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Analysis of the Form and Pattern of Beshar River Basin Drainage Network Using the Order Matrix Model

Zahra Parvane[1], Heeva Elmizadeh[2]✉

[1]M.S. in Geomorphology, Khorramshahr University of Marine Science and Technology, Khorramshahr, Iran

[2]Associate professor, Department of Marine Geology, Khorramshahr University of Marine Science and Technology, Khorramshahr, Iran

✉elmizadeh@kmsu.ac.ir

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Abstract

Rivers are dynamic geomorphological systems that shape the physical environment by adjusting their bed morphology in response to disequilibrium induced by physical and human factors, striving to achieve equilibrium conditions. The Order Matrix Model serves as a valuable tool for quantitatively analyzing, comparing, and assessing the degree of disorder in river networks, irrespective of their size. This study employs the Order Matrix Model to examine the relationship between the form and pattern of the drainage network in the Beshar River basin, a significant tributary of the Karoon River in Kohgiluyeh and Boyer-Ahmad Province, southwest Iran, located in the Zagros Mountains foothills. Vector data of streams were derived from 1:50,000-scale topographic maps and processed using ArcGIS software. The basin was divided into right and left halves, and a drainage network map was generated. Results from the Order Matrix Model revealed distinct drainage patterns: the left side exhibits an undeveloped, near-parallel pattern, while the right side approaches a dendritic pattern, indicating low hierarchical order. Tectonic activity and unequal rock strength in the basin are the primary causes of this disequilibrium, with greater disorder observed on the left side. The Order Matrix Model effectively quantifies the complexity and disequilibrium of river networks, providing insights into their geomorphological evolution.

Keywords: Beshar River, Order Matrix Model, Drainage Network, Equilibrium, Tectonic.

1- Introduction

The endless competition between tectonic processes that produce rugged and erosive processes, although seems slow to occur, is the main fundamental changes in hydrological, geomorphological, and environmental equilibrium (Avşin et al., 2019). The network of streams under the influence of factors and various variables is constantly changing in terms of dimensions, shape, direction, and pattern, and they seem to be out of order (Ariza-Villaverde et al., 2013; Kycl et al., 2017). For this reason, instability is an inherent feature of these environments and due to the influence of physical or human factors; they change direction and pattern (Zhihui et al., 2017; MR & Achyuthan, 2019).

rivers, as a systemic identity, one of the most significant forms and geometric patterns are as an important and dynamic part of the physical environment that change their bed morphology in response to disequilibrium caused by physical and human factors to reach further equilibrium conditions. There are complex interactions between river morphological variables including discharge, sediment load, the slope, and river profile (Moavi & Elmizadeh, 2020; Mohamadkhani et al., 2021).

Therefore, any change in any of these variables will be clearly reflected in the morphological reaction of the river. The course of rivers represents equilibrium conditions, an equilibrium that is continuously created over time and space by fluctuations in discharge and sediment load. While the result of these fluctuations is revealed by vertical and horizontal changes; this dynamic change which guarantees the power and diversity of physical systems stimulates the river to reach equilibrium. Thus, changing is a natural and vital part of a dynamic river system (Zhihui et al., 2017).

Meanwhile, numerical analysis of drainage networks based on river ordering system in earth sciences helps to the identification of the stream network quantitatively and leads to new findings of basin equilibrium. In this regard, to identify inequalities in river geosystems and survey the relationship between the drainage network forms and patterns, as well as predict the behavioral patterns of such physical environments can use the geosystem forms rules and arranged them with the help of quantitative models (Rai et al., 2018; MR & Achyuthan, 2019).

One of the applications of stream network modeling in defining quantitative dispersion and analyzing the concept of geomorphic equilibrium is basin streams, which are often used as an indicator to express the condition of streams, rainfall, runoff, topographic evolution, tectonics, and basin erosion, and shows the equilibrium between the forces of erosion and the resistance of the earth's surface forming materials (Ortega-Becerril et al., 2018; Avşin et al., 2019; Prakash et al., 2017).

In this regard, the ordering systems of rivers in four models proposed that are applicable (Prakash et al., 2017).

