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Geomorphological Analysis for Wadi Mousa Region / South of Jordan using the Digital Elevation Model

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Abstract
This study aims at analyzing the geomorphology of Wadi Mousa region by identifying the land units that make up the region using the Digital Elevation Model (DEM). The study also includes the analysis of geomorphological processes impact on determining the morphology of the landforms for the region and connecting the morphological variation in Landforms with the topographical, geological and climatic characteristics of the region. The (DEM) is considered to be a suitable modern technology for the analysis of the geomorphology of Wadi Mousa region; as the region is characterized by extreme variation in heights and by severity of rugged territory, where heights ranged from (900-1600) meters above sea level.In its methodology to analyze the geomorphology of the region using the (DEM), the study relied on employing Arc GIS version 10.2 and its applications Arc catalog10.2, Arc Map 10.2, Arc Scene 10.2; as well as using the applications of Global mapper 15 program to build the (DEM) of the studied region and analyze its landforms geomorphological characteristics. The results showed a diversity of landforms as the geomorphological analysis showed six major land units, namely: the planation surfaces, the erosion slopes, the valley streams, the alluvial terraces, the rocky terraces, and erosion hills. These units vary in their geomorphological and morphometric characteristics as a result of multiple geomorphological processes that contributed to their formation. The most important of those processes are the tectonic movements that affected the region in the past geologic periods and the subsequent noticeable water erosive forces in rainy periods.
Keywords: Wadi Mousa, Digital Elevation Model (DEM), Geographical Information System (GIS), Geomorphological Analysis.

1. Introduction:

The Digital Elevation Model (DEM) is one of the Geographic Information System applications that have been commonly used in many geomorphological studies over the past three decades. This application provides modern technology which enables the researchers to analyze the geomorphology of regions and drainage basins (Hadi and Shahid, 2010; Mirza et al., 2011; McDowel, 2014). The model also helps in determining the land units and analyzing their geomorphological characteristics to determine the appropriate uses of these units in accordance with their geomorphological characteristics. Moreover, the model determines the geomorphological problems that limit the appropriate usage of these units (Demetre and Aneglos, 2003). In the analysis process, the (DEM) relies on setting up a Triangulated Irregular Network (TIN) map as a basic map created through linear data, whether in the form of a point, a line, a polyline, or a polygon. The geometric construction of this map consists of adjacent and non-intersecting triangles, each triangle has three heads, each head has known coordinates (X,Y) as well as (Z) value which represents the height. The group of the triangles represents the (TIN) model.

The following is an explanation of the various geomorphological studies that used the Digital Elevation Model in geomorphological analysis process for regions that vary in their natural characteristics:

- Manjare and Suyog (2013) used the (DEM) in analyzing the geomorphology of Salbardi region and adjoining area in India. The researchers managed by using the model to analyze the geomorphological features in the study region and identify its geomorphological characteristics.
- Jian et al (2012) analyzed the geomorphology of the devastating earthquakes regions that occurred in (Wenchuan County, Sichuan Province, China) using remote sensing data and the (DEM). The researchers were able to identify the seismic-active regions. The analysis showed the role of geological and topographical variables - such as rock competence, slope, proximity to drainage, and fracture – in increasing the severity of earthquakes destruction.
- Liu et al (2012) studied the spatial analysis of the risks of floods that occur in the eastern tributary of the Pearl River in China using the (DEM). The Model was used to estimate the flooding area and the hydrological measurements. The study found a correlation between the flooding area and the flood frequency.
- Toudeshki (2011) showed in his study the importance of using the (DEM) in analyzing the morpho-tectonic processes in Ghezel Ozan River basin. The researcher managed to identify the regions that were affected by those processes.
- Marianne et al (2010) used the (DEM) to analyze the stream gradient index to evaluate the tectonic effects in

the Normandy intra plate area, north-west France. The digital analysis showed that the stream length (SL) index has been used to characterize the fluvial systems in relation to tectonic movements.

- Chrestoph et al (2009) studied the geomorphological characteristics of landforms in the middle of Crete using the (DEM). The study showed that the variation in the geomorphological characteristics of those landforms in terms of shape and size is due to a combination of variables, namely: the geological setting, the climatic impacts, the neo-tectonics and the elevation.
- Maria et al (2007) used the (DEM) in the Geographic Information System to analyze the relationship between the vegetation community distribution and the landforms characteristics in Ajusto Volcano in Mexico. The study was based on fieldwork data and the interpretation of aerial photographs scale (1:20000). The study showed the importance of landforms characteristics in determining the quality of vegetation community types. The most important of those characteristics are the gradient and slope shape.
- Cheng et al (2006) used the (GIS) modeling for predicting river runoff volume in ungauged drainages in the Greater Toronto Area, Canada. The study showed that the variation of runoff volume is due to the variance of drainage basins characteristics, and the variance in the characteristics of soil and land topography.

This study is a scientific addition. It is characterized by using advanced technology in the analysis of the geomorphology of Wadi Mousa region besides the fieldwork. This analysis included the study of the role of the geomorphological variables in determining the topography of the region and the creation of morphological variation in its landforms.

