Journal of Environment and Earth Science www.iiste.org
ISSN 2224-3216 (Paper) ISSN 2225-0948 (Online)
Vol.5, No.6, 2015

The Geomorphology of Gravelly Bars in Wadi Ewhaideh –Jordan

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Abstract
The study deals with the geomorphology of gravelly bars in Wadi Ewhaideh through the analysis of its morphological, sedimentary, and morphometric characteristics. The study also aims at determining the extent to which the phenomenon of gravelly bars spreads alongside the Valley, and the impact of the different water characteristics of the stream in determining their morphometric characteristics.
The study relied in its methodology on remote sensing techniques through the analysis of (1-25000) - scale - aerial photographs for the year 2011. The remote sensing techniques were used to analyze the morphometric dimensions of gravelly bars and their geographical distribution areas, then matching the results of the analysis of aerial photographs with the field results.
The study found that the evolution and growth process of gravelly bars are associated with two variables, namely: the amount of sediment carried by the river flows and deposited above the gravel accumulation which forms the body of the gravelly bar; while the second variable is represented by the capability of the body of the gravelly bar to resist the water shear forces caused by water currents when colliding with it.
The study also showed that the loose banks of the river directly affected the sedimentary characteristics of the gravelly bars, as the deposits of the bars in those areas are characterized by coarseness and increased sizes rate, where their average size rate reached (29.5 mm).
Keywords: Gravelly bars, Wadi Ewhaideh, remote sensing, fluvial processes, sedimentary characteristics.

1. Introduction:

Gravelly bars are considered landforms that are widespread in river basins. Their formation process is associated with the active fluvial processes along the waterways (Church and Rice, 2009). They are also considered to be one of the landforms of limited areal extension. In spite of their small areal extension along the waterways, they have a direct impact in determining the stream pattern and the overall shape of water channels through directing the power of water currents towards the valley banks, and towards the areas of the most vulnerable geological structure (Hooke, 1986).

Recent geomorphological studies have covered some aspects associated with the dynamics of the formation of river bars in the valleys in humid areas in terms of its inception and evolution. Nevertheless, those studies overlooked important aspects related to the geomorphological and morphometric characteristics of the river bars in the dry valleys. Of the most important studies that have tackled the geomorphology of river bars are the following:

Li et al (2014) studied the dynamics of gravelly bars development in the rivers. They made clear the importance of climate, vegetation, and the morphological processes – especially the river deposition process – in the growth and development of gravelly bars.

Ham and Church (2012) insured the importance of the morphodynamics processes role in determining the morphology of the gravelly bars in Fraser River in British Colombia.

Rice and Church (2010) also studied Grain-size sorting within river bars in relation to downstream fining along a wandering channel. They found that gravel sizes measured on compound bars in a 50 km reach of a large wandering gravel-bed river vary systematically with down-bar position, morphological setting, and with bar surface elevation.

Ross et al (2010) explained the importance of hydro-geomorphological processes role in the development of cluster deposits in gravel-bed rivers. The study also emphasized the importance of gradient in the development of cluster-shaped deposits.

Rice et al (2008) studied the morphology and evolution of bars in a wandering gravel-bed river. They found that bar formation take place through lateral accumulation as the river has limited capacity to raise bed load onto higher surfaces. Styles of accumulation and erosion and the major bar formation morphologies on Fraser River are common and consistent with those in gravelly braided rivers, but the wandering style does exhibit some distinctive characteristics.

Richard and Peter (2005) studied the bedload path length and point bar development in gravel-bed river models. The study showed the importance bed load in developing point bars. It also showed that the development of point bars depends on erosion processes that occur on the river bed.

Lunt and Bridge (2004) studied the evolution and deposits of a gravelly braid bar in Sagavanirktok River, Alaska. The researchers found that compound braid bars in the Sagavanirktok River develop by chute cut-off of point bars and by growth of mid-channel unit bars. Following growth is mainly through accumulation of unit bars onto their lateral and downstream margins. The researchers argue that the patterns of braid bar development and migration, and the nature of the deposits described from the Sagavanirktok River are generally similar to other sandy and gravelly braided rivers.

Lane et al (2003) examined the volume of eroded and deposited sediments in gravel-bed braided rivers using remote sensing. The study showed the significance of the hydro-morphological processes in determining the volume of allochthonous sediments.
Darby and Delbono (2002) studied the role of banks erosion and surface topography in determining the river bend. The study also showed the role of barriers in determining the river bend.
The geomorphological importance of studying the phenomenon of gravelly bars stems from the latter being of changeable dynamic nature according to the change in the prevailing environmental and basin conditions. Therefore, the study of their morphometric properties and the associated geomorphological indications will contribute to determining the changes that the gravelly bars and their spatial extension are exposed to. This makes it possible to develop appropriate solutions to reduce their negative effects on agricultural and water projects.
The study of morphometric characteristics of the gravelly bars sheds light on the various environmental factors that determine the evolution of the morphology of river channels. Wadi Ewhaideh is a suitable model for such study which its findings can be generalized on other river basins that have similar natural characteristics, as the basin environment of Wadi Ewhaideh is characterized by diverse types of soil and diverse climatic and geological characteristics.