Based on these systems, streams connections quality could be quantifiable by ordering. Since then, numerical analysis of drainage basins has been used based on the ordering systems of rivers. Today, many earth sciences attempt in finding novel ways to study the relationship between the form and pattern of river networks, and many studies have been carried out across the pattern of stream networks. Among these studies, Moavi and Elmizadeh (2020) applied the model to the Ramhormoz basin, revealing significant network disorder driven by tectonic activity. Similarly, Mohamadkhani et al. (2021) used the model to assess equilibrium in the Seymareh basin, demonstrating its utility in analyzing geological and morphological controls. Other studies have explored morphometric and fractal analyses to understand drainage evolution. Biswas (2016) investigated hydrological changes in the Parbati River basin, India, linking early-stage network development to loose formations and tectonics. Mohammadi-Khoshoui et al. (2021) analyzed erosion susceptibility in the Yazd-Ardakan basin using fractal dimensions, finding that older geological formations contribute to denser stream networks. Additionally, Gautam (2024) utilized geo-informatics to study the Karanja River basin, highlighting the role of geospatial tools in drainage analysis. Patidar et al. (2024) extracted tectonic imprints in the Mandakini River basin, underscoring the role of structural controls in shaping drainage patterns. Similarly, Swetha et al. (2022) elucidated anomalies in the Kuttiyadi River basin's network, linking parallel and dendritic patterns to tectonic and lithological variations

Also can refer to the studies of Cámara et al., 2016), (Moavi & Elmizadeh, 2020), (Zhihui et al., 2017), and (Patidar et al., 2024).

Therefore, the study of the drainage network pattern and its relationship with physical and human influencing factors is widely recognized as a useful tool to determine the evolutionary course of rivers and proper planning for the protection and reconstruction of rivers (Prakash et al., 2017). The evolution of networks is a gradual and complex phenomenon that undergoes a change of direction and pattern under the influence of physical and human processes over short and long periods (Ortega-Becerril et al., 2018).

Therefore, describing the complexities and changes in the components of the drainage network and studying the quantitative parameters of the river is of special importance for better planning and management. The prerequisite for this knowledge of the river is identifying the parameters affecting each basin (Cámara et al., 2016; Swetha et al, 2022). Meanwhile, the Order Matrix model, as a valuable tool, offers a method that examines compares and analyses river networks regardless of their size and presents the degree of disorder of river networks. The Order Matrix model can reflect the complexities of the basin shape and quantitatively examine streams network and river routes winding. This action reflects the characteristic shape of the basin to understand the analysis of the pattern of development and evolution of natural flow in the river. Therefore, the purpose of this study is to know the geomorphological status and analyze the relationship between forms and network patterns of streams in the Beshar River basin using the Order Matrix model.

2- Study Area

Beshar River is one of the most important sources of running water in Kohgiluyeh and Boyer-Ahmad Province and one of the most important rivers of the Karoon basin that is the largest river in Iran (Fig. 1).

This river is in Yasuj city and part of Ardakan city that flows from the southwest to the northwest and also is located in the southern and western parts of Khersan and Marbar Rivers. By joining these rivers in a place called Sarsour, they form the Kherasan River. Beshar River is composed of Ganjgan, Batari, Dasht-e Rome, and Kabkian rivers. The basin area of Beshar River is 3180 square kilometers and its maximum height is 4437 meters and its minimum is 1420 meters and its average height is 2358 meters above sea level. The boundary of this basin is adjacent to Marbar basin from the north to the Zohreh basin from the south to the Maroon basin from the west and to the Kor basin from the east. This basin is in the higher mountainous area so during winter, a large extent of the mountainous area is covered by snow. Flora of the area is mainly native trees and shrubs of the Zagros region in highlands and lowland areas consist of most agricultural lands (Moavi & Elmizadeh, 2020).

3- Material and Methods

The basics of any quantitative analysis of drainage network characteristics are related to the concept of river order. Hence, the first step in studying the linear properties of a river system is to analyze the composition of the streams and consider them as lines on a plane level. Thus, the Order Matrix technique has been used to analyze the equilibrium in the drainage network in the study area. Order Matrix analysis is a new method in studying the network of streams that have used the science of mathematical matrix in the right and left halves of the Beshar River basin.

In this method, the network of streams of the studied basin by using Arc GIS software was extracted from topographic maps with a scale of 1: 50,000 of the geographical organization of the Armed Forces. Consequently, for the Order Matrix model, the network of streams is divided into two parts, right and left. The dividing line of the basin in the direction of the streams that have the largest order, and then this stream joins the main ridge between the right and left parts of the basin and divides the basin into two sides. In this way, the upper parts of the matrix belong to the right of the basin and the lower part to the left of the basin (Mohamadkhani et al., 2021) (Fig. 2).