2. The Problem of the Study and Its Objectives:

Wadi Mousa region is characterized by complex geomorphological and topographical characteristics. The topography of the region's surface represents a product of many overlapping geomorphological variables that affected the topography of the region during the period from the Miocene Epoch until the Quaternary Period. The Digital Elevation Model is one of the effective technical means in the analysis of the topography and geomorphology of regions due to its extraordinary ability to analyze the ground surface especially regions with small areal dimensions and with complex topography. Moreover, the (DEM) helps to achieve the objectives of the research which include the following:

1. Analyzing the geomorphology of Wadi Mousa through identifying the land units that form the region using the (DEM).
2. Correlating the geomorphological variation of Wadi Mousa region with its topographic, geological and climatic characteristics.
3. Analyzing the morphometric and gradient characteristics of the major land units.
4. Measuring the morphometric characteristics of water network in Wadi Mousa and identifying the watershed areas.

3. Research Methodology:

Phase I: This phase is exemplified in determining the study region and examining its natural characteristics based on the topographic maps of Wadi Mousa region scale (1: 25,000) for the year 2010, issued by the Royal Geographic Center; and the geological maps scale (1: 100,000) for the year 20005, issued by the Natural Resources Authority, in addition to the available climatic reports and data for the study region.

Phase II: In this phase, the study used the Arc GIS version 10.2 and its applications Arc catalog 10.2, Arc Map10.2 and Arc Scene 10.2 for analyzing the geomorphology of the study region. The study also used the applications of Global mapper 15 program. The following is an explanation of the uses of these applications in this the study:

- **Arc catalog:** this application was used to prepare the graphic files type (Shape File) that belong to the study region after determining the spatial coordinate system of the study region. The metric system UTM was adopted.
- **Arc Map:** this application was used to process the topographic map of the study region which was introduced to the application in the form of image with unknown coordinates. The coordinates were entered by the tool (Georeferencing). Then, the image was geometrically corrected using the tool (Rectify). Next, drawing the layers and geographic feature types which take the form of Line, Polygon Point, Polyline according to known coordinates, as the spot height and contour lines were drawn and their values were saved in the geo-database.
- **Arc Scene:** in this application, the 3d Analyst program was used to prepare the Triangulated Irregular Networks (TIN) map depending on the spots elevations that were entered to the study region through the Arc Map 10.2 application. This (TIN) was used as a base map for determining land units in Wadi Mousa region, analyzing its geomorphological characteristics; and preparing slope shade, gradient shade, and slope direction shade maps.

- **Global mapper 15** application was used to produce Polyphonic forms of the study region and making cross-sections of the study region.

Phase III: is this stage, the geomorphological characteristics of Wadi Mousa region was analyzed using (DEM). The digital maps derived from the GIS applications where used to determine the land units and analyze their morphometric characteristics through measuring these units using measurement tools available in the application Arc Map 10.2 and Global mapper 15. The results of these measurements were matched with the results of the field measurements.

4. The Study Region:
Wadi Mousa region is located to the northwest of Ma'an city, stretching between longitudes (35^{o} 26' and 35^{o} 33') east; and latitudes (31^{o} 14' and 31^{o} 21') north. The targeted area of Wadi Mousa is about (50 km^2). This area is suitable for conducting a detailed geomorphological analysis using the (DEM), as the accuracy of the (DEM) analysis increases with smaller studied areas (Figure 1). The population of the study region is about 13470 (Al-Hussein Bin Talal University, 2012).

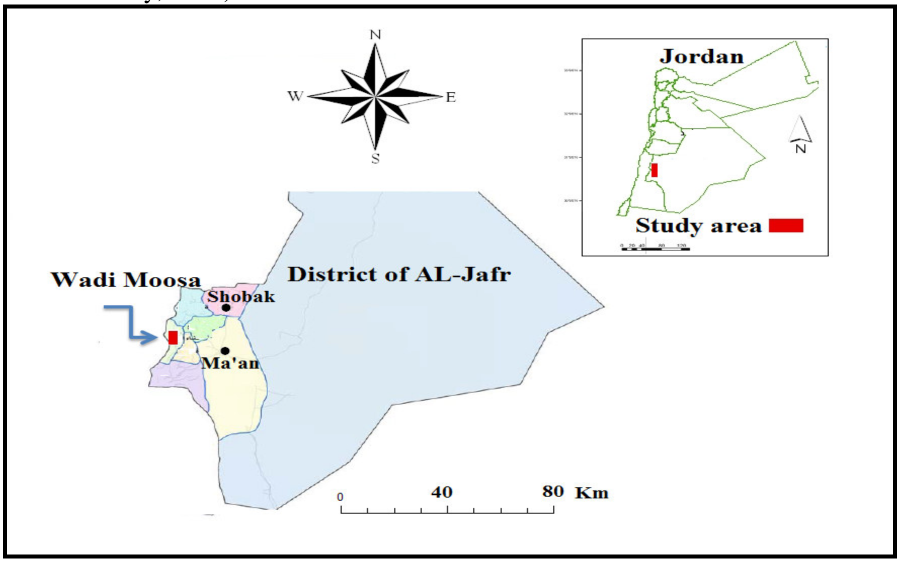

Fig 1.Wadi Mousa region

In terms of climatic conditions, Wadi Mousa region is located within the semi-arid climate range. The annual rainfall average is about (250 mm), and the annual temperature average is (16.7^{o} C). The daily relative humidity average is (43.8%), while the monthly evaporation average is (233.1 mm) (Meteorological Department, 2004).

Wadi Musa region is a suitable environment for the study. It is a model that its results can be generalized to other regions with similar geomorphological characteristics. The region is characterized by diverse land units. This diversity has been linked directly to the change in the climatic conditions and the geo-tectonic structures which directly influenced the topography of the region's surface and the variation in its morphometric characteristics. The morphometric characteristics of the land units have theoretical and practical geomorphological indications, as they shed light on the environmental and basin rules through which the region evolved.

