultural revolution and its economic and social changes appear in the Neolithic (Bader, 1993; Kozłowski, 1998, 2002; Watkins et al., 1989),

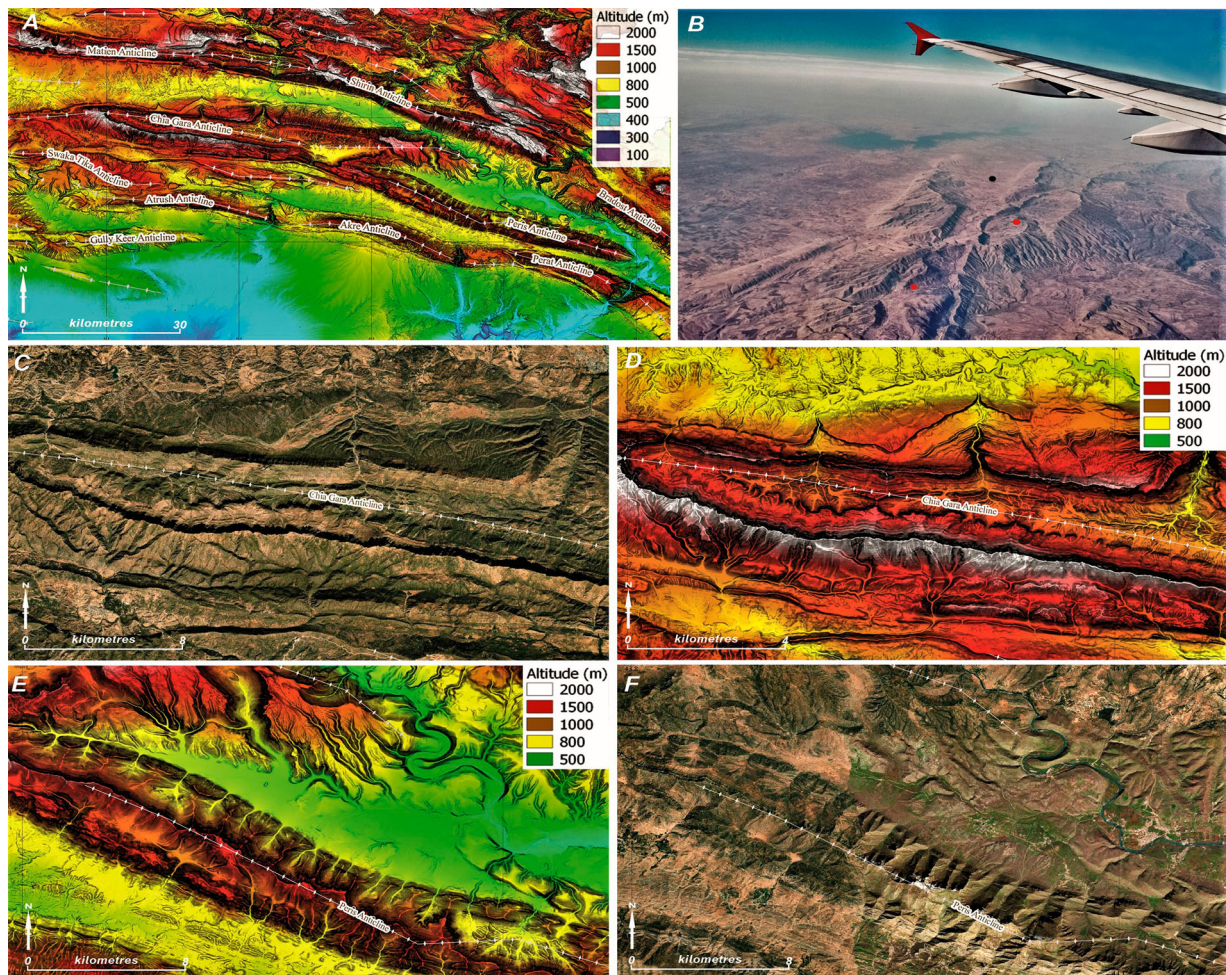


Figure 1. (A) DEM illustrating the distribution of anticlines and synclines in the eastern part of study area. (B) Oblique aerial picture showing the general geomorphological aspects of the Zagros Mountains with erosional anticline valleys (red dots) and syncline valleys (black dots); in the background, the Mosul Dam Lake. (C and D) Hogback hillslope of Chia Gara Anticline as Esri World Imagery and DEM. (E and F) Cuestas hillslopes of Peris Anticline as DEM and in Esri World Imagery.

when the major sites (here called *tells* or *mounds*) show a complex architecture and an economy based on agriculture and herding during both the pre-ceramic and ancient ceramic Neolithic (Braidwood, 1983; Matthews et al., 2016, 2019). Since the Bronze Age, the study region was intensively occupied, with a dense network of permanent settlements that developed into large tells that remained active through the Islamic era, and a landscape that was intensely modified.

