ISSN 2350-1049

International Journal of Recent Research in Interdisciplinary Sciences (IJRRIS)
Vol. 12, Issue 1, pp: (1-15), Month: January - March 2025, Available at: www.paperpublications.org

Morphometry and Geomorphic Characteristics of Al-Hawad Valley within the Arid Cycle of Erosion in Semi-Arid Northern Sudan

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DOI: https://doi.org/10.5281/zenodo.14938397

Published Date: 27-February-2025

Abstract: **This research aims to analyze the morphogeomorphic characteristics of Al-Hawad valley within the arid cycle of erosion so as to curb its floods by prospecting agro-animal investment that will support into flood mitigation; by applying the morphometric analysis approach and GIS techniques. Al-Hawad valley runs across an area of 598 meters high and 359 meters low; characterized by a moderate ruggedness; a gentle slope of 1.28 m/km, a relative topography of 54.4 m/km; and a roughness value of 0.006; as well as a stability rate of 2.5 km^2 for each 1 km, and a dense water drainage network with a dendritic drainage pattern. It also holds rank 5 at its entrance into the river Nile; and owns 789 watercourses; almost regular with large numbers of water courses concentrated in the first and second orders. The total length of channels for all ranks is 2947 km decreasing gradually from first rank to third rank; with an overall average height of 198 for all ranks; and the fourth rank owns the smallest length ratio followed by the second rank, while the largest length ratio was in the fifth rank. The average bifurcation ratio is 5.88 while the highest branching ratio is in the third rank. The basin area is 7476.33 km^2 with a basin circumference value of 439 km of 178 km; the drainage density is 0.024; river frequency is 0.11; the texture of the basin is 1.8; shape facto is 0.24, rate of roundness is 0.04, and the elongation rate is 0.27. These Morphometry and geomorphic characteristics distinguish Wad-Al-Hawad within the arid cycle with predictions for becoming a source for water security and future governmental investment initiatives.**

Keywords: **morphometric analysis, geomorphic analysis, erosion cycle, investment initiatives.**

1. INTRODUCTION

It has become important for modern countries to secure water resources to provide an effective environment for State's future development and investment plans. Sudan's vast areas are characterized by an arid to semi-arid environment which makes research into such topics very important, particularly in situations of global climate change. This research works on that trend by examining the morpho-geomorphic characteristics of Al-Hawad valley within the arid cycle of erosion based on GIS digital maps and geomorphic- morphometric database analysis.

2. THEORETICAL BACKGROUND

The morphometric analysis approach is one of the modern geomorphologic approaches intended to quantitatively describe the shapes of the Earth's surface and water drainage systems (Abu El-Elinain, 1995). It helps to identify the characteristics of water drainage networks and the factors affecting the formation of the Earth's surface and interpret those shapes. Terrain

ISSN 2350-1049

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means the extent to which the land is rugged or winding, that is, it means the shapes of the land's surface, including highlands, depressions, valleys, plains, etc., and terrain analysis is intended to study the nature of the terrain and its various characteristics, such as the degree of ruggedness and the extent of convergence or divergence of the types of terrain, their extension, and their areas, by making measurements of their dimensions.

Morpho-geomorphic characteristics of a valley include terrain, drainage network, morphometric, spatial, and formal characteristics. Morphometric studies are concerned with quantitative and numerical analysis of the shape of the land and finding the mathematical relationship between topography and water drainage networks. The morphometric variables can be classified into three groups: terrain and shape characteristics (Relief), area and shape characteristics (Morisawa, 1968), and the characteristics of the drainage network. These characteristics include detailed topographic characteristics, formal area, perimeter, and basin dimensions, as well as morphological characteristics of the water network including the numbers and ranks of the river courses and their branching ratios.

The total ruggedness index is the difference between the highest and lowest levels. The eroding coefficient index shows the relationship between the total eroding of the basin in meters and the maximum length of the basin in km. The Low values indicate that the basin was able to make great strides in its erosion cycle and vice versa (Al-Maghari, 2015).

Relative topography in percentage shows the relationship between the total indentation of the basin in meters and the basin circumference in km. Low values of relative topography indicate weak rock resistance and the activity of erosion factors in the basin and vice versa as they rise (Al-Maghari, 2015). The roughness value shows the relationship between the total ruggedness of the basin in meters and the drainage density per km. The ruggedness value is an indicator of the extent of the basin's progress in the geomorphological cycle. The lower the value, the more it indicates that the stream is in advanced stages in the erosion cycle. The stability of the stream explains the relationship between the area of the basin and the total lengths of streams in the basin in km2. The coefficient indicates the extent of the remaining area of the basin for the extension of the water network in the future. The degree of slope affects the quantity and density of drainage, the topographic texture, the erosion process, and the structural capacity of the stream. The variation of the slope is controlled by the geology of the region, the cycle of erosion, and the stage of stream development (Anglieri, 2008).

Morphometric characteristics of the water drainage network are ranks of river courses, numbers of streams, lengths of streams, general average streams, average length of streams, and bifurcation ratio. Ranking is defined as a system of classifying streams in a water drainage basin according to their hierarchy within the basin. The best and most widely used method is the Strahler's method (1964), which is the classification of the river and its tributaries into different orders. Each pair of first-order streams is united to form a second-class stream, then two second-class streams combine to form a third-class stream, and so on for the rest of the ranks. This method is useful when studying the amount of water drainage at each valley. The average length of channels means comparing the ratio between the average lengths of a certain rank to the average length of a rank immediately below it (Horton, 1945). It expresses the relationship between the lengths of channels for each two successive ranks. The bifurcation rate is a comparison of the ratio between the numbers of streams belonging to a certain rank to the number of streams belonging to a rank directly above it. It expresses the relationship between each two successive ranks (Schumm, 1956).

Areal characteristics are the dimensions of the drainage basin such as area, perimeter, length, density, frequency, and texture, while formal characteristics are shape, roundness, and elongation. These characteristics are directly related to the natural characteristics prevailing in the basin's environment, such as rock formation, soil types, and vegetation cover, and also affect the characteristics of surface runoff and the amount of erosion, transport, and sedimentation (Al-Maghari, 2015). Drainage density expresses the lengths of waterways that exist in a specific area unit in the basin, and river density constitutes one of the important indicators of the extent to which the surface of the water basin is exposed to erosion and the ability of the water network in it to drain the water that reaches it (Horton, 1945). River frequency reflects the intensity of river discharge. It expresses the extent to which the basin is interspersed with streams and depends on the climate and natural characteristics of the basin. It is measured by calculating the ratio between the number of rivers present in a specific area and the area of the basin in general. The higher its value, this indicates the fragility and weakness of the rocks intersected by the basin or the high humidity of the climate, and vice versa, the closer the ratio is to zero which indicates the hardness of the rocks over which the basin runs or the dryness of the climate. The texture of the basin is a measure of the extent of the discontinuity and indentation of the surface of the basin, and by its light, the type of tissue can be identified. The value of the rough texture is less than 4, the value of the medium texture is 4 to10, and the fine texture has a value of more than 10.

