Indian Journal of Ecology (2020) 47(3): 638-644

Manuscript Number: 3058
NAAS Rating: 4.96

Water Erosion of the Slopes of Tayyar Drainage Basin in the Desert of Muthanna in Southern Iraq

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Abstract: This study examines the most important phenomenon of water erosion of Wadi Al-Tayyar basin, one of the seasonal valleys in the lower valley area of the south Iraqi desert, near the Iraqi-Saudi border. It is located in the southern part of Sawa lake, which has an area of 2522.921 km² and a 447.537 km perimeter. Among the most important natural factors that have been analyzed are those affecting the creation and formation of this phenomenon, such as the geological structure, slope system, climatic elements, water resources and natural plants. The rain proves to be partially inefficient when it comes to collision damage, due to the fact that the basin occurs in a semi-arid climate characterized by relatively low precipitation. There is a wide spread of plate tectonic erosion, especially in the area around the springs, due to the prevalence of relatively flat land among similar contouring sectors. This leads to the gathering of water in form of a shallow layer with a relatively large area. There is a noticeable variation in the number of water torrents between the basins, as the generally highest number found in the main Tayyar basin reached 645 torrents, whereas the lowest value was at the secondary Tayyar basins, being 79 ones. Another variation is that in the total length of the gullies within the drainage basin.

***Keywords*:** Water erosion, Drainage basins, Geomorphological processes, Geographical Information System (GIS)

Water erosion is considered to be one of the essential and most significant processes in geomorphological studies, merely for its important effects on the shaping of the earth's surface (Kisic et al 2018). The intensity of water erosion varies from one part to another depending on the abundance of rain and the intensity of the rainstorm, the larger amount of rain, and the more water will be flowing on the surface of the drainage basin. These could be in form of sheet runoffs, rills, gullies, streams or rivers, thus eventually increasing erosion. Studying this phenomenon and determining its causes, factors of origin, intensity, and spatial distribution consequently leads to taking the necessary and effective steps to limit its damages. Huge attention has been devoted in terms of research in many countries around the world. Many earlier worker observed the study attempt the evaluation of parameters accuracy to determine erosion factor and calibrate appropriate model by investigating 14 stations in all around Iran for 23 years according to Wischmeier and Smith model for erosion (Sadeghi and Tavangar 2015). Morgan and Mnomezulu studied gully erosion of the valley slopes located in central Switzerland (Morgan and Mngomezulu 2003), while Dabek et al. (2014) have been studied and analysed water erosion processes of the mountain slopes in zklarska Poręba Forestry in Netherlands, Holze and et al (2015) studied water erosion in rather humid areas in selected locations in western United States and suggested a classification of erosion patterns for the region. In addition, (Al-Abdan, Raheem Hameed, Al-Samarrai 2008) studied the rain erosion of the slopes of the Hamrin hills in northern Iraq, using Geographic Information Systems (GIS), (Hasan 2000) examined the water erosion in the basin of the Darbendikumspan Valley northeast Erbil-Iraq, in terms of its drainage network. The current research aims to identify the most significant natural factors that evoked water erosion at Wadi Al-Tayyar basin in the desert of Muthanna in southern Iraq.

MATERIAL AND METHODS

The phenomenon of water erosion in Wadi Al-Tayyar basin was analyzed an interpretation of its main types, spatial patterns of spreading, formation factors, and essential geomorphological processes of influence. This is done by relying on geospatial data such as the digital elevation model (DEM) type (SRTM) with a resolution of 30 * 30m, issued by the US Department of Defense, and satellite imagery from the American satellite LANDSAT ETM + 8BANDS for the year 2013, with a distinctive accuracy of 30m, and topographic maps scale 1: 100,000 issued by the General Authority for Iraqi Survey and Geological Maps. Additional data sources were the hydrological scale 1/250000 issued by the Iraqi Geological Survey, and the data collected through the field study. These data were analyzed using the GIS and remote sensing software package (Arc GIS V.10.4.1 program) Earth GIS V.1.3, Global Mapper V.11, Surfer V.10, Google Earth Pro V.7.1, and SAS Planet V.16 to download high-resolution satellite imagery, after which a spatial database was created for the research area. Topological analyses and spatial conformity of all layers were performed, after which the transition was made to the next stage of geomorphological analysis and interpretation of the studied phenomenon, using models that explain the interaction between the factors and the process itself, and its structuring and formation of different forms of water erosion and their spread patterns. So as to calculate the rain-erosion rates of Wadi Al-Tayyar basin, the modified Fournier Index (1977) (De Luis et al 2010) is used as an indicator in the form of a mathematical equation 1:

$FI = (P)2 / P$ ……..…. (1)

Where, (FI) stands for index, (P) 2 represent the monthly rain amount, (P) represents the annual total of rain. If the result is less than 50, then the drift intensity is weak. Whenever F exists within 50-500, this indicates that it has a moderate drift, and the ranges (500-1000) and (more than 1000) refer to a high drift and intensively high drift, respectively. To measure the intensity of the gully in the Wadi Al-Tayyar basin, an equation (2) introduced by (Bergsma 1983) was used to measure the intensity of the gullies in the river basins. It has been applied to the main Tayyar valley basin and secondary basins, after the number and length of gullies for the riverine network were measured. The area occupied by these gullies in each secondary basin was measured through the interpretation of high-resolution satellite visualizations, topographic maps and field data for the main and secondary basins, using the following equation:

$AE = \sum Aw / A \times 100$ …………... (2)

Where:

AE: Average Gully Erosion

$\sum Aw$: Total Gully lengths (km)

A: Area of Basin (km^2)

Study area: Wadi Al-Tayyar basin is located in the western parts of Al-Muthanna desert in southern Iraq. It is bordered by the north and northeast by the city of Samawah, to the east by the Wadi Abu Hadair basin, to the south by the Wadi al-Faraj basin and the Iraqi-Saudi border (Fig. 1). The basin extends between the latitude circle (30 15-31 15) and the longitude (44 07 - 45 05), and Wadi Al-Tayyar basin, one of the seasonal valleys in the Lower valley area of the south Iraqi desert, is located in the southern part of Sawa lake, which has an area of 2522.92 km² and a 447.537 km perimeter. The total basin length is 150km starting from its upper sources near the Iraqi-Saudi border and ending with its estuary in the southwestern parts of Sawa lake, as the height at the basin ranges between 20 and 170 m above sea level, running from the southwest towards the northeast (Fig. 2 and 3).

Various geological formations are found within the basin, differing in their properties and areas, such as wind sediments spread in the northern parts of the basin which result from wind erosion processes in the region (Fig. 4), and expand in form of sandy layers containing sand, silt and gypsum, having different depths from one place to another