3. Methods

Mapping of the area was performed on data interpreted from both remote sensing images and field observations, according to the approach proposed by several authors for mapping arid and semi-arid regions (Azzoni et al., 2017; Costanzo et al., 2021; Hüneburg et al., 2019; Perego et al., 2011; Zerboni et al., 2015, 2020).

Data analysis from remote sensing was derived from several available datasets. Recent (11 August 2019) multispectral images (visible and infrared)

with up to 10-metre spatial resolution from ESA Copernicus Satellite 2A (tiles T38SLF, T38SLG, T38SMF, T38SMG, T38SKF and T38SKG, source: <https://scihub.copernicus.eu/>) (Copernicus, 2019) were composed in false colours (visible + near infrared). Images were then projected to UTM Zone 38 reference system and used as the background for remote observations in QGIS software. An AW3D30 Digital Surface Model (DSM) with 1° horizontal resolution (~30 m at the equator) available on the Japan Aerospace Exploration Agency (JAXA, 2020) platform was reprojected to UTM Zone 38 with 30-metre spatial resolution. Contour lines at 100 and 250 m derived from this model were used for landform interpretation as well as hillshade and slope models. An elevation-dependent colour scale was applied to the Digital Elevation Model (DEM), imported in QGIS and superimposed over a hillshade, in order to observe specific landforms (river terraces, water and wind gaps and alluvial fans). The channel network was extracted from the DEM using SAGA software. Results were reliable in the mountainous area, while the automatically rendered model of the alluvial

plain was manually corrected using satellite and field data. Other than topographical and satellite visual information, the Arbeel-Mahabad, Al-Mosul, Zakho and Kani Rash quadrangles (1:250,000 sheets) of the Series of Geological Map of Iraq helped define the bedrock geology and delineate linear structural features and occasionally supported the recognition and interpretation of landform features and trends. High-resolution (0.5–1 m) natural colour satellite images provided from Esri World Imagery (Esri, 2020) and visualised in QGIS were used to identify and validate detail and small-scale landforms. Declassified Corona Images were also used to observe the fluvial pattern of the part of the Tigris River below the Mosul Dam Lake before its construction (USGS, 1968).

Several field surveys confirmed and validated the geomorphological elements detected during the desktop study. The field survey included the Zagros Mountains, the low relief fluvial plains, and foothills, and the area of the Mosul Dam Lake, which was investigated for Late Quaternary sedimentary sequences. Some features recognized in the field were discussed in the following parts, but not included in the Main Map due to the scale of representation. Such elements include small scale karst landforms, anthropogenic features, and gorges.

4. Main geomorphological features

4.1. Structural landforms

Most landforms in the study area are directly or indirectly related to the effect of on-going convergence: the formation and orientation of mountain

ridges and valleys are direct surface expressions of tectonic folding, as well as the evolution of other landforms (see following sections). Since the Messinian, intense uplift affected the relief of the KRI area (Zebari et al., 2019); progressive development of the numerous anticlines (Al-Obaidi & Al-Moadhen, 2015) that are oriented E–W to the west of the Greater Zab River (namely the Tsawoq, Matien, Be'khair, Ber Bahr, Al Qosh, Gully Keer, Dahkan, Zainiyat, Geri Baran, Duhok, Atrush, Swaka Tika, Ravan, Chia Gara, Shirin, Peris, Akre and Perat Anticlines), and NW–SE to the east of the Greater Zab River and in the south lowland (the Kand, Shaikhan, Maqloub, Barda Rash, Bashiqa, Ain Al Safra, Bradost, Sarta Anticlines). In the western sector of the study area, between Dohuk and Zacko, the Gera Ban and Be'khair anticlines show little different change in direction due to an en-echelon system faults, that were active during the Quaternary (2020). Rock weathering (mainly karstic dissolution) and linear erosion affected anticlines in subsequent phases, shaping specific landforms according to the different dipping of strata (Figure 2(A)). Along monocline slopes, cuestas develop in forelimbs and along the gently dipping strata, while hogbacks are in the inner limbs marked by steeply dipping strata (Hasan et al., 2019; Sissakian, 2014) (Figure 2(B)). In the Main Map, these features were not differentiated mostly because the different exposure of satellite images hamper their immediate attribution to one of the previous categories. However, several forelimbs and toe of anticlines showed very evident slope triangular shape mapped as flatiron areas (Figure 2(C)).