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The shape factor expresses the relationship between the area of the basin and its length. A low value closer to zero indicates a small area of the basin relative to its length, and a large value close to one indicates a large area of the basin relative to its length. The rate of roundness indicates that the shape of the basin is approaching or moving away from the circular shape, as the values of the roundness factor range between zero and one. High values indicate that the shape of the basin is approaching the circular shape, while low values reflect moving away from the circular shape (Al-maghari, 2015). The elongation factor or percentage shows how close or far the basin is from the rectangular shape. The value is measured between zero and one, where the closer the value is to one, the closer the shape is to elongation, and vice versa.

3. RELEVANT RESEARCH

Many relevant researches to our topic are carried out word widely. The analysis of drainage morphometry of Wadi Aurnah Drainage System in Western Arabian Peninsula by Al-Saud (2009) tackled stream behavior, morphometric setting of streams within the drainage system and interrelation between connected streams, while for the Martian valley networks (Lu Chen et al. 2021), three cases from the Noachian to the Amazonian were selected to be compared with streams in the Mangya area in terms of the maturity of the dendritic river system, shape, concave index, and branching angle (BA). In the Siwalik Hills in the Himalayas, Nepal, Ghimire et al. (2023) identified the average slope, area, elevation range, valley angle, shape index, hypsometric integral, basin asymmetry factor and drainage density, and the spatial distribution of first-order basin types exhibits a distinct pattern of geomorphic regions. Alredaisy et al (2018) studied the seasonal valleys of the Sabaloqa area in north-central Sudan where the valleys were divided geographically into eastern valleys based on the area's topography and water divide, and western valleys based on area's slope towards the River Nile. Eastern valleys differ in depth, type, and shape, and size of deposits.

The stratigraphic and morphometric investigations in eastern Libya Montes, Mars by Erkeling et al. (2010) revealed a dendritic valley networks, while the Khari River basin in the semi-arid region of Rajasthan in India revealed a dendritic pattern of drainage with low values of drainage frequency, gentle slope, coarse drainage texture, moderate to low relief, and elongated shape (Mundetia et al. 2018), and the rim of the great east African rift valley indicate a pattern of stream networks that is less controlled by structural condition and its geomorphic development is at late youth stage, and depth, velocity and bed slope of the channel are less explained by stream order (Mogeset et al. 2015).

Similarly, the morphometric parameter of the Al-Shumar watershed in Jordan shows a dendritic and parallel pattern, with a drainage density value of 1.49 - 1.85 km/km^2, a bifurcation value of the sub-watersheds varies from 2.679 to 4.434, a form factor value near the rectangular shape except for the Al-Shiah and Al-Zarnouk watershed which are close to the circular shape (Makhamreh et al. 2020). Also, Sreedevi et al. (2009) analyzed the watershed of South India and revealed that it has an elongated shape of the basin; lower order streams, and the mean Rb of the entire basin is 3.89. The quantitative analysis of various aspects of river basin drainage network characteristics in a structurally controlled terrain carried out by Sreedevi et al. (2005) reveals complex morphometric attributes where the streams of lower orders mostly dominate the basin, and the elongated shape of the basin is mainly due to the guiding effect of thrusting and faulting.

In western valleys of Sabaloqa area, shape and size of deposits differ according to means of transportation in the seasonal valleys of the area (Alredaisy et al. 2018). The main channels of the seasonal valleys depict parallel, dendritic, and radial types of drainage, and the morphometrical analysis of Abu Gaidoum and Abu Gadad valleys reveals that Abu Gaidoum is more developed than Abu Gadad, and morphometrical differences between these two valleys could be referred to area factor.

Fenta et al. (2017) study in the Agula watershed in the semi-arid northern Ethiopia indicate elongated shape, fine drainage texture, high relief and steep slopes, rough landforms, with hypsometric integral of 0.4 suggests that it is in mature stage of geomorphic evolution. Khoshoui et al. (2022), similarly, revealed that the multi-fractal analysis of valley cross-sections in geological formations of arid areas showed the transition of valley sections from a mono-fractal to multi-fractal nature, while the study by Costa (1987) in the twelve watersheds in the conterminous United States, revealed that elongation ratios were larger, and first-order channel frequency lower than other small flash-flood prone basins in the United States. Also, the quantitative analysis of the morphological features of the Biggest Basin in Western Plateau of Iraq by Mohammed et al. (2005), showed that longitudinal drain density was 0.1698 km / km2, a circulation ratio of 0.08566 which indicates that the basin is in an early geomorphologic stage and that the linear structures control the pattern of its drainage network, elongation ratio was 0.112, which means that there are significant differences in the hardness of its geological structure.

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The study of Big Creek, central Idaho in USA, by Lifton et al. (2009) confirmed the positive dependence of hill slope gradient on rock strength on the north side provides evidence that differential weathering across lithologies determines the gradient, and that in situ rock strength exerts strong influences on some measures of valley morphometry by modulating hill slope mass wasting processes and limiting lateral erosion. Ping Yan et al. (2015) study in exterior watersheds, desert area in northern China, depicted that interior watersheds have good correlations between them (Ping Yan et al. 2015), and in the Siwalik Hills in the Himalayas, Nepal, Ghimire et al. (2023) confirmed that the shape of the basin is far from the round shape, which reflects the basin's characteristics with the regular surface flow in time and relatively low drainages. The study in Wadi Al-Mohammadi basin in Western Iraq showed that it has reached the 5th order to flow into the Euphrates River, has two types of drainage patterns, and has the dendritic pattern and the parallel pattern and could be categorized as extremely low drainage density, very low drainage frequency, very coarse drainage texture, lower infiltration number, and low relief slope (Mahmood et al. 2023).

The study of the Upper Draa basin of High Atlas of Morocco shows that it has an elongated shape, with a drainage density of 0.14 km/km2, with altitudes and slopes vary little are oriented in most cases towards the southeast (Mostakim et al. 2021). Similarly, the drainage system network and the Khumal basin in western coast of Saudi Arabia showed that it has a fifth-order wadi network with an elongated shape, possesses dendritic to sub-dendritic drainage pattern, have moderate to steep slope, and low form factor results with circularity ratio and elongation ratio; moderate stream frequency, moderately coarse drainage texture with high relief, a low value of asymmetrical factor, a high relief ratio; and a highly steep ridge (Abboud et al. 2017).