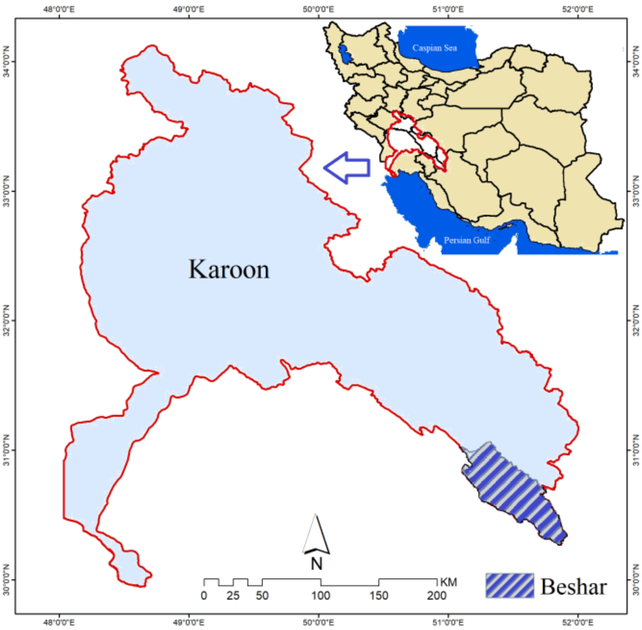

Figure 1- Map of the study area

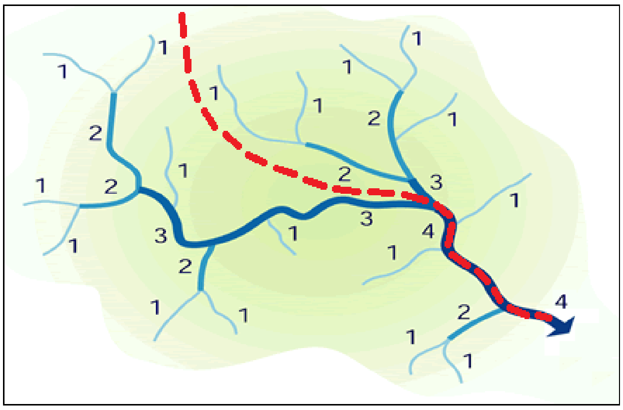

Figure 2- The Strahler's ordering system and division of the basin into two right and left sides

In this regard, the basin drainage network has been quantified based on the Strahler model and then the mentioned data has been arranged and examined in the form of a mathematical matrix. In this system, the beginning of each stream is determined as the first-order. When the two streams of the first-order are connected, a stream of the second-order is formed. When the two streams of the first-order are connected, a stream of the second-order is formed.

Thus, at the junction of the first two streams, a second-order stream is created and it expands downwards to the point where it connects to the other second-order streams, resulting in a third-order as well as a fourth-order. If the first-order stream enters a second-order stream, there is no changing the order for the second-order streams. So the first-order stream may connect to a second- or third- order stream and no order increase occurs at the connection point.

The increase in order in streams occurs only when two streams join each other with equal orders. In the whole order system, the mainstream of each drainage basin has the highest order. In this method, in addition to the orders, the connection of the lower orders to the higher order is calculated and the result is arranged and analyzed in the form of a matrix. On the diameter of the matrix are the cells [1, 1]; [2, 2]; [3, 3]; [4, 4]; [5, 5] and [6, 6] record the number of order that form a higher-order when they connected. For example, in the cell [1, 1] the total number of connections of one order that formed the second-order is recorded and in the cell [2, 2] the number of collisions of the second-order that formed the third-order is written, and this process continues to the last level of a stream network. It should be noted that the last cell of the diameter [n, n] will always be equal to one because when the last order of a network is for example 6, there is only one stream with the mentioned order.

In this way, the order of streams on both sides of the basin can be assembled in the form of a matrix. On the diameter of this matrix, the number of orders (1 to 1, 2 to 2, 3 to 3, etc.) is counted and written, and the orders that have joined the main orders are also counted and written in the left and right side of the matrix. In this regard, the distribution of stream orders is counted and written in the framework of a square matrix whose number of rows and columns is equal to the largest stream order of the basin.

By surveying the adjusted matrix, can understand how the streams are scattered and reveal the existence of equilibrium or disequilibrium in the stream network, in the sense that quantitatively in the right and left cells of the diameter of the stream network matrix that has a relative equilibrium in the right and left sides of the mainstream, relative equality is seen and vice versa. There is a quantitative difference in the left and right cells obtained from the study of the network of unbalanced streams (Patidar et al., 2024).

Finally, a square matrix with the same rows and columns with the last order in a stream network is obtained and the matrix of orders in the tables is calculated and drawn using the Excel software in terms of the number of orders, length of orders, and average length. Ultimately, the results of the data are analyzed using this method, will able to quantitatively identify the distribution of the basin streams, and quantitatively analyze the concept of its equilibrium.