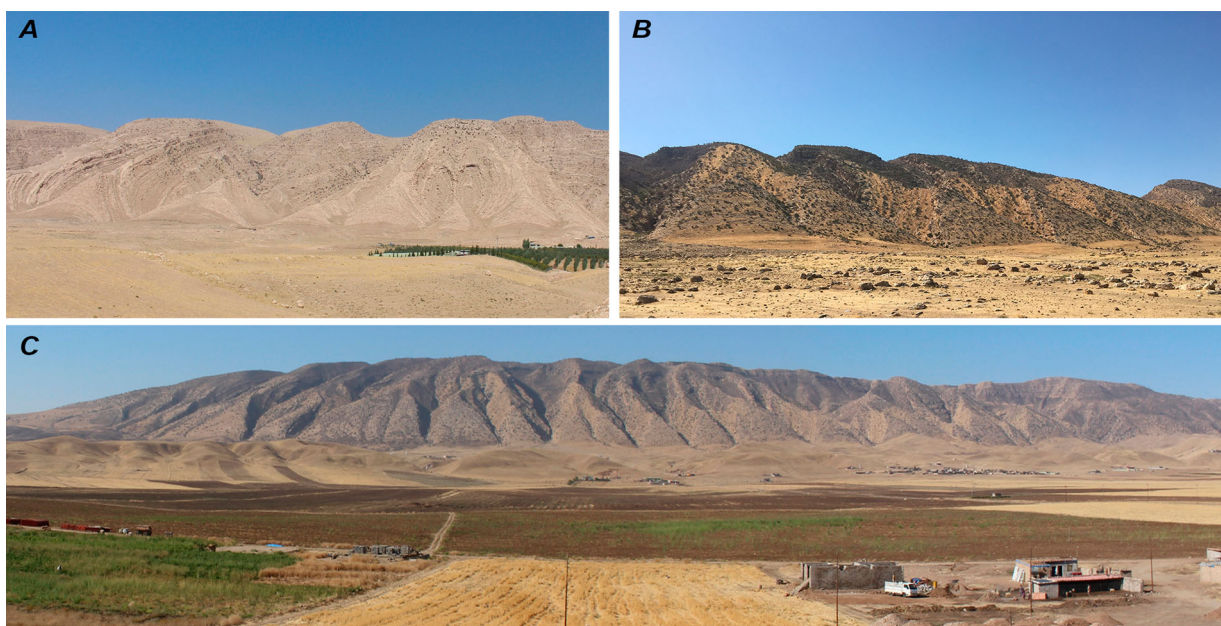


Figure 2. (A) A slope of an anticline near the Atrush Valley. Notice the combined result of erosion and karst weathering on deformed rock strata. (B) Detail of a flatiron along the slope of an anticline. (C) Panoramic view on northern slope of the Jebel Maqlub Anticline.

4.2. Hillslope landforms

The slopes of monoclines are influenced by processes controlled by gravitational forces. The presence and relevance of mass movements is documented in the area by Sissakian et al. (2016), most of them at a scale not compatible with the one of the Main Map. The largest slope landforms are represented by deep-seated gravitational slope deformations (DSGSD, *sensu* Dramis & Sorriso-Valvo, 1994) usually several hundred meters high. Their occurrence is occasional, but widespread over the whole study area, mostly in relation to the southern slopes of the anticlines. DSGSDs, as those along the Dohuk, Swaka Tika, Al Qosh and Bradost anticlines, are controlled by the structural orientation of strata in the dip-slope direction. The age of Al Qosh landslide is estimated about 3000 years (Sissakian et al., 2016). The presence of faulting and dipping strata is usually a main control on the formation of DSGSDs on sedimentary bedrock, influencing their occurrence and geomorphological development (Mariani & Zerboni, 2020).

A gentle slope is present at the junction between anticline foothills and alluvial plains; it consists of a belt of pediment or peneplain composed of fine to coarse alluvial sediments derived from the dismantling of upland rocks. When these pediments development along unconfined valleys they are affected by sheet erosion and exploited for cultivation. The fine grained and unconsolidated conglomerates slopes and foot-slope are characterized by intense gully erosion by overland flow, resulting in a badlands landscape (Figure 3). In the proximity of the Akre city, Plio-Pleistocene conglomerates bajada spread out at foot-slope of Perat anticline. Near the Great Zab River,

conglomerates are dissected by several rills and gullies; in some locations, they are tilted by neotectonic (Sissakian et al., 2014) (Figure 3). In the western part of the area and at the northern border with Turkey, the low gradient hillsides of silty-clay to arenaceous limestone and the Quaternary unconsolidated bedrock outcrops is dissected by strong gullies erosion, due to unconcentrated overland flow to sculpt a badland landscape (Figure 3).

4.3. Karst landforms

Karst related processes are very active in the study area, especially well expressed in the mountains, where the combination of tectonic deformation, uplift and climate-related processes produced epikarst and ipokarst landforms (Fouad, 2014; Sissakian et al., 2015). The most evident karstic landforms formed by the combination of prolonged deep and surface dissolution, fluvial erosion, vertical uplift and a further lithological constraint due to limestone resistance to erosion (Zerboni et al., 2020). The interaction of these processes produces a complex system of incised deep gorges, canyons and gullies erosion on monocline limestone slopes and some large polje-like depressions that open towards the main drainage systems (Stevanović et al., 2009). Small to medium-scale visible epikarst landforms are evident in the field. Karst pavements, walls with grikes and clint, and solutional flutes (rillenkarren) are evident along the flanks of the Atrush and Chi Gara anticline ridges. Many caves and rock shelters open along the slopes of the Zagros Mountains and at the head of valleys; in the study area, underground networks were not