2. The problem of the study:

The problem of the research lies in the study of the geomorphological characteristics of the gravelly bars that are formed along the river bed of Wadi Ewhaideh as well as the analysis of the morphometric characteristics of gravelly bars and the changes that occur in their sedimentary characteristics in unstable situations; and the change in the hydrological conditions that vary - significantly - on the longitudinal section of the river bed. The problem of the study centered on the following topics:

1. Identifying the prevalence of gravelly bars phenomenon along the course of the valley, and the impact of the varying water characteristics in determining their morphometric characteristics.

2. Studying the geomorphological characteristics of the gravelly bars in Wadi Ewhaideh.

3. Analyzing the sedimentary and morphometric characteristics of the gravelly bars.

4. Analyzing the geomorphological indications associated with the process of gravelly bars formation, and their development within the basin environment of the valley.

3. Methodology of the Study:

The study adopted the methodology of the remote sensing techniques through the analysis of (1-25000)-scale-aerial photographs for the year 2011. Remote sensing techniques were used to analyze the morphometric dimensions of the gravelly bars and determining their geographical distribution areas; and then matching the results of the analysis of aerial photographs with field results. While, on the other hand, the deductive approach was used to investigate the information from (1-50000)-scale- topographic and geological maps for the year 2006, and (1-100000)-scale maps of soil of the year 1993. Moreover, this study focused on the analysis of the available climate information and hydrological data of the valley during the period (1980-2014). The study used the Geographical Information System (GIS) and its applications (Arc catalog 10.2, Arc Map 10.2) for the preparation of the cartographic maps. Mathematical equations were used to measure the following variables:
- Stream Energy (RE): It is calculated according to the following equation (Eq1):

$$\mathbf{SE = A\,(V)^2 / 2} \qquad (1)$$

Where: V: is the speed of water discharge m/s, A the volume of water discharge m^3/s (volume of water discharge was measured according to the following equation: Q = XV where X is the cross-sectional area of the river m^2, of V is the speed river water m/s).
- The sphericity of gravelly sediments that form the body gravelly bar: It is calculated according to the following equation (Eq2):

$$SG = \sqrt[3]{\frac{L}{L \times W \times T}} \qquad \mathbf{(2)}$$

Where: L The length of the gravelly sample, W IS width of the sample, T thickness of the sample (Krumbein, 1941).

The roundness of the gravelly sediments was classified within four categories: rounded, semi-rounded, angular, and semi-angular particles.

4. Basin Environment of Wadi Ewhaideh:

The basin of Wadi Ewhaideh is located in the southwestern part of the Hashemite Kingdome of Jordan between the longitudes 35° 25 and 35° 41 east, and the latitudes 29° 55 and 30° 12 north. The maximum length of the basin is 26.5 km from east to west, and 15.2 km from north to south. The basin area amounts to 252 km^2. Wadi Ewhaideh meets with Wadi Husseinan to form one course that flows in Qa' Al-Jafr. The basin environment of the valley is characterized by drought, and its vegetation is severely sensitive to climatic changes (Figure 1).