5. The Geological Structure of Wadi Mousa Region:
The geological structure of Wadi Mousa region is the outcome of past geologic ages and the accompanying geomorphological processes in those ages that formed the geological structure of the region. The following illustrates the geological structure in Wadi Mousa region:

1. **Rock Formations:** the rock formations in Wadi Mousa are as follow:
   - **Limestone:** limestone – which belongs to Ajloun, Amman and Wadi Shoaib formations – prevails in the upper basin of Wadi Mousa. It constitutes the major part of the upper basins area which flow in Wadi Mousa, as it extends for a distance ranging from (0.5 - 3 km). These rocks are characterized by solidity and the presence of cracks, faults and joints. As a result of receiving high amounts of rain in the Pleistocene, the valleys in Wadi Mousa region have been able to deepen, trench and chop the ground surface. Hence, increasing the severity of its roughness and increasing the differences in its levels. Part of those rocks contain marl, dolomite and flint stone which directly affected the geological stability of the rock layers of

limestone. Limestone ability to collapse increases in rainy periods of in the winter after marl is saturated with water. These rocks go back to the Cretaceous.

- **Sandstone:** sandstone is found in the lower basin of the valley. It belongs to the formations of "Karnab, Um Ishreen, and Dici". It is characterized with little solidity; responsive to water erosion forces which led to deepening the valleys courses; multiplicity of colors; and its coarse mass structure which consists mainly of quartz and feldspar and silt. Sandstone thickness in some locations is more than (200 m). Its origin goes back to the Ordovician age (Natural Resources Authority, 2005).
- **Quaternary Age Rocks:** these rocks belong to the era of modern life. They consist of debris of limestone; gravels; sand; dust; and the remains of flint and clay. Quaternary rocks are the latest rock formations and sediment brought together in Wadi Mousa. They are found in the main course of the valley and on its both sides. Theses rocks are fragile and vulnerable to the forces of water erosion; which led to the widening of river divergence in this part of the river.

2. Faults and Joints:

The location of Wadi Mousa region near the edge of Wadi Araba fault which is an extension of the Jordan Valley fault affected the tectonics of the region. The structural and geomorphological evolution of the region is related to the tectonic processes that hit the Jordan Valley in the past geologic times. These tectonic movements led to ups and downs in the region which contributed to the variation in its geomorphological characteristics and to the formation of many folds and faults. There are many faults and joints in Wadi Mousa region that have affected its course. Wadi Mousa, Bir Khdad, and Qwairah faults are of the most important faults that affected the geological structure of the Valley and contributed to the complexity of the region's topography. Wadi Mousa fault extends from the north to the south-east; Qwairah fault runs from east to the west; while Bir Khdad fault extends from north to east.

6. Results and Discussion:

6.1. Topographic and sloping Characteristics of the Study Region:

The Triangulated Elevation Grid map which was made according to the (DEM) shows the complex topographic and sloping characteristics of Wadi Mousa region (Figure 2). It is clear from the analysis of these forms the great variation and diversity in the levels of the region's surface with heights ranged (900- 1600 m) above sea level (Figure 3). This topographic variation in a region with small area has directly reflected on its sloping characteristics. Hence, the region is characterized by diverse sloping categories, namely: flat areas with a gradient less than (5^o); areas of moderate gradient ranged between ($5^o – 10^o$); and steeper areas that appear in the form of cliffs with gradient more than (11^o) (Figure 4).