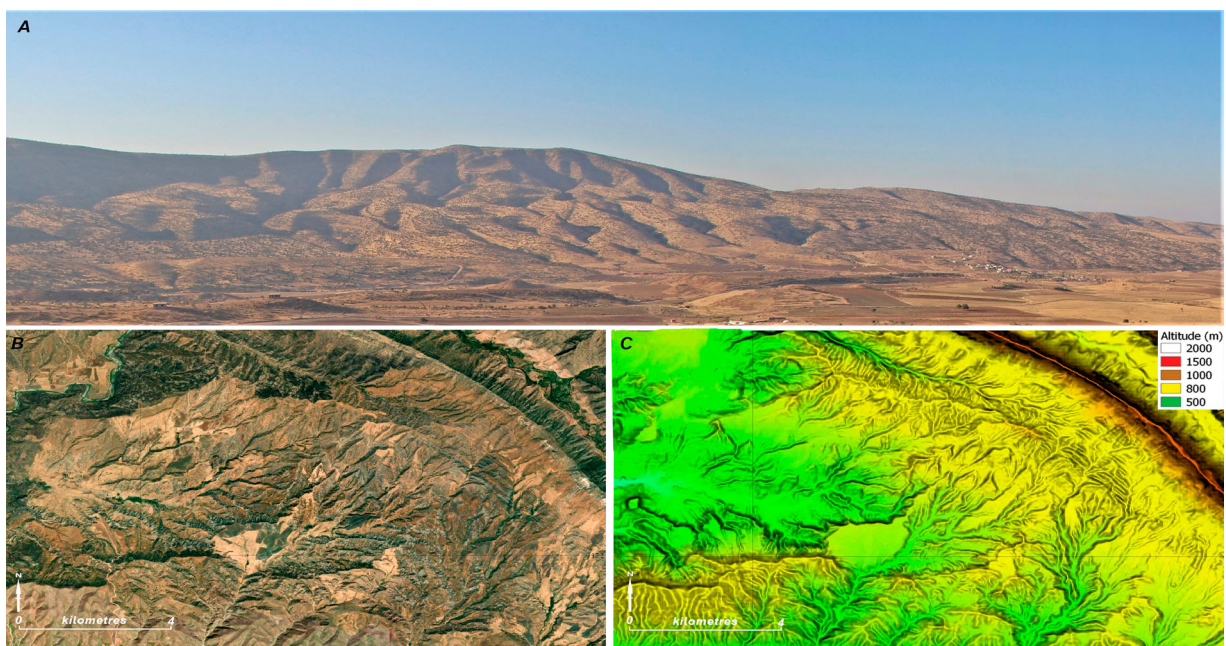


Figure 3. (A) A pediment along the Atrush Valley; the anticline is dissected by gully erosion. (B and C) Badland landscape of Zacko town in Esri World imagery and DEM.



Figure 4. Examples of karst landforms. (A) Caves entrance (or rockshelters) along the hillslopes of the Atrush Anticline. (B) Limestone pavement on the Chia Gara Anticline (Esri World Imagery). (C) Karst dissolution along vertical fractures of a limestone wall. (D and E) Speleothems inside caves. (F) Karst pinnacles in the central Zagros Mountains. (G and H) Rillenkarren on bare limestone.

systematically explored, but like elsewhere in the KRI, speleogenesis resulted from hypogenic and epigenic processes (Laumanns et al., 2008). The local caves and rock shelters preserve important archives of human and climate changes during the late Quaternary (Conati Barbaro et al., 2019; Flohr et al., 2017).

Springs, also exploited by humans for agricultural purposes since the Bronze Age (Morandi Bonacossi, 2018), are further evidence of the underground karst system in the KRI. The spring discharge is influenced by rainfall regime, size of catchment area, and aquifer residence time, seasonal or intermittent activity; only a few springs are perennial (Figure 4)

4.4. Fluvial landforms

The Tigris River and its tributaries Khabur, Rubar Dohuk, Khosur, Nahr-al-Khazir and the Great Zab are the main water network of the northern KRI. In the mountains, rivers follow a NW–SE trending

pattern according to the regional structural setting, while fluvial patterns inside the plain are almost all N–S oriented except for the Khabur River, which displays a N–S to W trend. The Tigris River has a high degree of sinuosity and a regularly meandering course in most of the area, where it incises sandstones, marls and evaporites. The Khabur River has a linear to meandering pattern in the mountain area, which changes into irregular meandering channels in the lowlands. The Great Zab River is braided before it reaches Dereluk plain, where its pattern becomes a linear to irregularly meandering; after cutting through the Perat Anticline, and as its course traverses Plio-Pleistocene conglomerates, it develops anastomosing-irregular meandering channels. The growth of anticlines, the presence of different lithotypes and climate changes drove the evolution of these drainage systems into a major river network of asymmetrical and symmetrical branch tributaries.