4- Results

To analyze the form and pattern of the drainage network of the basin using the Order Matrix technique, the data of each right and left parts of the research area were processed and the network map of the streams of the research area was drawn (Fig. 3.). The number of streams in the basin using the Strahler method is provided in Table 1.

Using the streams network map in the research area, metadata of number, total and average length of streams were obtained based on their order and presented in Tables 2, 3, and 4. As shown in Figure. 3, the highest order of streams is 6 in the study area. According to the obtained metadata (Table 1), the number of first-order streams that interconnected in the right part and form the second-order streams is 132, and the number of these streams in the left part of the research area is 216. The numbers of streams in the first-order of the right side that has joined 2 to 6 orders are 198, 90, 33, 18, and 15, respectively. This number is 129, 92, 51, 16, and 15 on the left side of the research area, respectively. Therefore, it can be said that there is a big difference between the first-order streams that are connected on both sides of the river and there is no equilibrium in this regard in the basin because the first-order streams that are connected on the left are more than the first-order streams that are connected in the right side. Besides, order one streams connected to the higher orders on both the right and left sides are different. This is more or less the case with other orders as well.

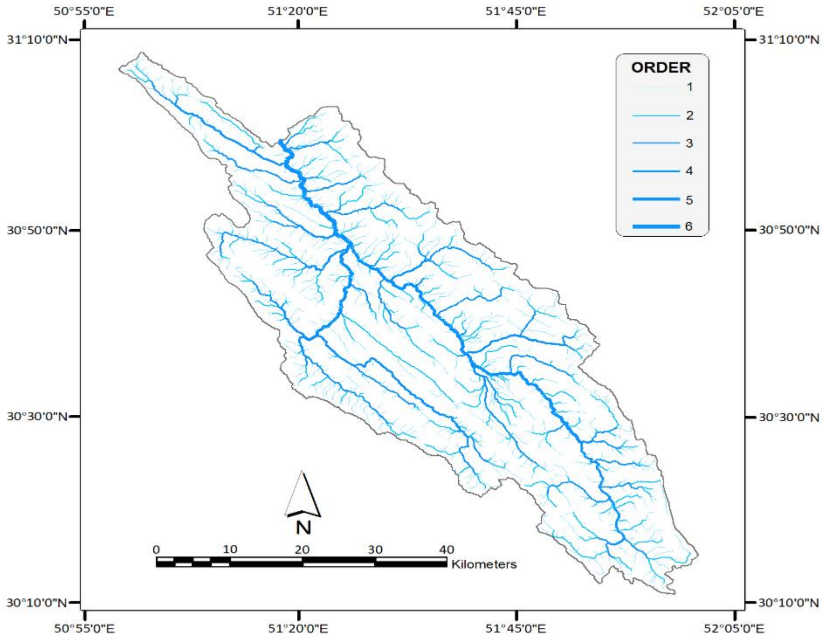

Figure 3- The orders of the stream network of the Beshar River basin based on the Strahler method

On the right side of the study area, 34 streams of order 2 are connected, but on the left side, this number reaches 56 streams, and the second-order streams, which are connected to orders 3, 4, 5 and 6, are 28, 9, 19 and 2, respectively. On the left side, it is 22, 9, 1, and 3 respectively (Table 1). Also, 12 streams with order 3 are connected in both the right and left parts. However, the number of streams in the third order, which have joined the 4th, 5th, and 6th orders, is 7, 12, and 4 on the right side, respectively, which is more than twice this number on the left side of the basin.

In each of the two right and left parts of the research area, two streams of order 4 have been connected and a total of two streams of order 5 have been created. Also, on the right side of the basin, number 3 and one stream of order 4 have joined orders 5 and 6, which on the left side are two streams for orders 5 and 6 (Table 1).

The total length of the first-order streams, which are connected, is 156.68 km on the right side and 224.08 km on the left side (Table 2). The length of all first-order streams, which are connected to orders 2, 3, 4, 5, and 6, in the right side are 201.24, 138.55, 38.72, 24.03, 29.13 km, and on the left side 134.87, 109.73, 50.75, 24.17, 15.36 km. On both sides, the process of changing the length of streams is decreasing.

The length of all connected second-order streams is 98.85 km on the right side and 161.29 km on the left side, so there is no equilibrium in this section (Table 2). Second-order streams leading to orders 3, 4, 5 and 6 are 73.07, 24/03, 52.94 and 8.94 km on the right side and 75.21, 16.68, 2.99 and 10.48 km on the left side, respectively, which shows the inequality in length and process on both sides of the research area. The length of the third-order streams that are connected on the right side is 86.61 km. On the left side, this number decreases to 69.56 km. These amounts were higher than the left side in the order 3 streams that join the orders 4, 5, and 6, indicating disequilibrium on both sides of the study area. The total length of the fourth-order streams on the right side is 11.89 km, which is almost half of this amount on the left side of the basin (24.36) and the fifth-order stream is 21.48 km long, which is about one-third of the five order streams on the left side with 60.39 km. The length of the sixth order stream in the research area is 25.98 km.