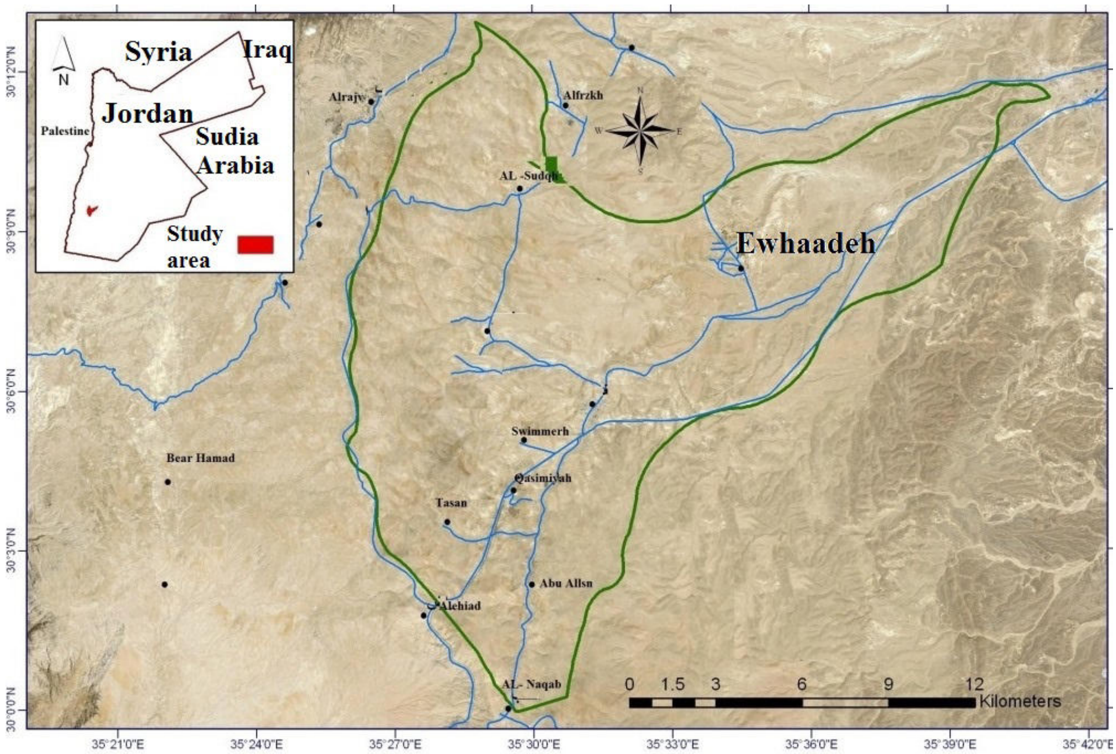

Fig 1. Satellite image showing the boundaries of Wadi Ewhaideh basin

The basin environment of Wadi Ewhaideh is characterized by drought as a result of the lack of rainfall and high evaporation rate. The annual rainfall rate is less than (150 mm.). In addition, rainfall is characterized by non-regularity and non-continuity; by being concentrated within short periods of time; and by varying precipitation rates spatially and temporally. The dry climatic characteristics of the basin directly influenced the fluvial processes over the course of the valley. We find that the lower basin being characterized by high annual temperature rate (17.7 C); low annual precipitation rate (50 mm.); and high annual evaporation rate (2886.5 mm) negatively reflected on the activity of fluvial operations. This negative impact is exemplified by low river energy of the valley as a result of the decline in its volume of water discharge. On the other hand, we find that the improved weather conditions in the upper basin exemplified in the increase in the amount of precipitation which ranged between (120-200 mm); the low temperature annual rate (12.7 C); and the decrease in the annual evaporation rate to (1752 mm.) positively affected the activity of those operations as a result of the increase in the volume of water discharge and river energy.

Fluvial processes in the valley have also been associated with the other elements of the basin system, especially geology and soils. The limestone formations that constitute the river bed and its banks have directly influenced the hydrology of the valley and the activity of its fluvial processes and the quality of the sediments that make up the gravelly bars. The volume of sediments has been affected due to the fact that the river bed along the course of the valley is formed of limestone formations that are characterized by too many cracks, fissures, and rock joints. Sand formations that cover the river bed in the lower basin contributed to the increase in water leakage factor due to its high permeability (Figure 2).

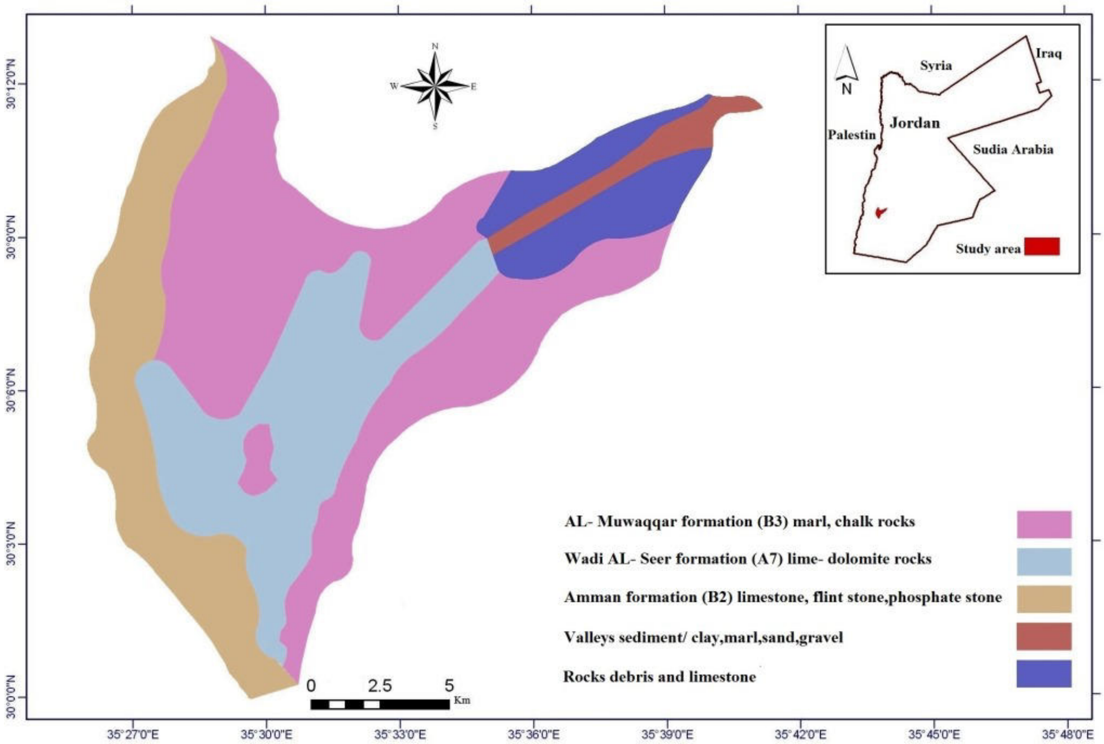

Fig 2. Surface formation in Wadi Ewhaideh basin

The characteristics of the soil represent a geomorphological factor that determines the power and size of the water discharge that is formed after rain storms. This role appears through the direct relationship between the permeability of the soil on the one hand, and the volume of water flow in the tributaries of the river on the other hand, as the volume of water flow increases in the tributaries of river with low soil permeability. There are different types of soils in the basin of Wadi Ewhaideh according to the American classification of soils in Jordan, which was adopted by the Ministry of Agriculture in 1993. The soils in the basin are characterized by high permeability, and the most important of which are: Typic Calciorthids, Xerochreptic Calciorthid, Calcixerollic Xerochrept, Typic Camborthid, and Typic Torriorthents.