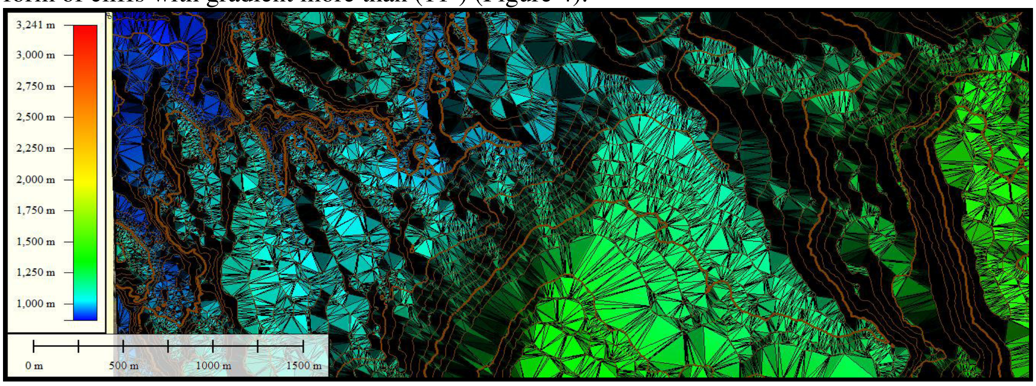

Fig 2. Irregular triangulated grid

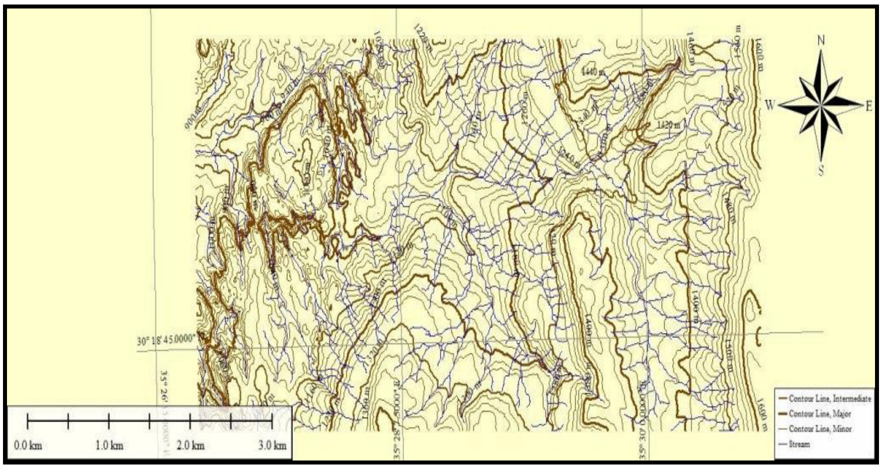

Fig 3. The contoured map of the study region

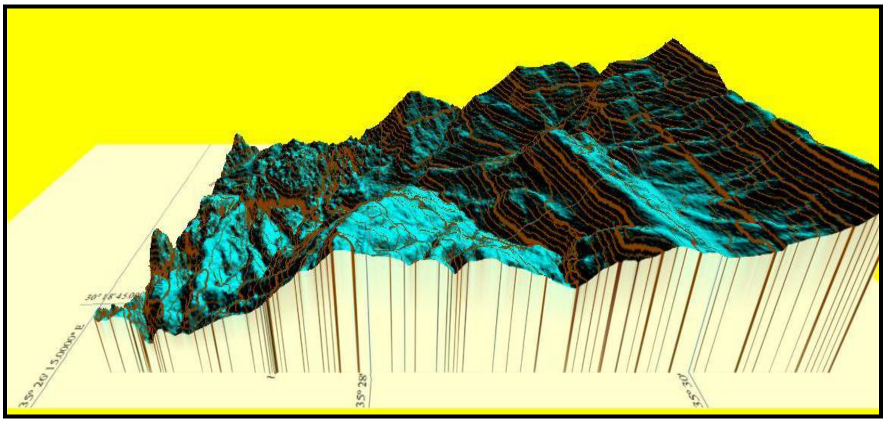
Fig 4.Three dimension 3D model shows the topography of Wadi Mousa region

The figures of slope shade, gradient shade, and slope direction shade show the degree of variation in the sloping characteristics within a region of small area, which classifies the region's surface within complex morphology. These figures also demonstrate the variation in the morphological shapes of the slope, which ranged between convex, concave and straight (Figures: 5, 6, 7).