4. LOCATION OF THE STUDY AREA

The Al-Hawad Valley is located in north-central Sudan between 00"20' 15˚-00" 50'16˚ N, and 00" 40' 33˚-00" 50' 34˚ E, and flows across three administrative States of Gedarief, Khartoum, and River Nile (Figure 1). This is important since it passes through many villages, urban centers, and archaeological sites, where agriculture and grazing are based.

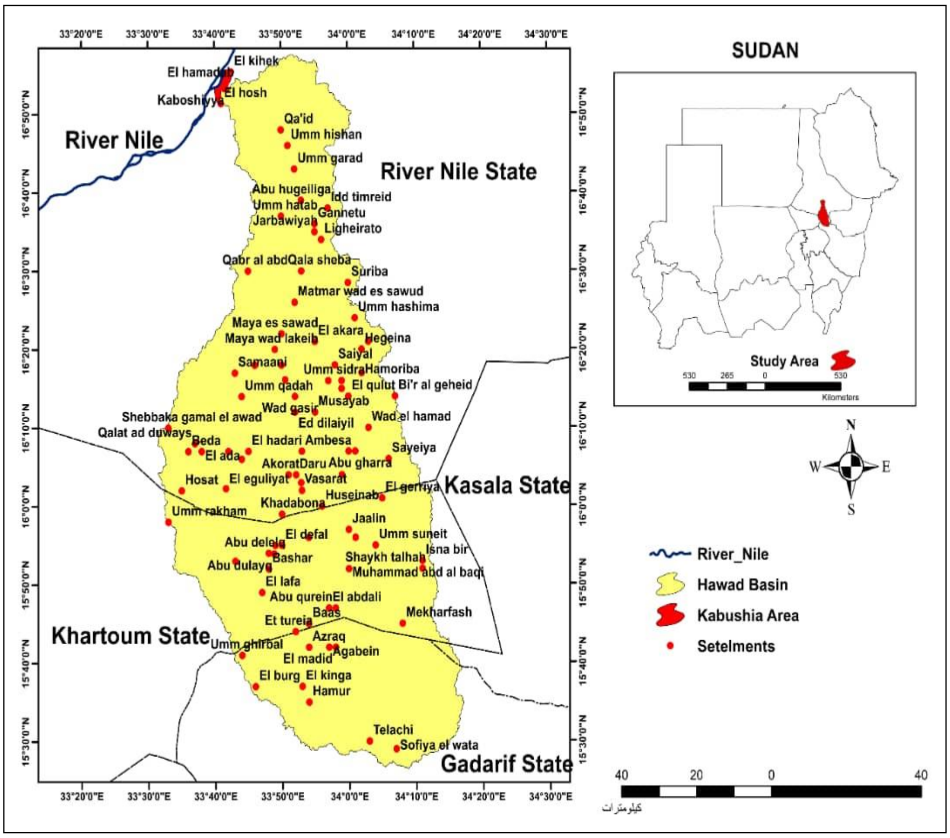

Figure 1: Location of AL-Hawad Valley Basin

Data sources and methodology, and analysis

5. DATA AND METHODOLOGY

5.1 Data sources, included:

- Digital Elevation Models (DEM) data available by Shuttle Radar Topography Mission (SRTM-90 m) (http://srtm.csi.cgiar.org).
- Climate data published by the General Meteorological Authority - Khartoum 2016, and the meteorological data registered in Shambat Station - Khartoum North for the period 1985-2015.
- The geological map of the Republic of Sudan 1:2,000,000 issued by GRAS "The Geological Research Authority", 2004, GRAS,International, 1995
- Relevant published research papers, references, official reports, and documents.

5.2 Stages of preparation of data for GIS analysis, included:

- Entering data into the Arc GIS 10.5 by using the Arc Toolbox Program to perform spatial analysis.
- Data derivation from the DEM layer of elevation models (srtm_43_09).
- Provision of different types of digital elevation image data (DEM) for SRTM radar.
- Calculating the elevations using the Arc GIS 9.5 program
- Production of digital maps in which the Wadi al-Hawad was derived and classified with its borders and dimensions, and the elevation anomalies were treated
- Division of the valley into terrain categories where the surface was analyzed to derive the degree of slope, and the water network was extracted after deriving flow directions, determining water collection areas and flow channels of the valley's tributaries and their ranks.
- Applying morph-metric equations and extracting the morpho-metric characteristics of the Wadi Al-Hawad by these equations (Schumm, 1956).
- Extracting the spatial and formal characteristics using the Arc GIS 10.5 program, and by applying special equations.

5.3 Method of data analysis, included:

- Cartographic methods including storing and processing of geographic data, and production of digital information maps showing the Valley with its dimensions and water drainage network.
- Quantitative methods including data tabulation, building the relationships obtained by GIS using equations concerning morphometry and hydrology of water drainage basins, which were represented graphically and analyzed using the Arc GIS 10.5 and Excel 19 programs.
- Conducting hydrological modeling operations by finding the drainage directions and then creating a cumulative sum of the drainage directions for every 1000 cells to obtain great accuracy after which the drainage channels were created.
- Ordinal classification of water drainages using Strahler's method and the Arc GIS 9.5.

6. RESULTS

6.1. Terrain characteristics of Al-Hawad Valley

The elevation units of Al-Hawad valley are shown by figure (2). The highest level of the area is 598 meters while the lowest level is 359 meters above sea level at the mouth of Al-Hawad Valley (Figure 3). Based on that, the following indices (Table 1) were calculated: -

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- Total ruggedness index: the difference between the highest and lowest levels equals 239 meters which indicates a moderate ruggedness of the Basin's area and that the valley runs across in a plain.
- Eroding coefficient index: equals 1.28 m/km indicating slope decreasing by about a meter per kilometer. This means a huge amount of sediment sourced from the upper reaching of the valley along its channel which works to decrease the speed of water flow.
- Relative topography: equals 54.4 m/km indicating a variation in rock hardness and erosion activity which depends on the speed of flow.
- Roughness value: equals 0.006, a very low value close to zero, indicating that the valley is at a very late stage of aging, with the slope and speed of flow weakening, thus the action of erosion decreases and the action of sedimentation prevails.
- Stability of the stream: is at a rate of 2.5 km^2 for each 1 km of the Valley length. This is a high rate that indicates an unsteady state of the Valley as erosion actively continues.
- Degree of slope: very gentle equals 1.4 degrees due to that the Valley runs in an area with weak
- Geological formations that do not resist erosion processes.