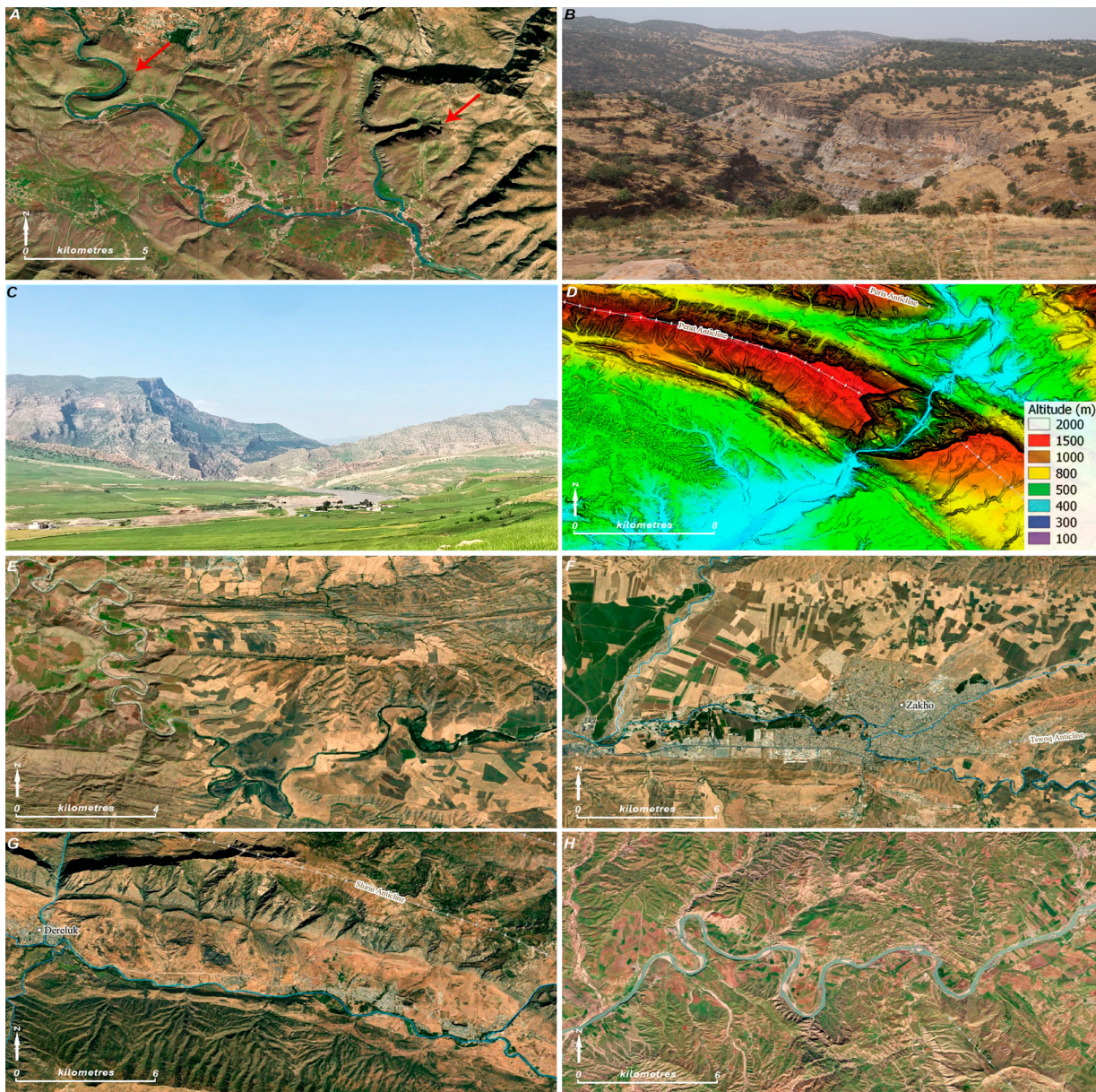


Figure 5. Examples of fluvial landforms. (A) Esri World image of the Great Zab and one of its left tributaries; arrows indicate deeply incised meanders. (B) Field pictures of a gorge valley near the Atrush village. (C) Panoramic view of a Great Zab water gap in the Perat Anticline. (D) DEM of the Great Zab water gap in proximity of the Perat Anticline (eastern sector of the study area). (E) Esri World image showing the meandering to tortuous channel pattern of the Khabur River, south of Zacko town. (F) Esri satellite image showing the low sinuous channel pattern of the Khabur River in proximity of Zacko town. (G and H) Esri World image illustrating changes of channel pattern along the course of the Great Zab River; from upstream to downstream, it shifts from low sinuous (G) to meandering channel (H).