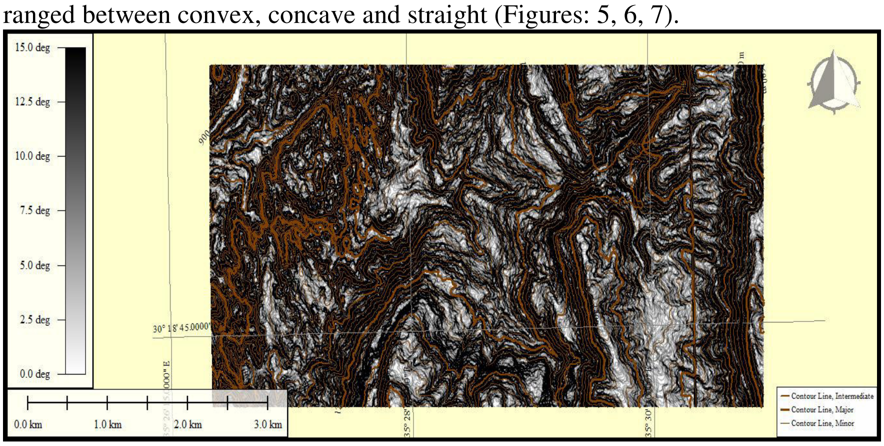

Fig 5. The slope shade map of the region

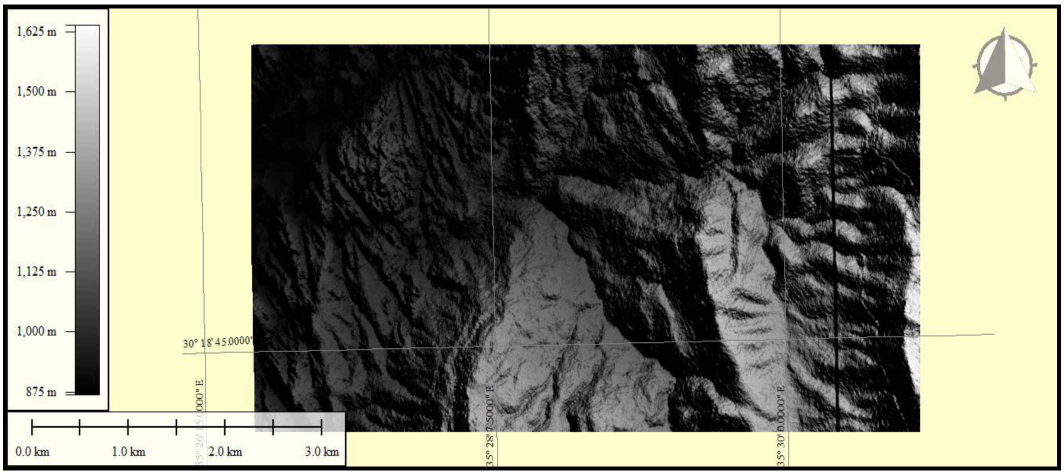

Fig 6. the gradient shade map of the region

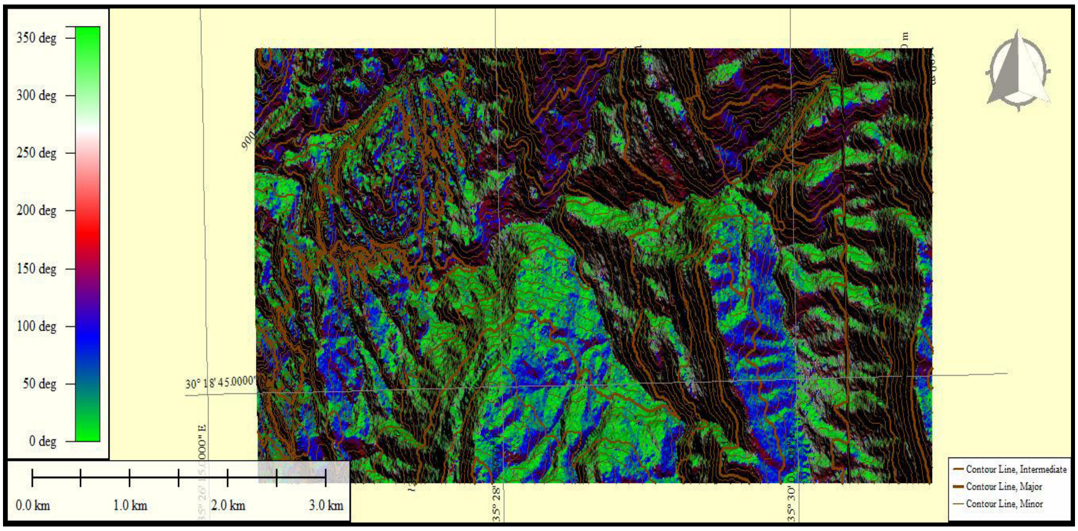

Fig 7. The slope shade direction of Wadi Mousa region

By analyzing the topographic cross-sections of Wadi Mousa, we find that the gradient was not distributed regularly along the section. The morphological shape of the section is related to the tectonic processes that hit the region in the Miocene age. Those tectonic processes have led to the decline in the lower basin of Wadi Mousa region towards Wadi Araba and the elevation in the northern and western upstreams (Figure 8).

Furthermore, water erosion processes in the Valley during the Quaternary age added to the complexity of the region's topography.

The relief ratio in the region reached (71 m / km). This ratio indicates an increase in the gradient of the region's surface, and the consequent escalation of the erosion processes.