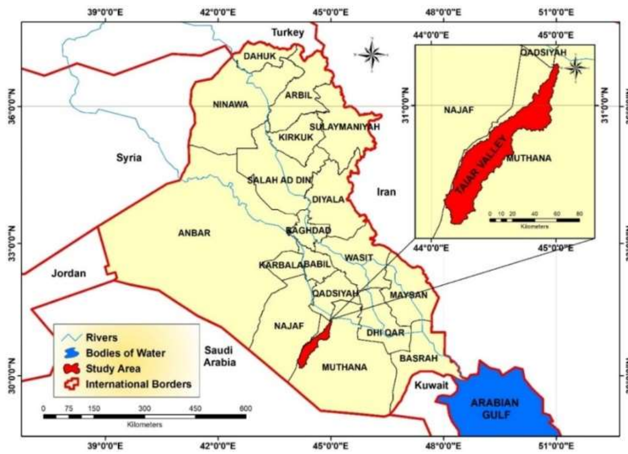

Fig. 1. Wadi Al-Tayyar in Iraq, the area of study

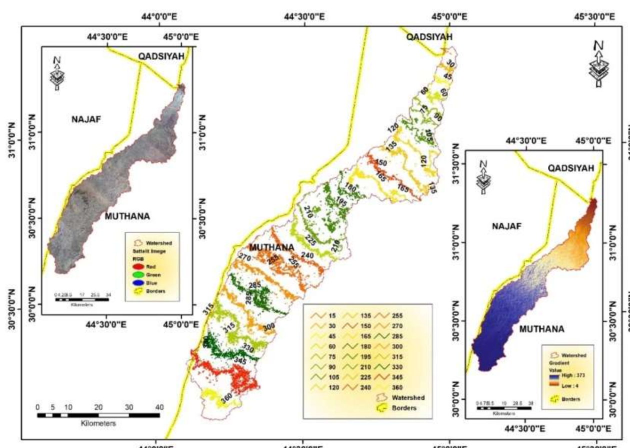

Fig. 2. Regression system of Wadi Al Tayyar Basin

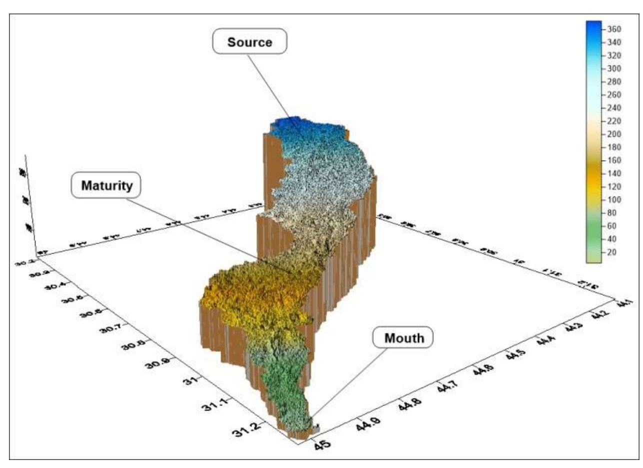

Fig. 3. Morphological model of Wadi Al-Tayyar basin

(Al-Jiburi and Al-Basrawi 2009). The middle Dammam formations are found in the central parts of the basin, as they are merely broken rocks and conglomerates covered by a layer of limestone, chalky and phosphate stones, while in the southern parts, the Jil formations date back to the lower Eocene era, formed within a shallow marine environment, and consist of chalky limestone and marl rocks that have coarse crystals nodes, the thickness of which is estimated between 60 - 88m (Jassim and Goff 2006).

Most climatic studies indicated that the basin is located within the semi-arid climate, and is characterized by a variation in temperatures, as temperatures increase during the summer months (June, July and August) and reach the highest rate in the month of July (35.7), and decrease during the winter season (December, January and February) and recorded the lowest values in January (11.2). The study area is also characterized by the seasonal annual and monthly rainfall, which falls over relatively long periods of time, and occurs as large rain showers that quickly turn into floods. It is restricted between October and May, with an annual average of 8.2 mm, without being distributed regularly over this period, as it was 4 mm in October, whereas, it reached 23.4 mm in January, and then began to decline from February onwards 11.7 mm (Table 1).

Wadi Al-Tayyar basin is one of the dry valleys within the lower valleys in southern Iraq, and it lacks a permanent source of flow due to its location within the semi-arid climate, as water does not run through it until after exposure to a rainstorm. The rainstorm provides it with the quantity of water that can flow into the main basin and the secondary basins (Fig. 5). The greater part of it is lost by evaporation, transpiration and infiltration into the ground. The lack and scattering of the natural plant has led to an increase in the effectiveness and activity of the different geomorphological processes (erosion, transport and sedimentation), as the slopes and edges of the valleys are in such a case highly susceptible to overall erosion processes (water and wind), landslides and rock falls (Zachar 2011). The quantity and quality of the natural plant in the basin varies from one place to another depending on natural conditions, and can generally be divided into two types. The first are annual plants, which are often small-sized herbaceous plants that grow in a particular season of the year when the conditions are appropriate, and they represent 75% of the total natural flora in the basin. Among the most important types are: Tephrosia, Bromus, Capparis and others species (Fig. 6). The second type is perennial plant that grows permanently and grows by various means such as by extending their long roots inside the soil or its small leaves that help to resist drought and reduce the transpiration rate, these plants regrow with the beginning of the rainy season, and represent 25% of the total natural cover of the basin. Examples of its most common types are Artemisia, Haloxylon, Rhanterium, Schanginia, Tamarix and others species.