Water gap and wind gap gorges form actual to ancient routes allowing the Great Zab, Khabur, Nahr-al-Khazir, Rubar el Atrush and Rubar Dohuk rivers to flow from the Zagros valleys to alluvial plains. Several water and wind gaps cut the Akre, Perat, Atrush, and Dohuk anticlines. Some of the major water gaps are the deep gorges of the Greater Zab, Kabur and Nahr-al-Khazir Rivers, where canyons reach 300 m deep; many other small canyons exist in the area of Dohuk (Al-Obaidi & Al-Moadhen, 2015; Fouad, 2014; Zebari et al., 2019). Here, the distribution of wind and water gaps reflects the response of the fluvial network to ongoing uplift (Burbank &

Anderson, 2011; Burbank & Pinter, 1999). Along syncline valleys, the main rivers have several perpendicular tributaries and flow along symmetric valleys, whose shape are controlled by tectonics. Along the Khabur, Great Zab and Nahr-al-Khazir Rivers some tributaries show a braided pattern with coarse to medium size bars; others follow instead a mature meandering pattern with several changes in sinuosity. Different fluvial patterns depend on both bedrock lithologies and flow regime; on conglomerate, rivers display a braided pattern, whereas they meander while traversing fine clastic sediments. Abandoned and occasional deeply incised meanders are evident

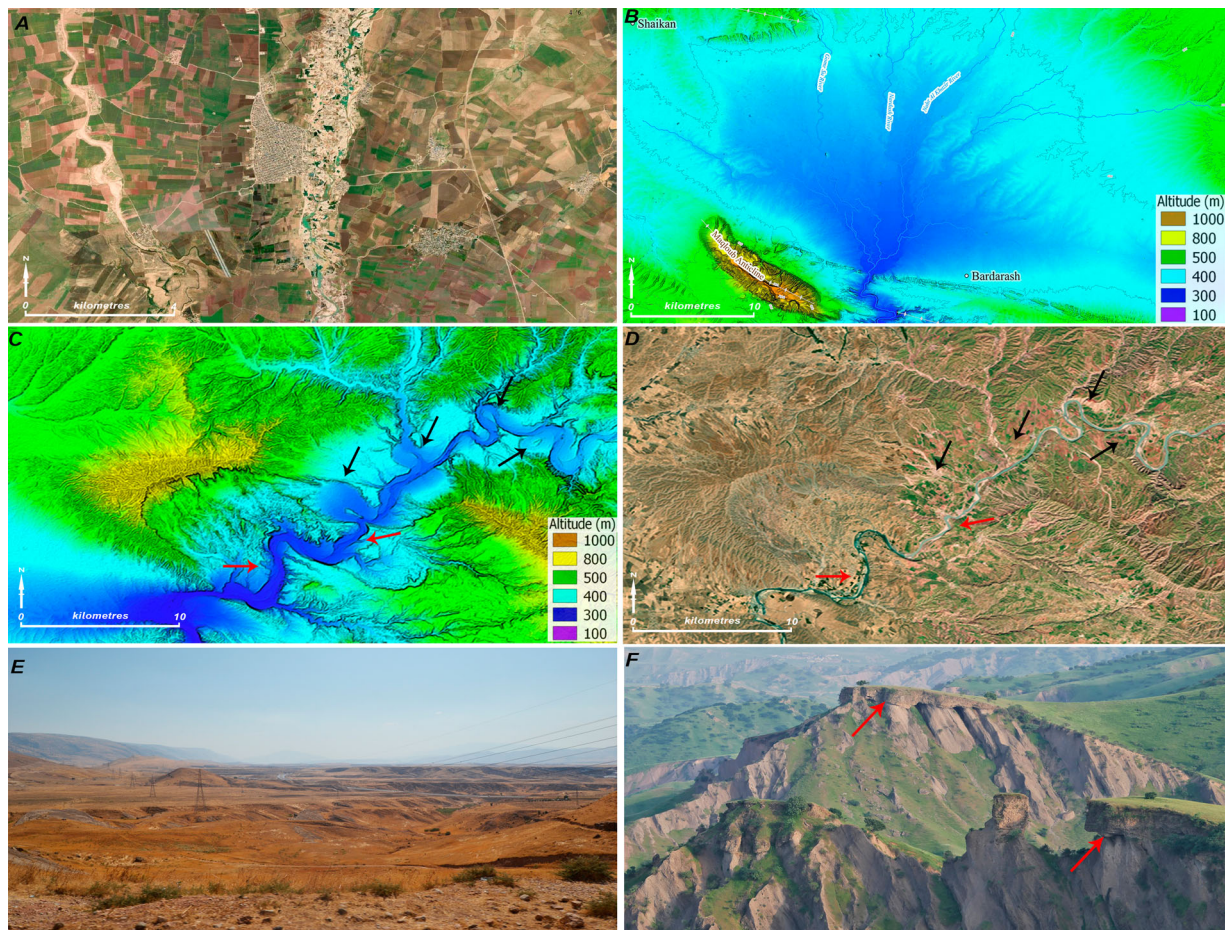


Figure 6. (A) Esri World image of the Nardush–Gomel Su alluvial plain; notice the belt of anastomosing channels of the Nardush River. (B) The DEM of the same area of (A) reveals the dendritic pattern of the drainage system. (C and D) DEM and Esri World image of the Great Zab River illustrating the meandering to sinuous straight channel belt; abandoned meanders (black arrows) and the effects of erosion forming an anticline valley (red arrows) are evident in the DEM. (E) General view SE of the Akre village showing several levels of terraces. (F) Field picture of tilted alluvial terraces (red arrows) (modified from Zebari et al., 2020).

along the Great Zab and Nahr-al-Khazir catchments (Figure 5).