5. Dynamism of Gravelly Bars Formation:

Gravelly bars are direct result of the changes in the volume of water discharge and the consequent changes in the river energy and its ability to carry sediment that result from river bed and banks erosion (Figure 3). The formation of bars in the valley is linked to imbalanced state between the river energy and its ability to carry sediment, as the stream tends to offload its load of gravelly material when its energy to carry sediments declines. The decline in river energy is associated with a number of geomorphological variables, the most important of which are: low volume of water discharge; low speed of water flow; and the presence of a natural barrier that hinders the force of water flow. The volume of water discharge is associated with the areas in which the river bed has a gradient less than $4^{o.}$ The natural barrier is represented by the river bed characteristics in terms of roughness, vegetation, and accumulation of rock debris resulting from landslides.

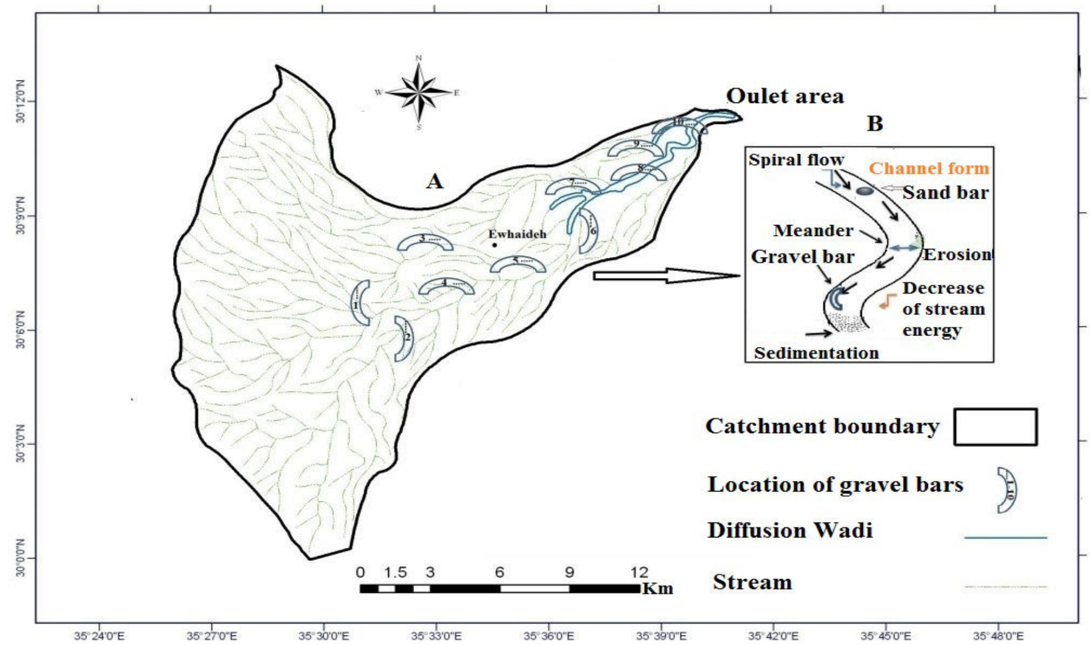

Fig 3. A: The distribution of gravelly bars alongside the course of Wadi Ewhaideh, B The dynamism of gravelly bars formation

Barriers and obstacles on the bed of Wadi Ewhaideh constitute a major factor in increasing the river's ability to form barriers. Their role is manifested through their ability to direct the water flow outside the banks. This increases the erosive activity of water flow on those banks and carries the product of erosion away from the outer banks to be deposited at the inner banks. Understanding the dynamism of bars formation helps determining the pattern of river barriers.

6. Longitudinal Profile of Wadi Ewhaideh:

Studying the longitudinal profile of Wadi Ewhaideh sheds light on the dynamism of gravelly bars formation, as the longitudinal profile of the valley is characterized by clear variation in its gradient characteristics. This variation has affected the strength of the water flow and its ability to carry its load of sediment (Figure 4).