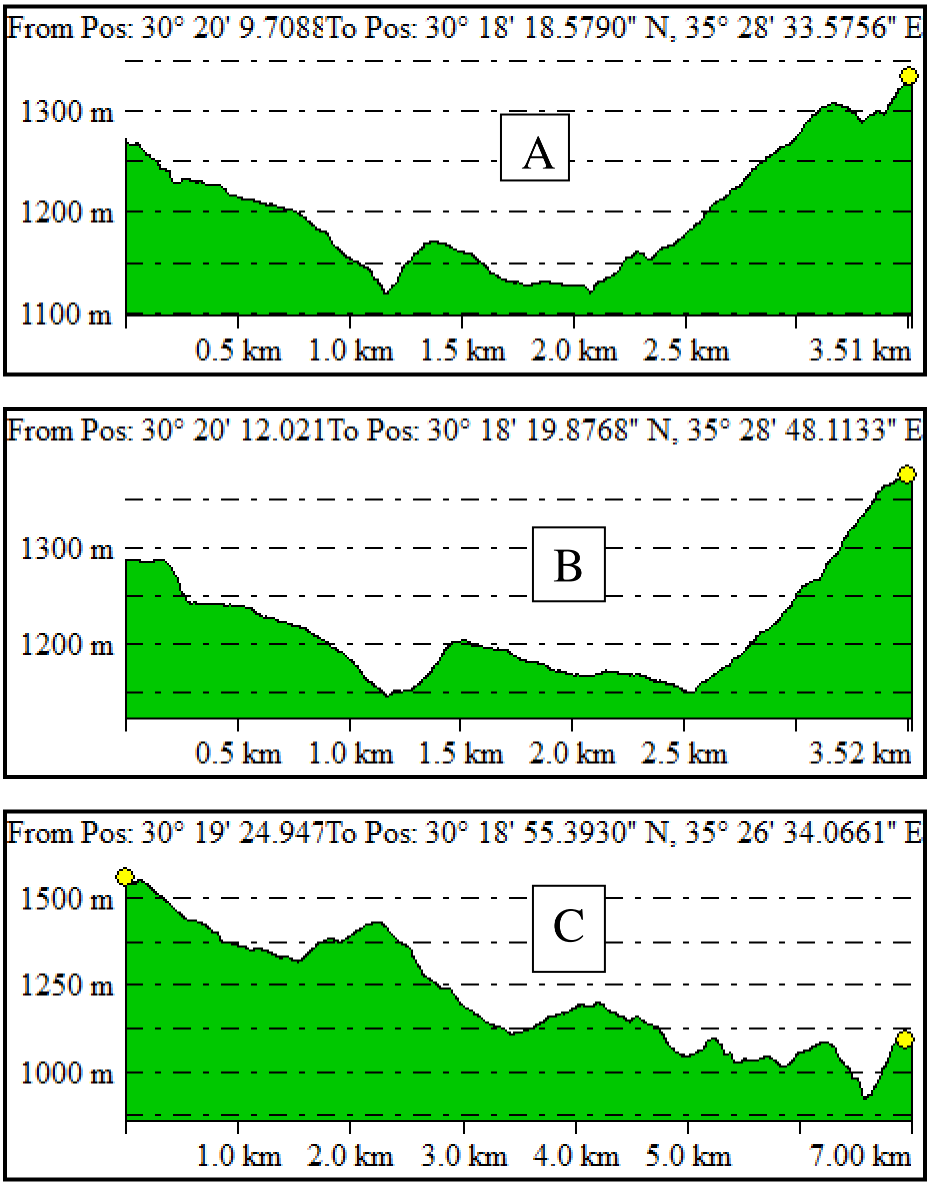

Fig 8. Cross-sections of Wadi Mousa region (A,B,C)

6.2. The Land Units and their Geomorphological Characteristics:

Several land units were identified in the region depending on maps and aerial photographs analysis, and field work. They were categorized according to their origin, evolution, and the geomorphological processes that have formed them. These units feature homogeneous rocks, soil, vegetation, and morphometric characteristics (Figure 9). Six major land units were identified in the region, namely:

1. **The Planation Surfaces:** represent the areas that the erosion processes made them leveled during Pleistocene era. The gradient of these surfaces does not exceed (6°). They are related to the tectonic movements, as the existence of a series of planation surfaces indicates tectonic movements that took place in the region, and led to a decline in the base level of the lower basin of the Valley. Theses surfaces are not morphologically and topographically stable; they are exposed to erosion processes by runoff. The planation surfaces extend mainly in the northern and eastern areas on the high cliffs overlooking the town of Wadi Mousa and they form (8%) of the region's area. The planation surfaces were trenched by sub-valleys. Their morphology and levels are varied which ranged between (1300 – 1600 m) above sea level. They also have semi-flat surfaces, as their gradient ranged between (1.5^{o} – 6^{o}). They usually have very steep hillsides (55^{o}) trenched by a number of rills and gullies.

   Furthermore, planation surfaces are characterized by thick soil which is derived from limestone with depth reaches (150 cm). These surfaces witness little erosion activities due to their flatness. Agriculture activities are practiced on this land unit, such as planting olive, almond, and apple trees as well as some vineries.

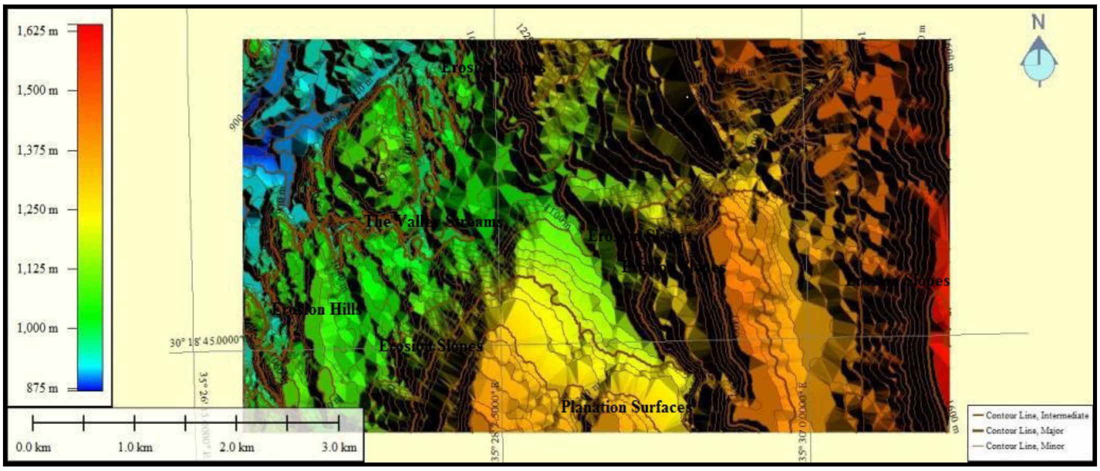

Fig 9 Digital elevation model of the study area shows the land units of Wadi Mousa region

2. **The Erosion Slopes:** the erosion slopes are found on both sides of the Valley (Wadi Mousa) and on the sides of the sub-valleys that flow in Wadi Mousa. They stretch in different directions depending on the headwaters of the main and sub-valleys and have different sloping characteristics in terms of gradient and the length and shape of the slope. The gradient of the erosion slopes ranges between (5.7^o – 65^o) and increases as we head west; the valleys get deeper as a result of vertical and lateral erosion, and the morphodynamic processes. The most important of these processes are surface erosion, rock fall, and landslides.
   The longitudinal section of the erosion slopes different shapes, ranging between concave and convex. These shapes are frequently found in the areas of gradient (6^o-15^o), and decrease in slopes with gradient more than (16^o). They are not found in slopes with gradient more than (25^o); because those slopes represent steep cliffs. The erosion slopes also vary in terms of length, depending on the valleys lengths, and their vulnerability to the morphodynamic processes that occur on the erosion slopes. The lengths of the studied erosion slopes ranged between (90 - 1200m). They usually end with bottom sediments, which have a gradient between (3^o – 7^o), and covered with gravel deposits and boulders.
3. **The Valley Streams:** the water network in the region, which takes dendritic pattern, is a product of water erosion processes (Figure 10). The difference in the water network patterns is due to the gradient factors, the geological structure, rock quality, and the presence of cracks and joints. Streams tend to develop a certain drainage pattern according to the variation in the characteristics of these factors affecting them.