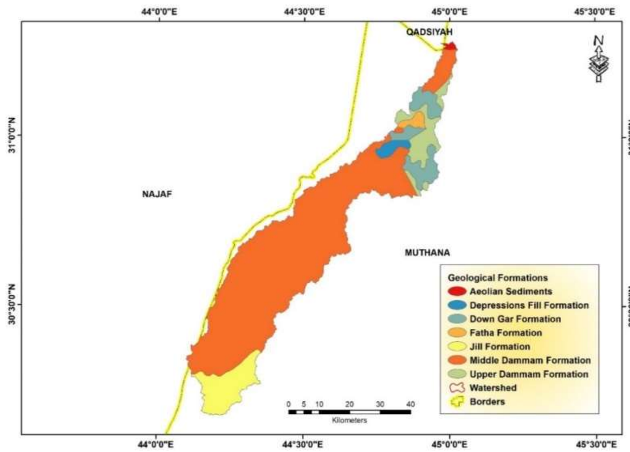

Fig. 4. Geological formations of Wadi Al-Tayyar basin

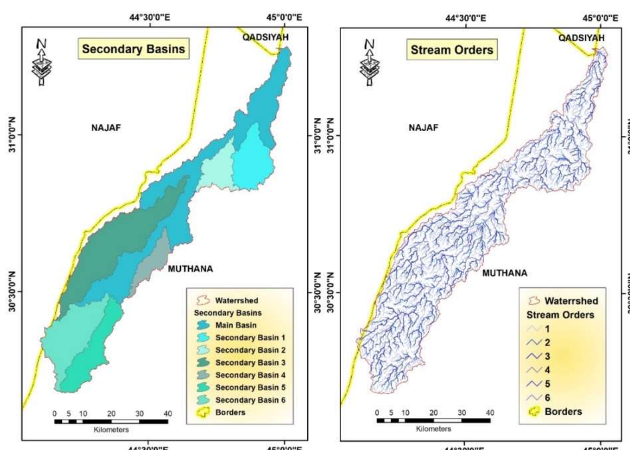

Fig. 5. The riverine levels and secondary basins of Wadi Al-Tayyar basin

Fig. 6. The natural plants in the central parts of the basin

RESULTS AND DISCUSSION

The results showed the highest value for rain erosion was recorded in January (5.58), and the lowest value in October (0.16), sheet erosion due to field observation was wide spread in the valley, rills erosion was diagnosed through the number of water torrents for the main Tayyar basin which reached 645 as the highest value in the main basin, while its number in secondary Tayyar basin 4 reached 79 torrents, which was the lowest value. As for the other secondary basins, these numbers varied were 168, 111 and 409 torrents for each of the secondary basins 1, 2 and 3, respectively (Table 3), and gullies erosion showed there is a clear variation in the rate of width and depth gullies, as some of them do not exceed 2 m in width and no more than 15 m in length, whereas others exceed these dimensions as shows (Table 4). The gullies may be subjected to extinction due to the process of refining materials and accumulating them, as these transported materials impede the development of the gullies.

Rain erosion: Rain erosion is caused by raindrops that turn into torrents after coming into contact with the surface of the earth, through their quantities, kinetic energy, frequency, and duration of their fall, causing uprooting and transfer of soil particles from one place to another (Annab 2006). The raindrops erode soil grains by separating and extracting them from the surface in order to be transferred over varying but relatively limited distances (Holz et al 2015). This process depends on a number of factors, especially the geological structure, as there is a clear variation in the types of geological formations in the basin where formations prevail wind sediments in the water of the basin. This spreads in form of sandy layers with different thicknesses, consisting of silt,

Table 1. Rates of climatic elements according to the data of Samawah climatic station (1973-2014)

Month	Average temperature (ºC)	Rainfall (mm)
January	11.2	23.4
February	13.6	11.7
March	18	11.6
April	24.3	11
May	30.2	11
June	33.8	–
July	35.7	–
August	35.1	–
September	32.4	–
October	26.4	4
November	18.7	12.2
December	13.3	13.9

Table 2. Rain tendency according to the modified Fornair Index (1977) (Fornier-Arnoldos) for the monthly averages for the climate station in Samawah