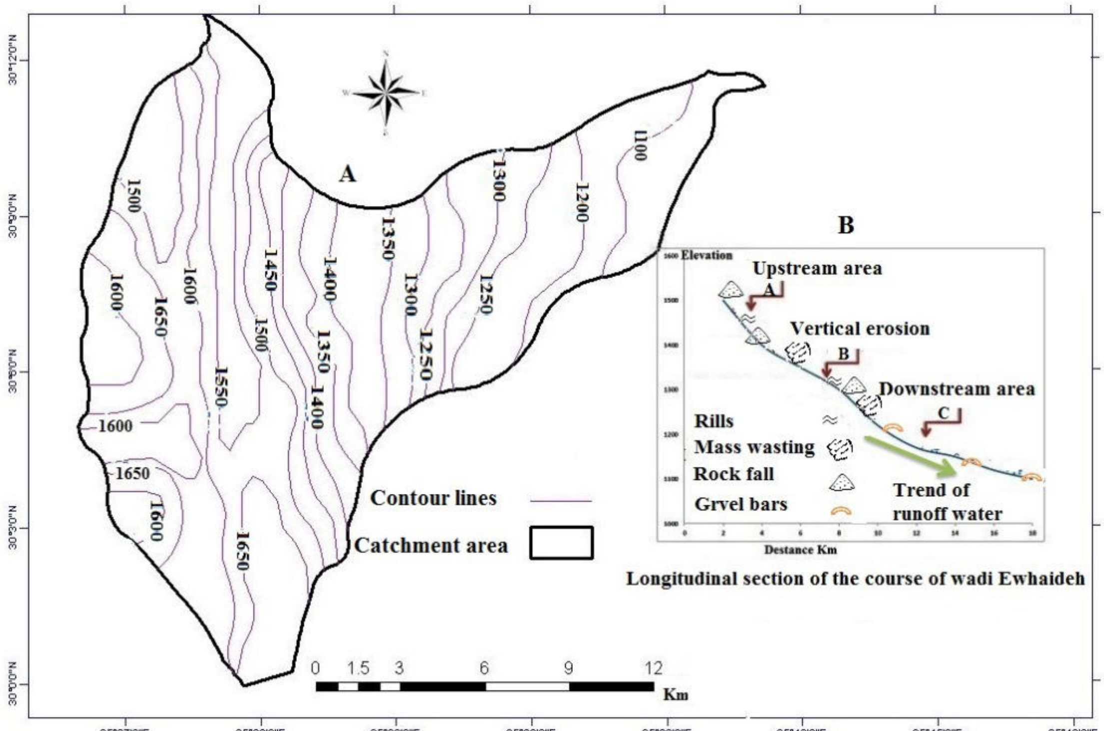

Fig 4. Longitudinal section of the course of Wadi Ewhaideh, A: The topography of Wadi Ewhaideh, B: The longitudinal section of the course of Wadi Ewhaideh sheds light on the processes geomorphological

The gradient rate changes over the course of the valley, depending on the different natural conditions of the basin. The gradient in the headwaters area ranges between (5.3˚ - 7.8˚), then it begins to decline gradually as we move toward the downstream area where it ranges between (1.7˚-5.1˚). This change is explained by the variation in the rate of vertical erosion exerted on the stream bed by runoff water flowing into the mainstream, as the vertical erosion ability of the water flow increases depending on the increase in the volume of water discharge and the speed of its flow, and the consequent significant increase in the gradient rate of the stream and its ability to carry sediments (Figure 5).