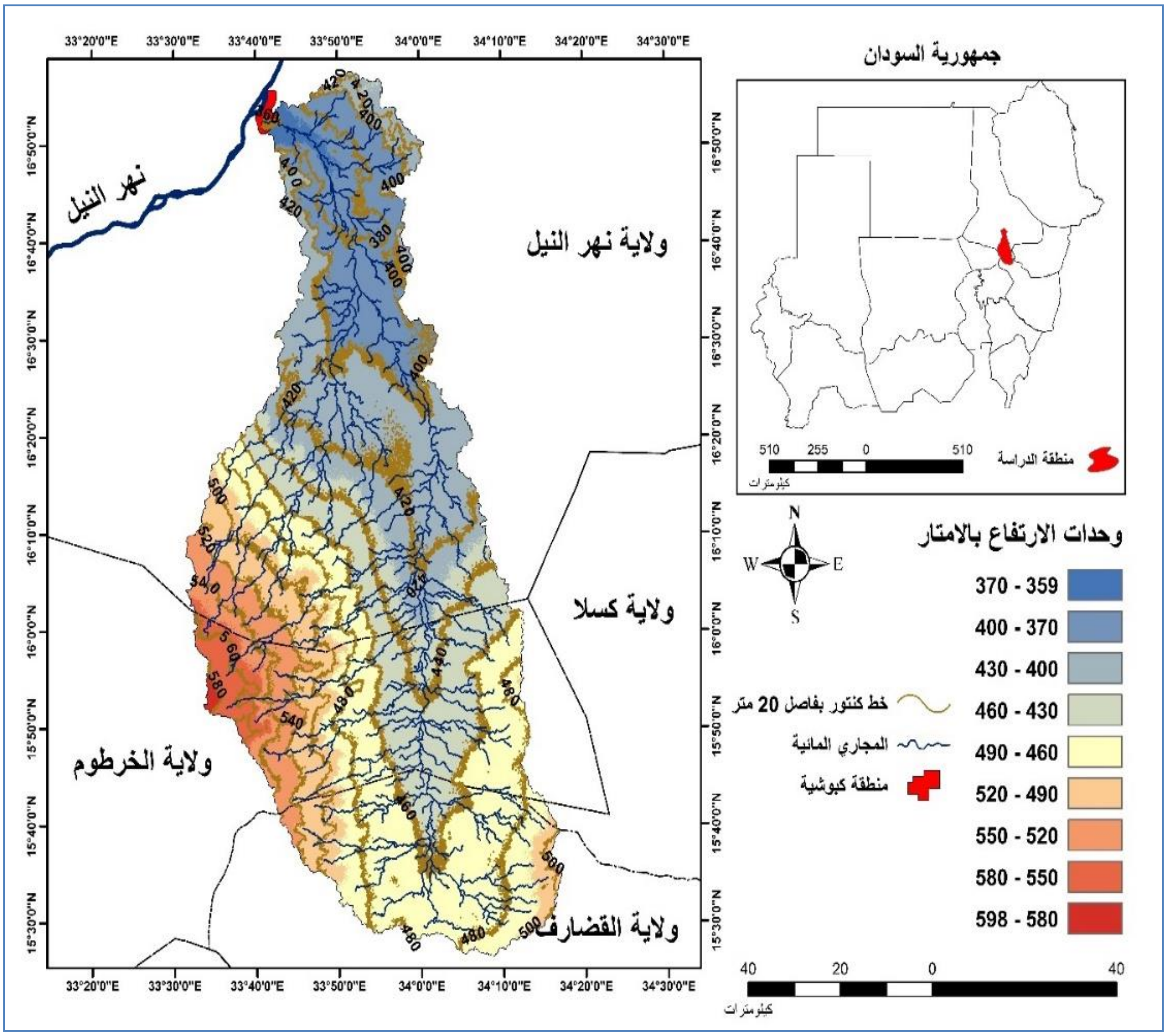

Figure 2: Elevation units of Al-Hawad Valley

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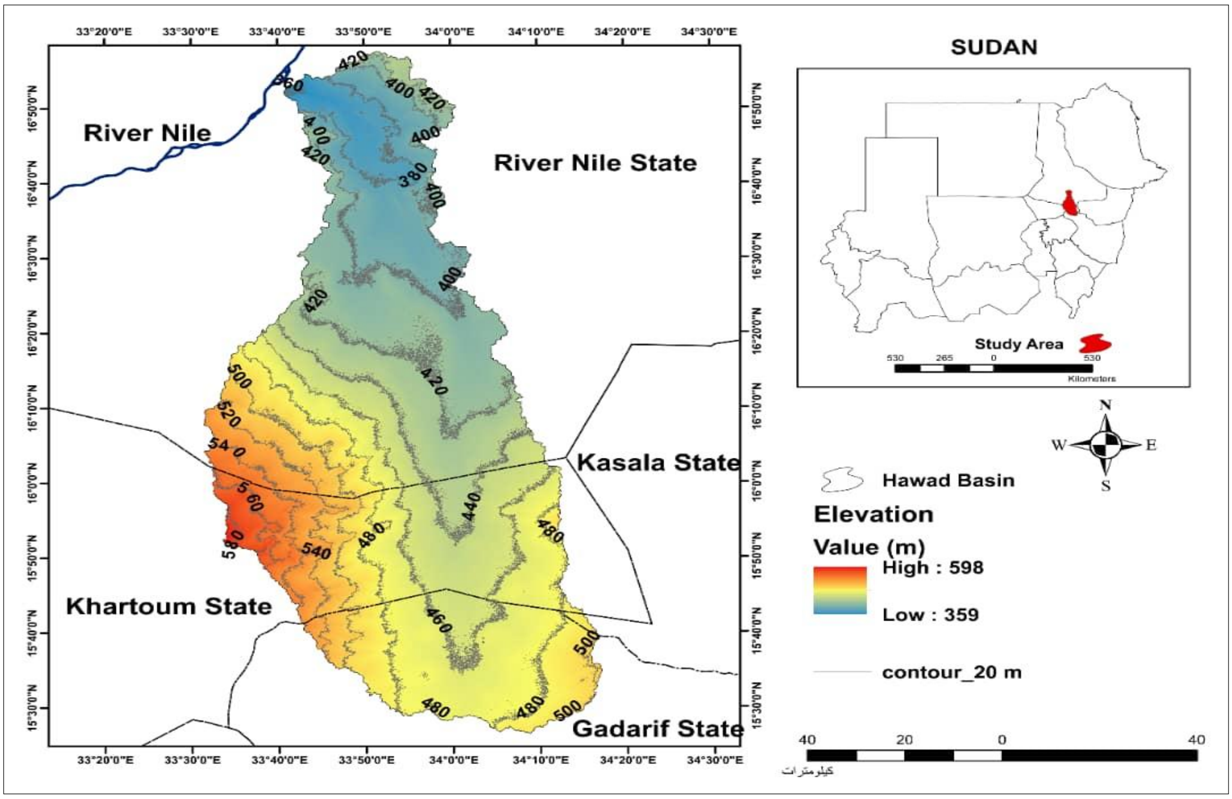