The lowlands are covered by floodplains; the largest one belongs to the Nahr-al-Khazir and Gomel Nardush fluvial system; it consists of coarse gravels overlaid by fine sand, silt and clay deposits and interlayered pebble lenses with erosional surfaces (channel facies) (Sissakian et al., 2014). Along the Tigris, Great Zab, Khabur and Nahr-al-Khazir Rivers fluvial terraces are present at different elevations; they incise fluvial gravel and conglomerates of former alluvial fans, and some are tectonically displaced. The Great Zab River has at least 3/4 levels of fluvial terrace cut into Plio-Pleistocene and Holocene conglomerates and fine to medium sand bodies (Al-Dabbagh & Al-Naqib, 1991; Sissakian et al., 2014, 2015). On the Main Map, four different terrace levels are represented and labelled T1, T2, T3 and T4, progressively upper and older. The younger terrace levels (T1, T2 and T3) are composed by fine-grained sand with basal lenses of conglomerates cupped by silty-clay sediments. The T4 terrace consists of conglomerates with interlayered lenses of fine to coarse sand.

Runoff discharge from the mountains accreted several alluvial fans along the anticline foothills, which connect the steep mountainsides to the plain below. The largest is located near the Al-Qosh and Dohuk municipalities; Plio-Pleistocene alluvial fans are also evident along the Akre-Great Zab transect. In this area, alluvial fans are composed by conglomerates deeply incised by ephemeral streams; they are also strongly tilted by Quaternary tectonic activity (Figure 6).

In the 1980s, a large dam was built along the course of Tigris River (upstream of Mosul) creating an artificial lake basin and submerging ca. 350 km² of the region around the Tigris canyon, including hundreds of archaeological sites (Sconzo & Simi, 2020). Observations of declassified Corona aerial photographs helped identify the course of the Tigris River before the construction of the dam. It meandered inside deep gorges with scroll and point bars along convex banks; four levels of fluvial terraces can be spotted along its submerged course. Such terraces recorded the lateral migration E to W of the river, and a progressive transition from a continuous meandering to a braided pattern (Al-Dabbagh & Al-Naqib, 1991).