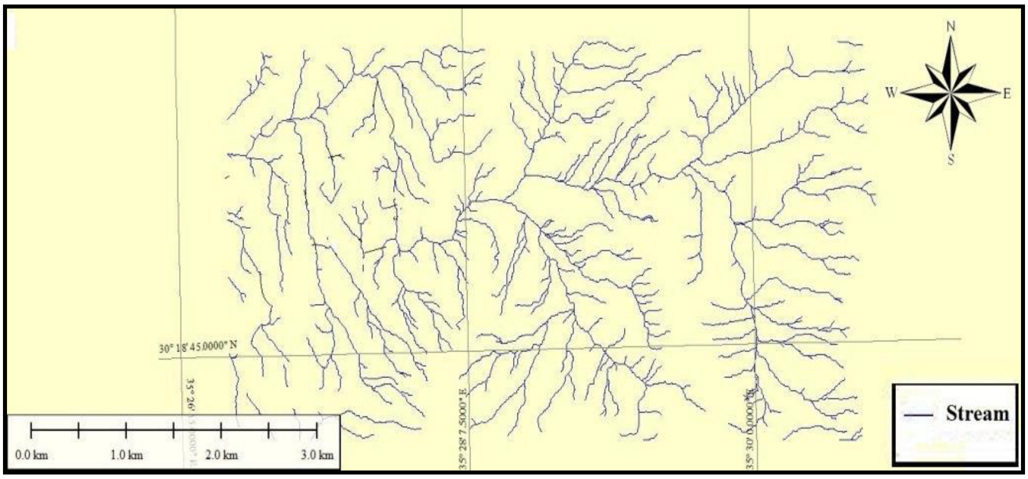

Fig 10. Water network in Wadi Al-Arja basin.

The valleys in the region are characterized by seasonal runoff, which depends on the amount of rainfall in the winter. The surrounding environmental conditions determine the amount of runoff and its sustainability in the region. The morphometric characteristics of the valleys in the region are different in terms of their channel shape, stream pattern, gradient, drainage density and stream order.

The cross-sections of water channels in the region take shapes that range between the U shape, in which the banks are very steep, and the channel bottom flat with a variation in their width and depth. This pattern represents most eastern and northern valleys (Wadi Kfar Saham, Abu Sa'd, Al-Hay, Mount Ezbireh, Kharbout, and Abu Aliqah). The channel shape approaches the U shape as we move away from the headwaters area, approaching the downstream environment. On the other hand, channels in some valleys take the V shape, in which the banks are less steep and its depth exceeds its width. This shape represents (Wadi Al-Madares, Almataha, and Wadi Al-Siegh). A group of factors controls the channel shape in the region through making variation in the vertical and lateral erosion activity of the channels. These factors include: the climatic conditions, the quality of the rock, relief, geological structure, and time.

With regard to the stream pattern, that determines the overall shape of the horizontal extension of the water stream; the stream pattern ranges between the sinuous pattern (1.5), and the meandering pattern (more than 1.5).

Valleys vary in their gradient between (1.5^o - 6.8^o). The gradient value increases in the headwaters area and decreases in the downstream area. The increase in gradient leads to an increase in the speed of runoff; and a decrease in evaporation and water leakage amount. Consequently, this increases the erosion forces of runoff which in turn affect the slopes stability through vertical and lateral erosion process.

The valleys in the region also vary in their drainage density which ranged between ($0.53km\backslash km^2$ – $0.86km\backslash km^2$). This indicates the presence of a large number of tributaries in the region (551 tributaries). It also indicates the degree to which the surface is exposed to lateral and vertical erosion forces (Figure 11).

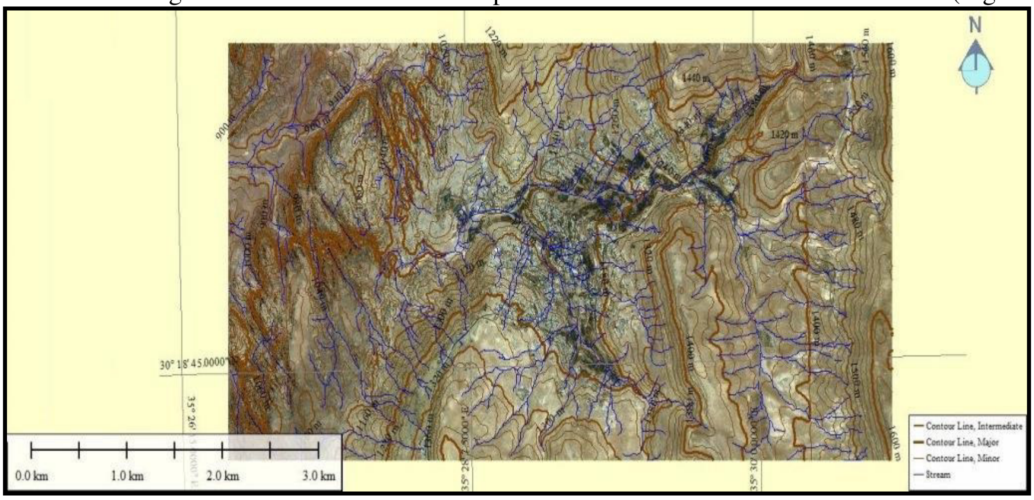

Fig 11. Shows the trenching of the surface by the tributaries

The tributaries in the region vary in their stream order which ranged between first and fifth stream order, and stream orders vary in the number of their tributaries. First stream order had the most tributaries (318) followed by second stream order with (159 tributaries); then came the third stream order with (56) tributaries, the fourth stream order with (18) tributaries, and the fifth stream order which represents the mainstream of Wadi Mousa.