Figure 3: Upper and lower values of elevation of Al-Hawad valley

Table 1: Topographical characteristics of Wadi Al-Hawad Basin

coefficient	equation	Symbol explanation	source	value
Relief Ratio	(Rc) = (He-Le)/L	Rc = scarring coefficient, He = the level of the highest point in the basin (598 m), Le = level of the lowest point in the basin	(Schumm, 1956),	1.28 m/km
Relative Relief Ratio	Rhp = (H / P) *100	Rhp= Relative relief, H= Height difference (239 m), P= Basin circumference (439 km)	(Schumm et al., 1987),	54.4 m/km
Ruggedness Number	Rn =H*Dd/1000	Rn= Ruggedness value, H= Height difference (239 m), Dd = Discharge density (L/A) = Basin length (187 km) / Basin area (7476.33 km2) = 0.03	(Schumm, 1956),	0.006
Stream Stability	Ss = A / Lu	Ss = Stream stability, A = Basin area (7476.33 km2) Lu = total length of channels (2947 km)	(Al-Ghilan, 2008)	2.5 km2
Stream Slope	S = H / d	S = degree of slope, H= Height difference (239 m) d = horizontal distance of the valley (170 km)	(Anglieri, 2008),	1.4 degrees

6.2 Analysis of the water drainage network characteristics of Al-Hawad Valley

The distribution of the water drainage network (Figure 4) reveals a dense water drainage network that descends towards the main channel of the valley, from southeastward to northwestward to drain into the Nile River (Figure 5). The Valley has a tree-drainage pattern, indicating homogeneous rocky composition and structure, as the tributaries meet each other at sharp angles, and they are many and short, however, they run over sedimentary formations.

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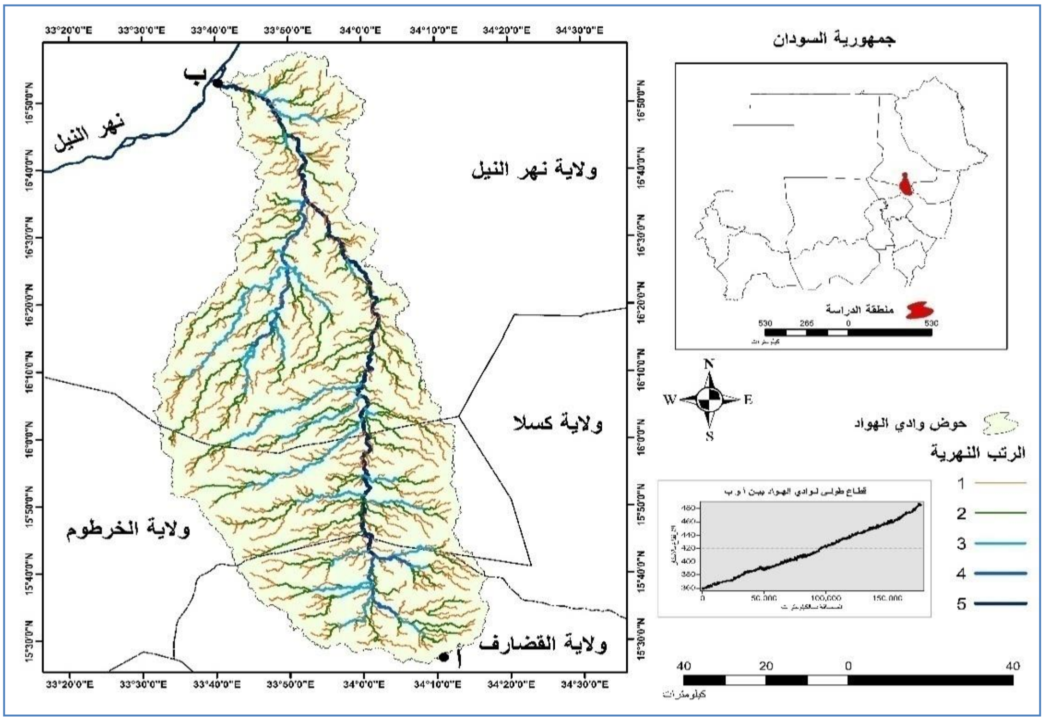
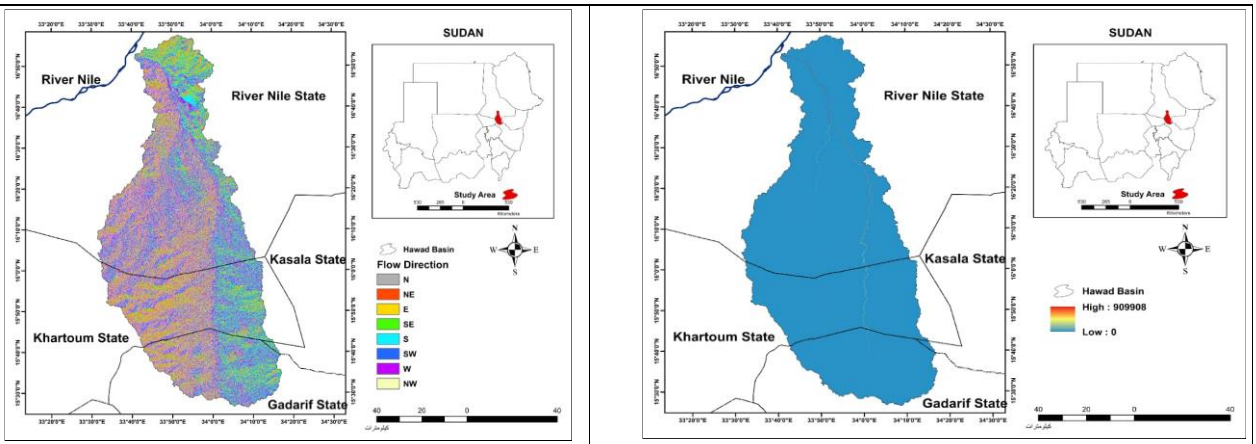


Figure 4: Drainage network of Al-Hawad valley



A- Flow Direction of Al-Hawad valley

B- Total cumulative of drainage directions

Figure 5: Flow and cumulative direction of drainage Al-Hawad valley

6.3 Morphometry characteristics of Al-Hawad Valley

* Ranking of tributaries holds rank 5 at the river Nile. This confirms for the advanced stage of development of this water drainage network, a huge amount of water draining, increased activity of the sculpting processes in its early stages, and the huge amount of sedimentation brought by tributaries (Figures 6 and 7).

* Number of water courses: totaled 789 (Table 2), gradually decreasing from smallest to largest levels. Indicating an almost regular valley with large numbers of water courses concentrated in the first and second levels.

* Lengths of channels: the total lengths of channels for all ranks reached 2947 km (Table 2). They are decreasing gradually from first rank to third rank, however, in fourth rank, their length decreases significantly due to their short lengths and few water courses, then their length increases at the last fifth rank. This indicates the regularity of the water courses of the Al-Hawad Basin.