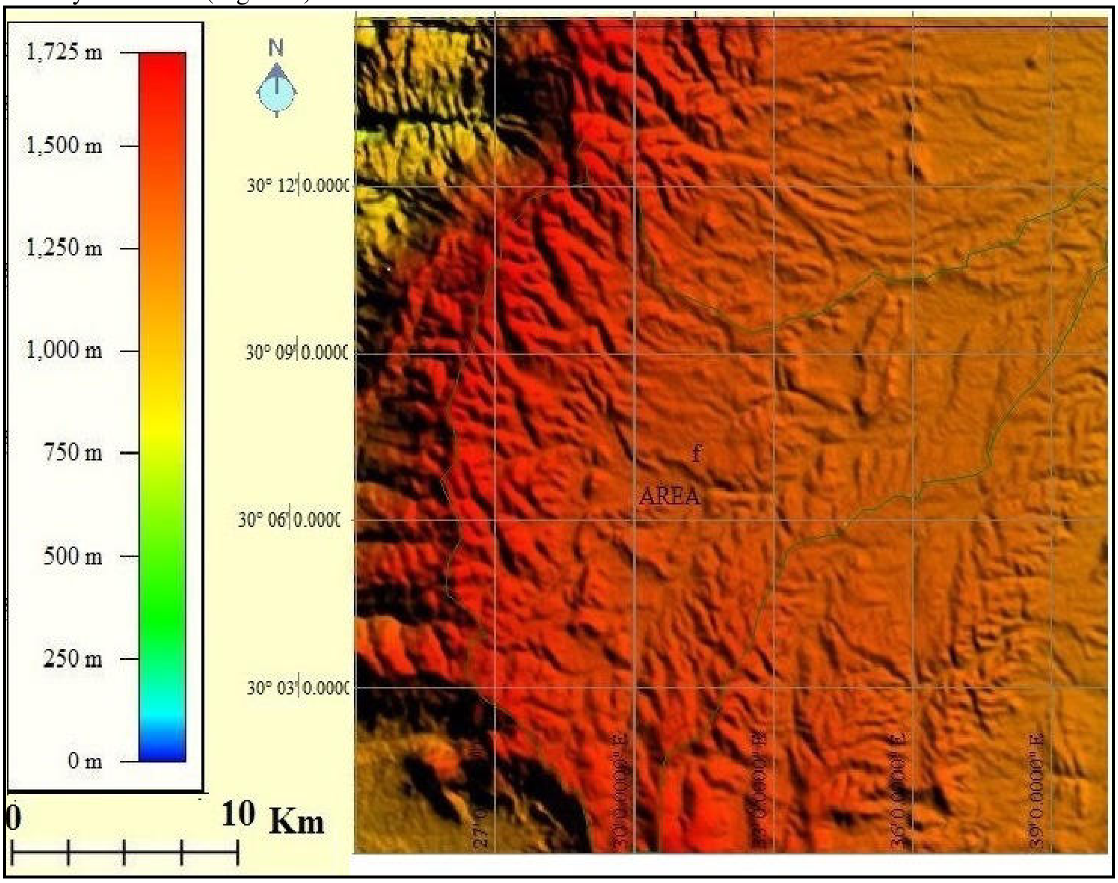

Fig 5. Digital elevation model of the study area

Moreover, the variation in the characteristics of rock formations of the stream bed and the amount of sediment and rock debris that cover it determines the vertical erosive ability of the water flow. This vertical erosive ability increases in the rocks which is characterized by a lack of solidity as Muwaqqar rock formation; and decreases in the rocks which are characterized by its solidity and its resistance to the process of vertical erosion, as Wadi AL-Seer rock formation.

The presence of numerous, short, steep parts that occupies a high percentage of the total sloping lengths indicates irregular longitudinal profile of the valley. The sloping parts with length less than 300 m have a percentage of (74.9%) of the total number of the sloping in the longitudinal profile of Wadi Ewhaideh.

The low gradient in the lower basin has a direct impact on the dynamism of gravelly bars formation. Low gradient in these areas decreases the stream ability to carry gravelly sediments as a result of the low speed of water flow, and the increase in leakage rate and decrease the volume of water discharge.

7. Results and Discussion:

7.1. Morphology of Gravelly Bars:

7.1.1. Morphological Shape:

The gravelly bars have variable morphological shape. Their shape changes during the phases of their formation. This change is associated with the dynamics of fluvial operations determined by the natural conditions of the valley. The process of formation passes through distinct stages. The beginning of barriers formation appears in the form of a platform composed of coherent coarse sediments; these sediments form the basis on which gravelly bars develop as a result of depositing the carried bed load. As the deposition process continues, the barriers grow supported by the vegetation that grows beside it. As the size of the barriers increases, the river tends to bend and change the direction of its course.

Most gravelly bars in Wadi Ewhaideh form in the shallow areas of the river bed and the areas adjacent to the stream away from the thalweg line where the volume of water discharge is low. Others form on the sides of the river bends as the water current manifests changes when it reaches these bends. The faster current on the outer side of the bend erodes the outer bank and carries the resulting sediments. And, while the water current flows away from the outer bank of the bend, it loses part of its power when it reaches the inner bank of the bend - which is characterized by being shallow and less steeper – and deposits the sediments beside the inner banks. Thus, the gravelly bars form at the inner side of the bend, and take the form of crescent which is consistent with the shape of the river bend.
Some of the barriers appear in the middle of the river channel as a result of the presence of a natural obstacle. They take the form of a hump where the large gravelly materials are concentrated on the top, while smaller sediments accumulate in the lower parts. The average height of the barriers in the upper basin reached (0.45 m) with a width of (0.80 m) and a length of (1.25 m). These dimensions increase as we approach the downstream area (the dam).

7.1.2. Morphometric Characteristics of the Gravelly Bars:

The growth and the evolution of gravelly bars; and the increase in their morphometric dimensions depend on two variables. The first variable is the amount of sediment carried by the river flows and is deposited above the gravelly rallies that make up the body of the gravelly bar. This variable determines the balance that exists between the stream energy of the water flow and the volume of carried sediment and the amount of gravelly sediment deposited. The increase in the stream energy reduces the amount of sediments deposited, while the decrease in the stream energy increases the amount of sediment that make up the gravelly bars.
The second variable is the ability of the gravelly bar body to resist the water shear forces caused by water currents when it hits the barrier. The changes in the amount of carried sediments, the stream energy, and the water shear forces make direct changes in the morphometric dimensions of the gravelly body. Table (1) shows the morphometric dimensions of some gravelly bars and their relationship with stream energy and the size of bed load sediment carried during the rain storm (7-12/1/ 2015). By analyzing the table, we find the following facts:

1. the difference in the morphometric dimensions of the gravelly bars in terms of length, width and height; where their average length ranged between (0.95 m - 4.21 m), the width ranged between (0.56 m - 1.91 m), and the height ranged between (0.15 m - 0.45 m). This difference is attributed to the change in the stream efficiency to carry bed load sediments, which in turn depends on the hydrological characteristics of the water flow in terms of its speed and the amount of water discharge. The average amount of water discharge during the storm ranged between (1.3 m^3 / s - 2.1 m^3 / s), while its average speed ranged between (0.35 m / s - 0.6 m / s), and the average volume of carried bedload sediments ranged between (5 mm -21 mm).