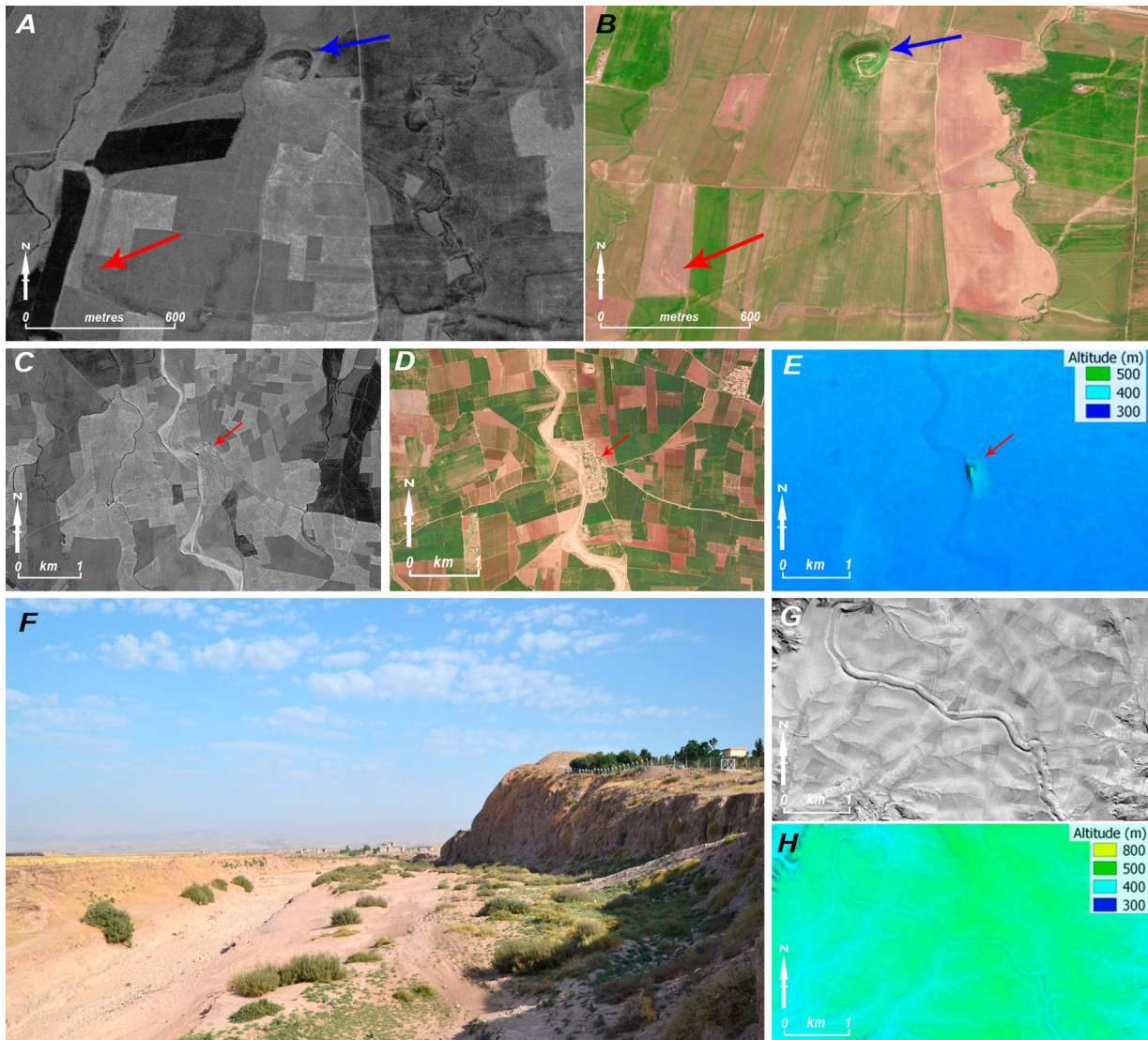


Figure 7. (A and B) Declassified Corona image (acquisition 16 August 1968) and Esri World image illustrating the Nardush alluvial plain; such images are helpful to identify anthropogenic landscape features as in the case of Tell Mubarak (blue arrow) and Khinis canal (red arrow). (C–E) Corona image, Esri World image and DEM showing Tell Gomel (ancient Gaugamela), along the Gomel Su River. (F) Field picture of Tell Gomel illustrating the destructive effects of fluvial erosion along the hillside of the tell. (G and H) Declassified Corona image and DEM of a well-preserved part of the Bandwai Assyrian canal, which can be interpreted in context with the natural hydrographic network.

4.5. Anthropogenic landforms

Anthropogenic landforms – created by artificial processes – are present and testify to the long-lasting human exploitation of the KRI. The most important cultural features are tells and artificial canals. Tells are raised mounds, very common in the archaeological landscape of the Near East, marking the location of ancient settlements and formed by the accumulation of anthropogenic sediments after several millennia of activity (Miller Rosen, 1986). Tell mounds are truncated cones with sloping sides, up to a few tens of metres high. They are common in the floodplains (Dohuk, Gomel Su plains) and along valleys (Atrush Valley) and are generally distributed along active streams or palaeochannels where they often offer an elevated position exploited by modern villages.

Canals are anthropogenic landforms typical of this part of Mesopotamia and were built by the Assyrians from 900 to 600 BC. The better-preserved system of canals, still evident in the field and from high-resolution satellite imagery were built by king Sennacherib (Morandi Bonacossi, 2018; Ur, 2005). Artificial canals were excavated in the geological bedrock, roughly following contour lines. Their intended function was to collect water from springs and streams at the foothills of the Zagros Mountains and convey it to the lowlands and Nineveh, the capital of the kingdom, for irrigation purposes (Figure 7).

5. Conclusions

Geomorphological analysis and mapping of the North Kurdistan Region of Iraq offers important insights about the active tectonic and climatic processes that

affected landforms and fluvial development during the Neogene–Quaternary. Different physiographic units in this complex landscape reflect the uplift and exhumation rate of the anticlinal ridges and syncline troughs. In fact, the presence of tilted alluvial fans and fluvial terraces or the development of water and wind gaps are clearly related to geomorphological processes triggered by tectonic. The analysis of further data on tectonic control over the evolution of the fluvial pattern of the Tigris River is ongoing, but preliminary data suggest that the same lithological and structural factors influenced the meandering pattern of the river north of the Mosul Lake Dam and the dynamic of the lake itself. Also, the evolution of the area is influenced by climate variations, especially after the Last Glacial Maximum, when the succession of dry and wet periods influenced erosion and karst processes. Finally, Late Quaternary human activities become progressively more impacting on the natural landscape: from the one hand, humans built monumental canals that are quite evident in the field and altered the local hydrography. On the other hand, a more intense and widespread modification of the landscape occurred when land use strategies shifted towards pastoralism, thus becoming progressively more impactful with the development of more complex societies (Zerboni & Nicoll, 2019). In conclusion, our geomorphological mapping of the northern KRI suggests that the interaction between endogenous and exogenous processes led to a complicate landscape. Since the late Cenozoic surface processes were modulated by lithological and structural factors, and climatic fluctuation and, more recently, by human agency.

Software

The project map and all shapefiles were realized using QGIS 3.4. Terrain analyses for DEM and hydrographic network were carried out in SAGA 2.3. Particular observation from satellite images was done with QGIS 2.3 viewer and Google Earth Pro 7.3.

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