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* Average overall height for all ranks is 198 (Table 2). Average length of channels: The fourth rank, 0.30, has the smallest length ratio, followed by the second rank, while the largest length ratio was in the fifth rank, 233.75 (Table 2).

* Bifurcation rate: each channels of the next rank has an overall average rate similar to the channels of the previous rank, with an average of 5.88 (Table 2). The highest branching rate in the third rank, 3.38, and the abnormal rate of 0.0043in the fourth rank, is closer to zero which indicates the scarcity of channels in it, otherwise, the branching rate of the basin's channels is regular and homogeneous.

Table 2: Characteristics of the water drainage network of the Wadi Al-Hawad Basin

coefficient	equation	ranks					total	source
		1	2	3	4	5		
Number of Stream	Nu = Number by rank	573	181	31	3	1	789	(Strahler, 1952)
Stream Length	Lu = Stream length by rank (km)	2005	666	87	2	187	2947 km	(Horton, 1945)
Mean Stream Length	Lsm=Lu/Nu Lsm = Mean Stream Length Lu = Length of stream by rank (km), Nu = Number by rank Lu-1 = The length of the stream in the previous rank (km)	3.50	3.7	2.7	0.8	187	198 km	(Horton, 1945)
Bifurcation Ratio	Rb=Nu/Nu+1 Nu = Number by rank Nu+1 = Number of channels in the next order	0.95	1.37	3.38	**0.0043**	0.94	6.64	(Schumm, 1956)
Mean Bifurcation Ratio	Rbm = The average bifurcation for all orders	-	-	-	-	-	5.88	(Strahler, 1952)

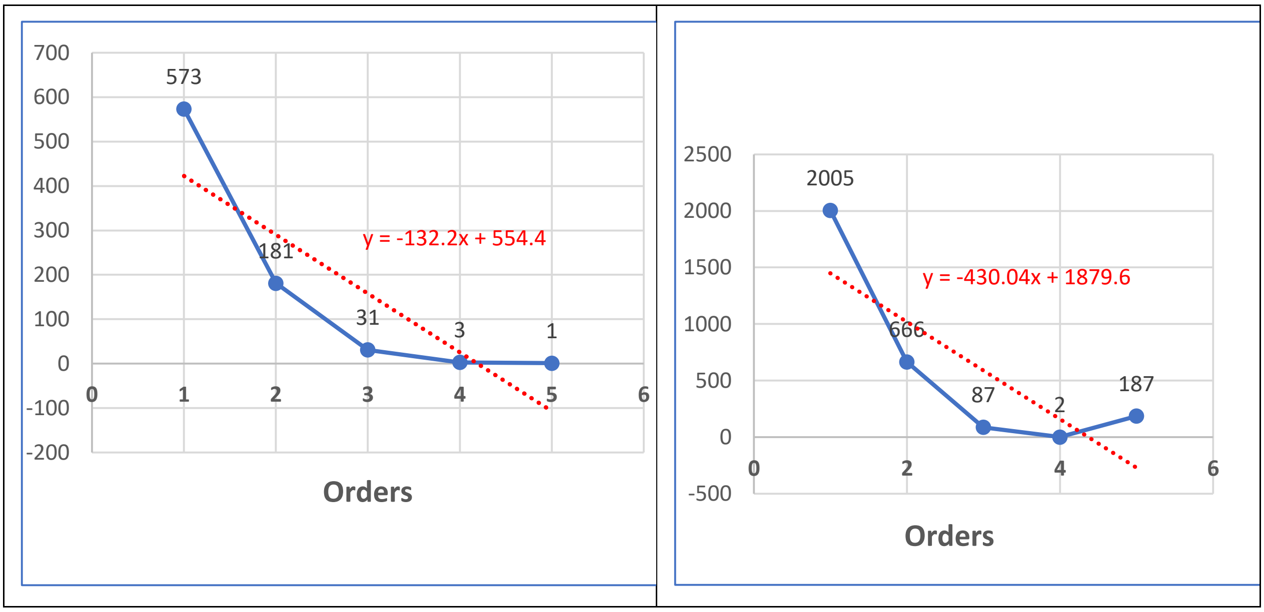

Figure 6: Orders of Al-Hawad tributaries

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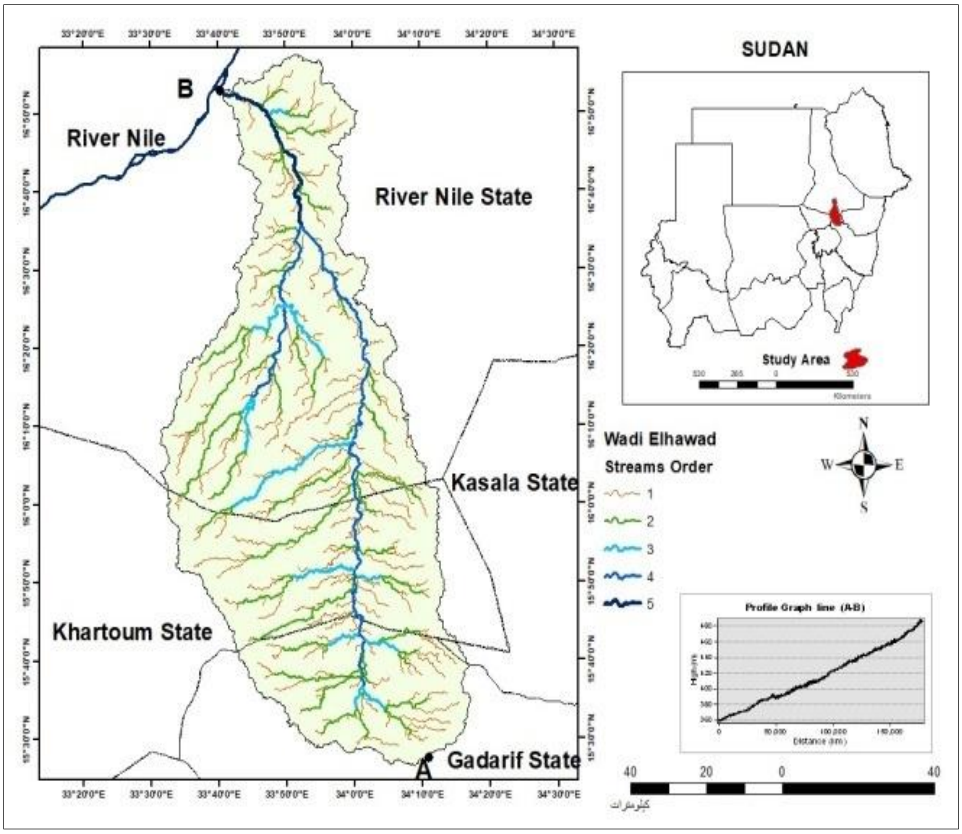