Month	Average rainfall for Samawah Station (mm)	Average fornier index
October	4	0.16
November	12.2	1.51
December	13.9	1.97
January	23.4	5.58
February	11.7	1.39
March	11.6	1.73
April	11	1.23
May	11	1.23
Annual Total	98.8	14.8

sand, and gypsum, are more responsive to raindrops. The Middle Dammam parts also prevail in the central parts of the basin, usually in form of broken rocks and conglomerates, and are more solid than the previous one and thus less responsive to rain erosion processes. This is a clear indication that the variation in rock hardness directly affects the rain erosion rates (Fig. 7).

There is a clear effect of the slope factor, for the higher slope, the more likely for the raindrops to be affecting and vice versa. The climate factor also has an influential role by increasing the amount of rain and the duration of its fall, for floods that are exposed to large amounts of rain during a long period of time are more vulnerable to rain erosion. An additional factor is the size of raindrops, the greater the size, the more chance there is to increase rates of erosion (Al-Abdan et al 2008) As for the vegetation, it is no less important than any other factor mentioned here when it comes to its effect on this phenomenon. The higher area of vegetation, the lower rates of rain erosion and vice versa (Zhang et al 2004). After hitting the soil surface, raindrops scatter large quantities of soil particles in the air and move them to distances relatively farther from their original location, and a part of them sprinkles more than once, eventually leading to soil collapse. As well, the hydraulic impact of raindrops in this situation increases in quantity, which leads to a corresponding increase in the volume of water runoff on the slopes, consequently increasing the rates of water erosion (Al Abdan et al 2008). After applying modified Fournier Index (1977) equation (1), which is based on the monthly averages for Samawah climate station which is located in the northern part of the basin, the results indicated a weak vulnerability to rain erosion, which is naturally caused by the occurrence of the basin within the semi-dry climate, characterized by relatively little rainfall. There is a relative temporal variation in the rates of rain erosion, where the highest value was found in

Table 3. Basin spaces, numbers, total lengths, and rates required for the water slopes of Wadi Al-Tayyar basin and secondary basins

Name of Basin	Average rill erosion	Total length of rills	Number of Rills	Area
Secondary basin 1	68.48	156.1	168	227.9
Secondary basin 2	69.73	105.5	111	151.3
Secondary basin 3	70.88	406.8	409	574
Secondary basin 4	68.31	80.72	79	118.2
Secondary basin 5	74.88	178.3	166	238.1
Secondary basin 6	66.1	228.3	240	345.4
Main Tayyar Basin	70.59	612.7	645	868

January (5.58), and the lowest value was recorded in October (0.16) due to the seasonal variation of rainfall (Table 2).

Sheet erosion: This type of erosion has commonly been found within the area of study, due to the prevalence of the flat lands within the similar contouring sectors, which leads to the gathering of water in the form of a shallow layer with a relatively wide area (Mathur and Sundaramoorthy 2019), increases the slope regularity and the amount of falling rain and weak soil susceptibility (Hua Lu et al 2003). A slight slope here contributes to the movement of the floodwater, carrying with it fine rocky particles to relatively lower places. Due to the drought conditions experienced by the drainage basin, the water soon fades away, either through evaporation which is the prevailing situation, or through leakage in case of high porosity, leaving behind the sedimentary granules of various sizes (Ayyanna, et al 2019) (Fig. 8). Moreover, this type of erosion causes the loss of soil organic and nutrients, which leads to a continuous decline in soil productivity, and this inevitably leads to the emergence of other types of water erosion, because the lower layers of the soil are less resistant to erosion than the upper layers (Prosdocimi et al 2016).