4. **The Alluvial Terraces:** alluvial terraces are part of an old alluvial plain, but as a result of deepening the river course, the river has developed another alluvial plain with lower level. Alluvial terraces spread to a limited extent over the course of Wadi Mousa and sub-valleys streams. Several factors helped to successively deepen the northern and eastern valleys since the beginning of the Miocene, some of which are: the base level drop in the downstream area and the increase in water discharge of the valleys.
   The height of the alluvial terraces ranged between (1200 – 1500 m) above sea level, while their surface gradient rate reached (4^o).
5. **The Rock Terraces:** formed by water erosion process to which they were exposed in wet periods. The surfaces of layers were eroded due to their softness, while the more solid layers remain, making up rock terraces. The thickness of the terrace varies depending on the thickness of the rock layers. The gradient of alluvial terraces ranged between (2^o – 6^o).
6. **Erosion Hills:** the hilltops form the basic watershed areas in the region (Figure 12.) and appear in two shapes, namely: semi-flat and semi-tapered hilltops.

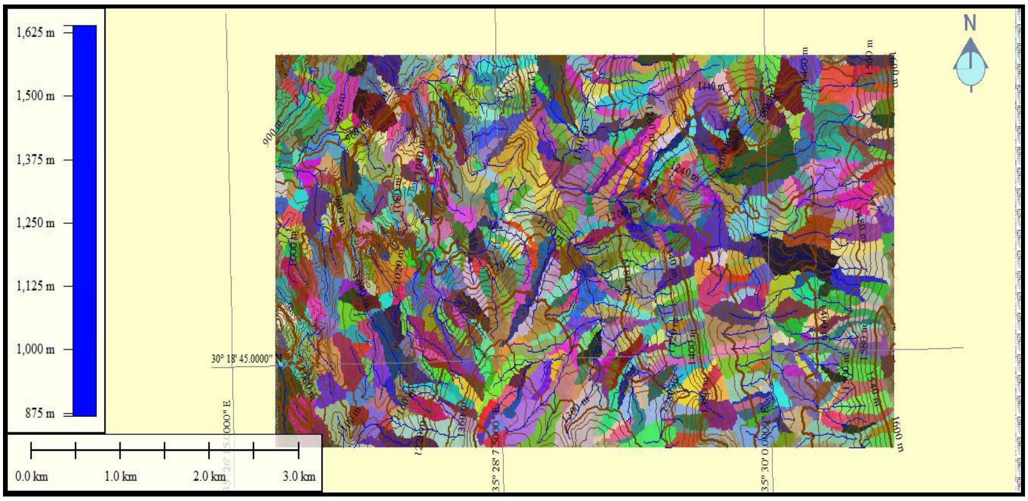

Fig 12.Watersheds in Wadi Mousa region

Some hilltops are covered with gravel deposits caused by mechanical weathering processes to which these hilltops are exposed. The northern and western hills have the highest rainfall rates and they are the main source of tributaries flowing in Wadi Mousa. There levels range between 1300-1600m above sea level. The thickness of the soil in this unit ranges between (35 – 90 cm) due to erosion processes. Gravels resulting from the weathering processes are frequently found among the soil components. Vegetation density on hilltops increases as we move west due to improved rainfall rates.

Since the sand rock formations spread over western hilltops, rock fall processes are active on these hills. Sand rocks have a lot of joints and cracks, which increases the activity of weathering processes that are considered important element in making up rock masses that are likely to fall.

Conclusion

The geomorphological analysis results, using the Digital Elevation Model, showed diversity in the landforms of Wadi Mousa region. Six major land units were identified, namely: the planation surfaces, the erosion slopes, the valley streams, the alluvial terraces, the rocky terraces, and the erosion hills. The Geomorphological and structural evolution of the region is related to the tectonic processes that hit the Wadi Araba in the past geologic times. These tectonic processes led to raising and lowering operations in the region, forming many folds and faults, which in turn contributed to the variation in the geomorphological characteristics of the region. After these tectonic processes, Wadi Mousa region was affected by significant activity of water erosion processes in the Pleistocene epoch. These processes have contributed to the deepening of the variation in the levels of the surface of the Valley. The slope shade, slope direction, and gradient shade figures show the severity of variation in the sloping characteristics within a region of small area. Hence, the surface of the region was classified to have a complex morphological structure; the morphological shape of the surface ranged between flat areas and very steep cliffs. The Geomorphological erosion processes also had its impact on the development of the water network morphology in Wadi Mousa. The increase in the drainage density rate of the valleys flowing Wadi Mousa indicates the large number of water channels on the surface. The vertical and lateral erosion processes led to the deepening of the valleys streams, which in turn increased the activity of the morphodynamic processes on the slopes of the cliffs overlooking the Valley. The most important of those morphodynamic processes are surface erosion, rock fall, and landslides. The stream pattern that determines the overall shape of the horizontal stretch of the watercourse ranges between the sinuous and the meandering patterns.

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