Figure 7: stream order of A-Hawad valley

6.4 Analysis of spatial and formal characteristics of Al-Hawad Valley

The analysis of these characteristics is shown in table (4): -

- Basin area: Since the basin area is defined as the area that supplies the tributaries with water, here it is 7476.33 km2.
- Basin circumference: Since it is the length of the water dividing line between the basin and its neighboring basins, it equals 439 km.
- Basin length: Since it is the total length of the basin, here it is 178 km.
- Drainage density: Since it expresses the lengths of waterways that exist in a specific area unit in the basin, here it equals 0.024 linear streams per square kilometer, which is a relatively weak density as a result of the low number of streams in the last ranks.
- River frequency of AL-Hawad equals 0.11, which is a very weak value. This means that the basin is still in the early stages of development, flows in a solid rocky area, and is characterized by an arid or semi-arid climate since it flows in fixed and shifting sandy areas.
- The texture of the basin: here, the value of the drainage texture is 1.8. This means that it is very rough; the basin runs on a very rugged area in its highest as mountain small water channels while in its middle channel runs in a dunes area until its it drains into the river Nile.
- Shape factor equals 0.24 which is close to zero and by so indicates the small area of the basin relative to its length. Therefore, there is no uniformity between the processes of sculpting and deposition along the area of the basin.
- Rate of roundness: the coefficient reached 0.04, which is very close to zero, indicating to a shape extremely far from the circular shape.
- Elongation rate is 0.27 which means that the shape of the basin is closer to zero, far from the rectangular shape, and is closer to the oval shape.

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Table 3: Area and morphological characteristics of the Wadi Al-Hawad Basin

coefficient	equation	Symbol explanation	value	source
Area (km^2)	A	A	7476.33 km^2	Arc GIS 10.5
Perimeter	P	P	439 km	Arc GIS 10.5
Basin Length (km)	L	LL = Length of the basin	178 km	Arc GIS 10.5
Drainage density	Dd =L/A	Dd = Discharge density L= length of the basin A= Area	0.024	Horton (1945)
Stream Frequency	Fs = N/A	Fs = River frequency N= total number of streams, A = basin area	0.11	Horton (1945),
Texture Ratio	Rt = N/P	Rt = Basin tissue ; N= total number of channels; P = basin circumference	**1.8**	*Horton (1945)*
Form factor	$Ff = A / L^2$	Ff = Form factor; A= area of the basin L^2= length of the basin	**0.24**	*Horton (1945)*
Circularity ratio	$Rc = A / P^2$	Rc = Circularity ratio; A= basin area P = basin circumference	**0.04**	Strahler)1964)
Elongation ratio	$Re = \sqrt{(A/\pi)} / L$	Re= Elongation ratio; L=basin length; A = basin area; π = 3.14	**0.27**	Schumm (1956)

Parameter Equation Interpretation of Source Value Symbols Basin area km2 A A = Basin area 7476.33 km2 Arc GIS 10.5 Area (km2)

7. WADI AL-HAWAD WITHIN THE ARID CYCLE

The Low values of the eroding coefficient index of Wadi Al-Hawad indicate that the basin was able to make great strides in its erosion cycle. The eroding coefficient index of Wadi Al-Hawad also, means that a huge amount of sediment comes from the upper reaching of the valley works to decrease the speed of water flow along its channel. The huge amounts of sediments with a decreasing speed of flow means high rate of sedimentation in Wadi Al-Hawad. The high value of the relative topography of Wadi Al-Hawad indicates to a variation in rock hardness and erosion activity. This means that Wadi Al-Hawad has an undulating basin floor due to unequal activity of erosion factors, a variation in rock hardness, and erosion activity which depends on the speed of flow. The moderate value of ruggedness in Wadi Al-Hawad indicates ruggedness that the valley runs across a plain and in the moderate stage of erosion cycle (maturity stage). However, the low roughness value of Wadi Al-Hawad indicates to a very late stage of aging, with a weakening speed of flow and a decreasing slope and, and thus the action of erosion decreases and the action of sedimentation prevails. Meanwhile, the rate of stability of Wadi Al-Hawad valley is high which indicates to an unsteady state of the valley as erosion actively continues. The high value of the coefficient of stability of Wadi Al-Hawad which could indicate to an unsteady state of this valley as erosion actively continues. Also, the degree of slope of Wadi Al-Hawad is very gentle since it runs in an area with weak geological formations that do not resist erosion processes. This degree of slope also affects Wadi Al-Hawad's quantity and density of drainage, its topographic texture, its erosion process, and its structural capacity.

The Ranking of tributaries of Wadi Al-Hawad confirms an advanced stage of development of this water drainage network. It also confirms a huge amount of water draining, increased activity of the erosion processes in its early stages, and a huge amount of sedimentation brought by its tributaries. The gradual decrease of the number of water courses from the smallest to the largest and the lengths of channels of Wadi Al-Hawad indicate to an almost a regular valley with large numbers of water courses concentrated in the first and second orders. This is more supported by the bifurcation rate of Wadi Al-Hawad which shows highest branching rate in the third rank and the abnormal rate in the fourth rank is closer to zero.

The distribution of the water drainage network of Wadi Al-Hawad reveals a dense water drainage network that descends towards the main channel of the valley, from southeast to northwest to drain eventually into the Nile River. The linking between the water drainage network and prevailing desert conditions of the region depicts its formation in a pre-rainy

ISSN 2350-1049

International Journal of Recent Research in Interdisciplinary Sciences (IJRRIS)
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climate condition. Wadi Al-Hawad valley has a tree-drainage pattern (dendritic), indicating a homogeneous rocky composition and structure, as the tributaries meet each other at sharp angles, and they are many and short, however, they run over sedimentary formations.

Drainage density in Wadi Al-Hawad is relatively weak as a result of the low number of streams in the last ranks. River frequency means that the basin is still in the early stages of development, flows in a solid rocky area, and is characterized by an arid or semi-arid climate since it flows in fixed and shifting sandy areas. The river frequency of Wadi Al-Hawad is a very low value which means that it is still in the early stages of development, flows in a solid rocky area, and is characterized by an arid or semi-arid climate since it flows in fixed and shifting sandy areas. The texture value of Wadi Al-Hawad confirms that it is a very rough valley; runs on a very rugged area in its highest in the form of mountain small water channels, while in its middle channel runs in a dunes area until it drains into the Nile River. The rate of roundness of Wadi Al-Hawad is very close to zero indicating to a shape extremely far from the circular shape. The elongation rate of Wadi Al-Hawad means that the shape of the basin is closer to zero, far from the rectangular shape, and is closer to the oval shape. The rate of roundness of Wadi Al-Hawad indicates to a shape extremely far from the circular shape while its shape factor is close to zero and by so indicates to a small area of the basin relative to its length. Therefore, there is no uniformity between the processes of erosion and deposition along the area of Wadi Al-Hawad basin.