Rills erosion: It is the second stage among the processes of water erosion, and begins after the end of the first stage (sheet erosion), where the water moves to steeper areas within the river basin. Sometimes it is rather difficult to distinguish between the two types of erosion due to the complex geological conditions on the one hand and practical simplicity of the hydration and its weakening on the other hand (Lu et al 2003). It is often possible to distinguish between them by noting that the second type begins with the formation of lower strips with a slight decrease, often not exceeding 70 cm. This type of water erosion is spread in the upper parts of the basin, that is, in the source area (Fig. 9 and 10), which is a result of severe water erosion operations in this region, due to the lack of vegetation and the effect of weathering operations, all contributing to the forming of rock debris and the disintegration of soil pellets ready for transportation and sedimentation. The degree of slope in this area increases the

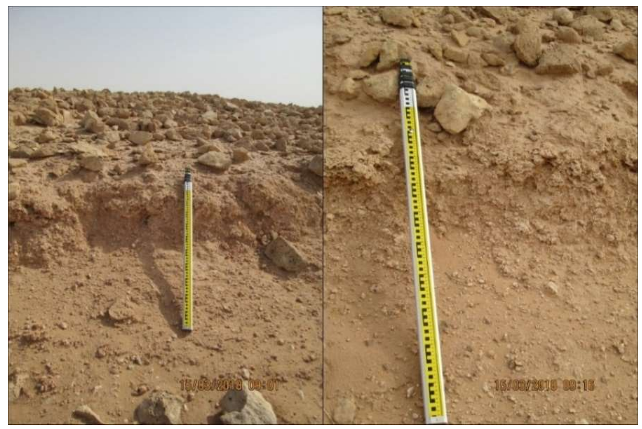

Fig. 7. Collisional rain erosion in the central parts of the basin

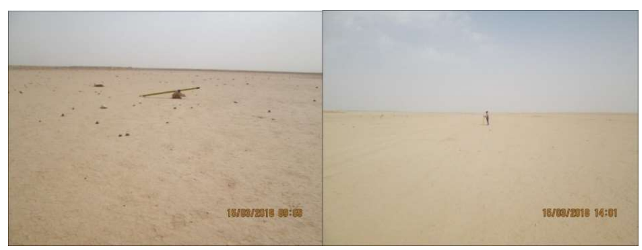

Fig. 8. Sheet erosion in the upper parts of the basin

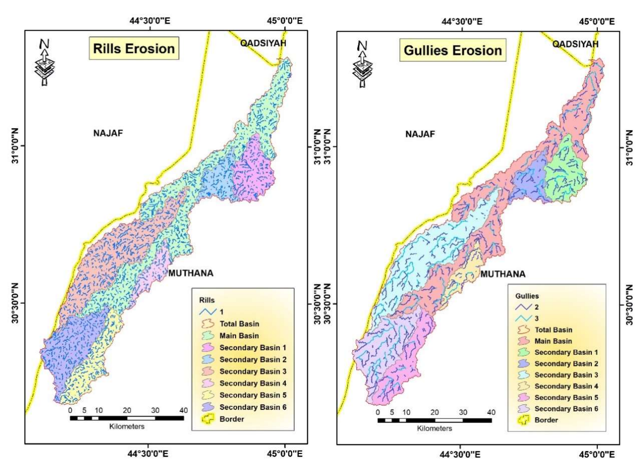

Fig. 9. Rill and gully erosion in the main and secondary basins of Wadi Al-Tayyar

effectiveness of these operations (Richard 2007). Through field reviews and numerical interpretation of remote sensitivity data, there is a clear variation in the numbers of water torrents. The number of water torrents for the main Tayyar basin reached 645, the highest value was in the main basin, while its number in Secondary Tayyar basin 4 reached 79 torrents, which is the lowest value. As for the other secondary basins, these numbers varied, were (168), (111) and (409) torrents for each of the secondary basins (1), (2) and (3), respectively (Table 3).

This is applicable to all secondary basins, as well as the factor of geological structure. Water torrents are located in areas of rocky weakness, which are often in the form of low depth striped areas. Additional factors of influence include climatic ones, especially rainfall and the natural vegetation. The secondary basins were characterized by a remarkable variation in the total lengths of water torrents, whereas in the main Tayyar valley it reached 612,715km, being the highest value. In secondary Tayyar basin 4, it reached 80,722km being, the lowest value (Table 3). The differences between the values of the other secondary Tayyar basins, was 74.875m / km^2 in secondary basin 5, while it reached 66.097 m / Km^2 in secondary basin 6, and the reason for this is due to the same factors mentioned above.