2. The stream energy determines the volume of the carried bed load sediments. This means that the formation of the gravelly bars is associated with the occurrence of a sudden drop in the stream energy causing a reduction in the capacity of the water flow to carry sediments of large volumes to be deposited in the form of gravelly bars. The average stream energy during the rain storm ranged between (0.08 - 0.378).

3. Sedimentary characteristics of the gravelly bars are linked with the quality and volume of carried sediments. This means that the development and growth of the gravelly bars depends on the amount of gravelly sediments that are deposited at those barriers.

Table (1): The Morphometric Characteristics of the Gravelly Bars

Number of gravelly bar	Average length (m)	Average width (m)	Average height (m)	Average water discharge speed (m/s)	Average volume of water discharge (m^3/s)	Average stream energy	Average volume of bedload sediments(mm)
1	0.95	0.56	0.15	0.6	2.1	0.378	21
2	0.95	0.57	0.2	0.55	1.9	0.287	17
3	1.99	0.59	0.22	0.55	1.8	0.272	18
4	1.98	0.54	0.29	0.5	1.5	0.188	10
5	2.27	0.6	0.3	0.45	1.5	0.152	9
6	2.3	1.6	0.35	0.4	1.4	0.112	9
7	2.85	1.76	0.35	0.4	1.4	0.112	8
8	2.9	1.8	0.39	0.4	1.45	0.116	8
9	3.96	1.9	0.4	0.35	1.3	0.08	5
10	4.21	1.91	0.45	0.35	1.3	0.08	5
Average	2.436	1.183	0.31	0.445	1.565	0.1777	11

7.2. Sedimentary Characteristics of the Gravelly Bars:

7.2.1. The Volume of Gravelly Sediments:

The gravelly sediments that form the gravelly bars vary in terms of their size. This variation is due to the fact that the carried sediments pass through basic changes determined by the hydrological characteristics of the valley, and the changes that occur on the stream energy of the water flow and its ability to carry and deposit sediments. Low stream energy of the water flow weakens its ability to carry large size gravelly sediments, which means that the sizes of carried sediments commensurate with the amount of stream energy of the water flow. The variation in the sizes of the gravelly sediments in the body of the gravelly barrier reflects the hydrological changes undergone by the valley during different time periods. The sizes of the gravelly sediments, that form the gravelly bars, vary in size from one region to another according to the variation in the stream energy determiners. The most important of these determinants are the gradient of the river bed, the volume of the river discharge, and the nature of the stream banks. The increase in the gradient leads to an increase in the stream energy, which in turn increases the ability of the water flow to carry large sizes. The average size of carried bedload sediments during the rainstorm (7-12/1/1015) in areas where the gradient ranged between (5-7˚) reached about (17.6 mm), while their average size in areas of gradient (1-3˚) reached about (28 mm). This directly reflected on the size of the gravelly sediments that make up the gravelly bars; as their average size ranged between (4 - 35.8 mm) in high gradient areas, while it ranged between (5 - 47.3 mm) in lower gradient areas. Figure (6) shows a positive relationship between the sizes of carried materials and the increase in the volume of water discharge during the rainstorm that hit the basin on 7-12 / 1/2015. The size of the carried gravel sediments increased with the increase in the volume of water discharge, according to the following regression line equation (Eq3):

$Y=0.1235x$ $R^2=7684$ (3)

Where: Y is size of gravel sediments, X is the amount of water discharge m^3 / s, R is the interpretation integral.

The rate of water discharge in the valley during the rainstorm ranged between (0.6 m^3/S – 2.31 m^3/S), while the volume of the carried gravelly materials ranged between (4 mm – 17.6 mm). The loose banks of river directly affected the sedimentary characteristics of the gravelly bars, as the deposits of the bars in those areas are characterized by coarseness and increased sizes rate, where their average rate reached (29.5 mm). On the other hand, the deposits of the bars near the solid banks are characterized by less coarseness and decreased sizes rate (16.9 mm).

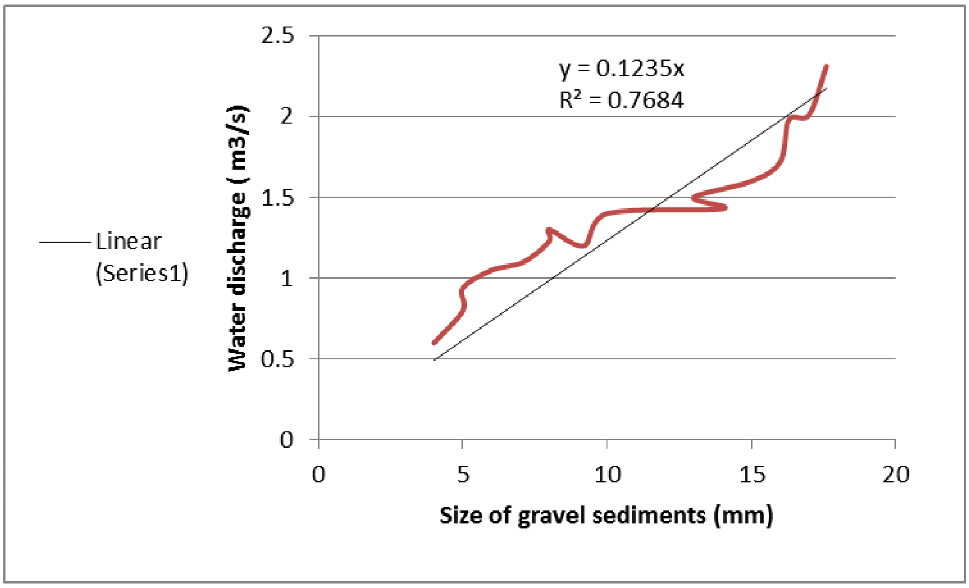

Figure (6) shows a positive relationship between the sizes of carried materials and the increase in the volume of water discharge during the rainstorm that hit the basin on 7-12 / 1/2015