8. DISCUSSION

The research done in Wadi Al-Hawad is similar to many other research carried out in some parts of the world's semi-arid environment, such as those by by Al-Saud (2009); Lu Chen et al (2021); Ghimire et al (2023); and Alredaisy et al (2018).

The dendritic pattern of Wadi Al-Hawad agrees with research results by Erkeling et al (2010); Mundetia et al (2018); and Alredaisy et al (2018); with research done in Wadi Al-Mohammadi basin, in Western Iraq by Mahmood et al (2023). On the other side, it disagrees in values of drainage frequency and shape with results of Erkeling et al (2010) in Khari River basin although it agrees with it in gentle slope, coarse drainage texture. It disagrees in its bifurcation value with research results in Al-Shumar watershed in Jordan carried out by Makhamreh et al (2020), and disagrees in its shape with research results of the Watershed of South India (Sreedevi et al. 2009); and with Agula watershed in the semi-arid northern Ethiopia which owns elongated shape according to Fenta et al. (2017), and with Upper Draa basin of High Atlas of Morocco (Mostakim et al. 2021), and with Siwalik Hills in the Himalayas, Nepal where its shape of the basin is far from the round shape (Ghimire et al. 2023), and with Big Creek, central Idaho in USA where positive dependence of hill slope gradient on rock strength (Lifton et al. 2009).

Wadi Al-Hawad research results shows a high index of drainage density, very high drainage frequency, moderate drainage texture, and high relief slope which disagrees with Wadi Al-Mohammadi basin's characteristics , in Western Iraq as indicated by Mahmood et al (2023). It furthermore, disagrees with Agula watershed in the semi-arid northern Ethiopia which owns elongated shape and fine drainage texture, high relief and steep slopes, rough landforms, and being in mature stage of geomorphic evolution as confirmed by Fenta et al (2017). Similarly, Wad Al-Hawad results disagree with the results of research carried out in Khumal basin in western coast of Saudi Arabia which owns elongated shape, however it agrees with in its dendritic to sub-dendritic drainage pattern, its moderate to steep slope, its low form factor, its moderate stream frequency, its moderately coarse drainage texture with high relief, its low value of asymmetrical factor, its high relief ratio; and its highly steep ridge (Abboud et al. 2017).

Wadi Al-Hawad research results disagree with Mogeset et al (2015) results concerns the rim of the great east African rift valley where the stream networks is less controlled by structural conditions and its geomorphic development is at late youth stage while Wadi Al-Hawad is still in the early stages of development as confirmed by the river frequency index, and this further agrees with research result in the Biggest Basin in Western Plateau of Iraq which is at an early geomorphologic stage (Mohammed et al. 2005).

A future prospect of Wadi Al-Hawad

The morphometry and geomorphic characteristics of Al-Hawad valley within the arid cycle of erosion in semi-arid northern Sudan confirmed a unique valley with distinguished characteristics on an area of about 2.4 million acres. Sudanese Government formed a supreme committee to develop a plan to establish a giant agricultural project in Wadi al-Hawad that accommodates modern developments in diverse and integrated agricultural production patterns (Figure 8); contributes to

International Journal of Recent Research in Interdisciplinary Sciences (IJRRIS)
Vol. 12, Issue 1, pp: (1-15), Month: January - March 2025, Available at: www.paperpublications.org

the development of the region; and promote it within the framework of Republic's Food Security Initiative, part of which will be allocated to Sudanese youth (Sudan Tribune 4/2016).

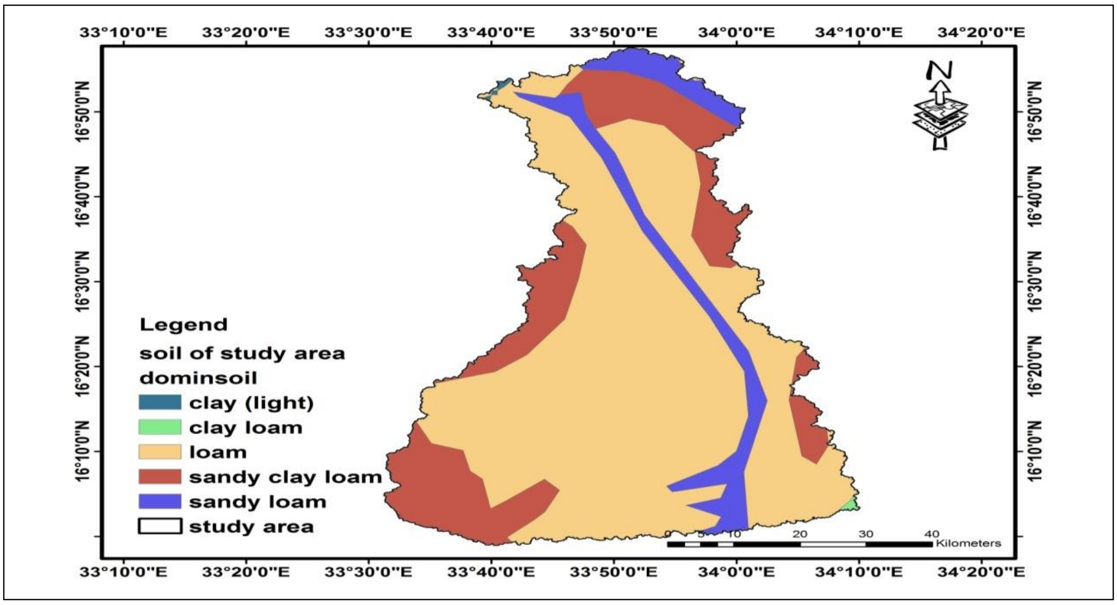

Figure 8: Soils of Al-Hawad valley

The waters Al-Hawad valley allows the cultivation of some crops such as corn and vegetables, and water harvesting to grow some crops. The IFAD organization contributed to the establishment of small projects for growing vegetables and fodder to improve family income. They had a significant impact, encouraging many groups outside the valley to settle in the region, and the population expansion reached the floodplains and low-lying areas, which are the areas at risk of torrential and flood disasters.

9. CONCLUSION

This research shows the morpho-geomorphic characteristics of Al-Hawad Valley Basin as being crossing areas with arid and semi-arid climates, running slowly over a gentle plain with less than 5 degrees of slope, and having dense drainage network nearly closer to a rectangular or oval shape. These morpho-geomorphic characteristics are beneficial for the development of this basin as they enable water management programs to enhance agriculture, grazing, population settlement, and reclamation of the desert lands.

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