Gullies erosion: It is the third stage of water erosion, and it starts after the water rills meet with each other to form a higher river level and the resulting surfaces are called gullies and are more extensive and longer than the preceding (Rill). This naturally leads to an increase in the amount of runoff water in it, consequently increasing the erosion capacity that works to deepen and expand those gullies so that they are of clear dimensions (Fig. 9 and 11). The runoff water has a great ability to flood the rock fragments and conglomerates (Morgan and Mngomezulu 2003). The gullies are affected by the length and degree of slope, the area of the vegetation cover, the nature of the rock formation and the severity of precipitation, as these factors directly or indirectly control the emergence and composition of these gullies. There is a clear variation in the rate of width and depth, as some of them do not exceed 2 m in width and no more than 15 m in length, whereas others exceed these dimensions much. The gullies may be subjected to extinction due to the process of refining materials and accumulating them, as these transported materials impede the development of the gullies.

There is a clear variation in the total lengths of the gullies excavated in the drainage basin, which ranged between (64.998) km in secondary basin 4 to (404.984) km in the main basin (Table 4). This naturally reflects the activity of the processes of water erosion affected by the slope factor. The lower the slope, the longer the grooves increase, indicating that there is a negative correlation. In addition to the influence of the geological structure, the secondary basins were slightly different, for the secondary Tayyar basins 1, 2 and 3 reached 119,340, 70,744, and 273,007 km each, respectively. There is a variation in the rates of gullies at the level of all secondary basins, as it reached 58.110 m / km^2 for secondary basin 6, which is the highest value, and 44.152 m / km^2 for secondary basin 5, which is the lowest value. According to Bergsma's classification (Table 5), all the basins of the study area fall within the scope of very low erosion, and the reason for this is due to the region's suffering from the length of droughts that lead to less rainfall, and thus less water flow within the water network, resulting in weak water erosion and formation of gullies, in addition to the actual shortage that the basin suffers from a general relative decline. This led to a less concentrated flow, yet not preventing the creation and formation of gullies in the study area to a certain extent.

Fig. 10. Rill Erosion in the upper parts of the basin (upstream area)

Fig. 11. Gullies erosion in the central parts of Wadi al Tayyar Basin

Table 4. Total length and average gullies erosion rates for Wadi Al-Tayyar main and secondary basins

Name of basin	Average gullies erosion	Total length of gullies	Area
Secondary basin 1	52.357	119.340	227.934
Secondary basin 2	46.758	70.744	151.297
Secondary basin 3	47.565	273.007	573.957
Secondary basin 4	55.003	64.998	118.170
Secondary basin 5	44.152	105.132	238.112
Secondary basin 6	58.110	200.717	345.407
Main Tayyar basin	46.654	404.984	868.044

Table 5. Bergsma's classification of erosion degrees

Average erosion rate	Erosion level	Erosion degree
0 – 400	Very low	1
401 – 1000	Low	2
1001 – 1500	Average	3
1501 – 2600	High	4
2601 – 3700	Very high	5
3701 – 4700	Strong	6
More than 4700	Very strong	7

CONCLUSIONS

The results indicated that weak ability of rain to have an impact on the plates, resulting from the occurrence of the basin in the semi-arid climate, which is characterized by relatively low rainfall rate. There is a relative temporal variation in the rates of rain erosion in the basin. There is a widespread prevalence of sheet erosion, especially in the upstream area due to the rule of relatively flat lands within identical contouring sectors, which leads to the gathering of water in the form of a shallow layer with a relatively wide area. The secondary basins were distinguished by a clear variation in the total lengths of water rills, this naturally reflects the activity of water erosion affected by the slope factor, there is a variation in the rates of gullies erosion at the level of all secondary basins, according to Bergsma's classification, all the basins of the study area fall within the scope of the very low erosion rate.

ACKNOWLEDGMENTS

The financial, technical and scientific support provided by the University of Misan - Iraq, and the presidency and members of the scientific committee in the Department of Geography at Faculty of Basic Education - University of Misan is acknowledged.

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Received 12 June, 2020; Accepted 19 August, 2020