7.2.2. Morphological Characteristics of the Gravelly Sediments:

The bedload of the valley determines the morphological characteristics of the sediments, as the shape development of the gravelly bars depends on the changes in the morphological characteristics of the carried bed materials. Several geomorphological variables interfere in determining their morphological characteristics in terms of roundness and sphericity and other shape categories. These variables include the quality of the rock from which the bed sediments are derived; the carrying distance; and shear and friction forces to which those sediments are exposed.

Table (2) shows the morphological characteristics of the gravelly sediments in Wadi Ewhaideh. By analyzing these characteristics, we find the following:

1. Low sphericity rate for the targeted gravelly bars, as the sphericity percentage reached (22.25%) with a variation in this percentage ranging between (13 – 41 %). This percentage increases in the lower parts of the valley, as the carried sediments collide with the rocks alongside the river course taking the spherical shape.

2. Low percentage rate of the gravelly sediments that have rounded and sub-rounded shapes in all gravelly bars, reaching a rate of (11.6%, 14.5%) respectively; while the percentage rate of the gravelly sediment that have angular and sub-angular shapes increased to reach (38%, 36%) respectively. The reasons for the variation in the degree of roundness in those groups are the difference in their carrying distance and the friction and fragmentation they experience during transportation. Sediments that are carried for longer distances are more likely to take the rounded shape than those that are carried for shorter distances.

Table (2) shows the sedimentary characteristics of the gravelly bars in terms of size, sphericity, and roundness.

Gravelly bar number	Location of bar	Gradient rate of stream course (o)	Average size of sediments (gravel) mm.	Sphericity percentage %	Percentage of roundness categories %			
					rounded	Sub-rounded	Angular	Sub-angular
1	Upstream	6	19.8	13	3	6	56	35
2	Upstream	6	22.3	13.5	5	9	53	33
3	Upstream	5	25.7	14	7	9	52	32
4	Midstream	5.5	27.3	16	6	10	54	30
5	Midstream	4	29.6	18	8	13	44	35
6	Midstream	4.5	28.2	19	12	14	37	37
7	Downstream	3	39.8	25	16	19	28	37
8	Downstream	3	39.5	29	17	20	25	39
9	Downstream	2	43.6	34	21	22	17	40
10	Downstream	1.5	48.9	41	21	23	14	42
Average	Downstream	4.05	32.47	22.25	11.6	14.4	38	36

3. The size of the gravelly sediments ranged between (19.9 – 48.9 mm) with an average of (32.47 mm). The size of gravelly sediments increases as we approach the lower basin; as the stream energy to carry coarse sediments is low.

4. There is an inverse relationship between the size of gravelly sediments deposited at the gravelly bars and the gradient. This is because the ability of water flow to carry gravelly sediments is linked to its speed, which in turn depends on the gradient of stream course. The gradient of the stream course near the gravelly bars ranged between ($1.5^o – 6^o$).

8. Conclusion:

The formation of gravelly bars in Wadi Ewhaideh is linked to its low ability to carry sediments due to its reduced gradient, or reduced stream energy due to a natural barrier. It is also linked to the increasing payload beyond its capacity. The increase in the sedimentary payload is due to the processes of lateral erosion to which the banks of the stream and the river bed are exposed.

The growth and evolution of the gravelly bars depends on two variables, namely: the amount of sediments carried by the river flows and deposited over gravel rallies that constitute the body of the gravelly bar; and the ability of the gravelly bar to resist water shear force caused by water currents when they hit the bar.

The gravelly bars differ in their morphometric dimensions in terms of length, width, and height. This difference in the morphometric dimensions of the gravelly bars is attributed to the difference in the river efficiency to carry bed sediments, which in turn depends on the hydrological characteristics of the water flow in terms of the amount of water discharge and its flowing speed. The study showed that the increase of the morphometric dimensions of the gravelly bars is inversely associated with the stream energy of the runoff in the valley.

The morphological development of the gravelly bars depends on the changes in the morphological characteristics of carried bed materials. Several geomorphological variables interfere in determining their morphological characteristics in terms of roundness, sphericity or other shape categories. These variables include the quality of the rock from which the bed sediments are derived; the carrying distance; and shear and friction forces to which those sediments are exposed.

The study also showed that the loose banks of the river directly affected the sedimentary characteristics of the gravelly bars. The sediments in those areas were characterized by big size and coarseness, where their average size rate reached (29.5 mm). On the other hand, the sediments of the bars near the solid banks were characterized by less coarseness and decreased sizes rate.

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