Table 1- The number of orders 1 to 6 of the right and left streams in the research area.

order	1	2	3	4	5	6
1	216+132	198	90	33	18	15
2	129	56+34	28	9	19	2
3	92	22	12+12	7	12	4
4	51	9	3	2+2	3	1
5	16	1	2	2	1+1	0
6	15	3	1	1	0	1

Table 2- The total lengths of orders 1 to 6 of the right, center, and left streams of the research area.

order	1	2	3	4	5	6
1	224.08+ 156.68	201.24	138.55	38.72	24.03	29.13
2	134.87	161.29 +98.85	73.07	24.03	52.94	8.94
3	109.73	75.21	69.56+86.61	50.03	36.38	26.06
4	50.75	16.68	16.96	24.36+11.89	31.84	1.85
5	24.17	2.99	7.55	43.37	60.39+21.48	0
6	15.36	10.48	16.82	31.54	0	25.98

The average length of connected first-order streams in the right and left sides of the study area is 1.19 and 1.04 km (Table 3). The average length of the first-order streams that join the second, third, and fourth orders varies from 1.02 to 1.94 km on the right side are 61, 47, and 36 meters, respectively, and on the left side from 0.99 to 1.51 km.

The average length of second-order streams, which are connected on the right and left sides, is 2.91 and 2.88 km. On the right side, the streams of order 2, which are connected to orders 3, 4, 5, and 6, vary from 2.47 to 2.79 km. On the left side, these amounts have more variability from 1.85 to 3.49 km. The average length of the third-order streams, which are connected in the right and left sides, is 7.22 and 5.8 km. These amounts show more changes on the right side from 3.03 to 7.15 km and on the left side with 3.78 to 16.82 km for the third-order streams that have joined the 4th, 5th, and 6th orders (Table.3).

The average length of two streams of the fourth order, which are connected on the right side and create a stream of the 5th order, is 5.95 km, which in the left part of the basin is about twice this amount (12.18 km) and the average length of two streams of order 5, which on the left side are connected and form a stream of order 6 (60.39 km), is about 3 times the right side (21.48 km).

Table 3- The average length of orders 1 to 6 of the right, center, and left streams of the research area.

order	1	2	3	4	5	6
1	1.04+1.19	1.02	1.54	1.17	1,34	1.94
2	1.05	2.88+2.91	2.61	2.67	2.79	2.47
3	1.19	2.60	5.8 +7.22	7.15	3.03	6.52
4	0.99	1.85	5.65	12.18 +5.95	10.61	1.85
5	1.51	2.99	3.78	21.69	60.39+21.48	0
6	1.02	3.49	16.82	15.77	0	25.98

5- Discussion and Conclusion

The Order Matrix Model effectively quantifies the Beshar River basin's drainage network disequilibrium, consistent with previous applications in Iranian basins (Moavi & Elmizadeh, 2020; Mohamadkhani et al., 2021). The near-parallel pattern on the left side aligns with tectonically active regions, where structural controls limit network branching (Patidar et al., 2024). In contrast, the dendritic pattern on the right suggests more uniform erosion and less tectonic influence (Swetha et al., 2022). These findings corroborate studies linking drainage patterns to tectonic activity and lithological variations (Avşin et al., 2019; Biswas, 2016).

Graph of order metadata and number of streams of orders 1 to 6 were drawn (Fig. 4). There is a high correlation (0.9989) between order metadata and the number of streams of orders 1 to 6. Exponential correlation is established on the right side of the basin and power correlation is established on the left side and the Determination Coefficient between these two variables on both sides of the research area is 0.9684. Based on the results, although the correlation between the order and the number of streams on two-sides of the research area is high, due to the greater number of streams on the right side, the morphological evolution of streams is faster than the left side.

Table 4- Number, total and average length of orders 1 to 6 of right, center, and left streams in km.

Order	Number of right streams	Number of left streams	Length of right streams	Length of left streams	Average length of right Streams	Average length of left Streams
1	570	435	655.75	491.56	1.15	1.13
2	114	69	320.27	186.21	2.81	2.7
3	35	18	182.03	127.94	5.2	7.11
4	6	6	58.05	86.89	9.68	14.48
5	1	1	60.39	21.48	60.39	21.48
6	1	1	25.98	25.98	25.98	25.98

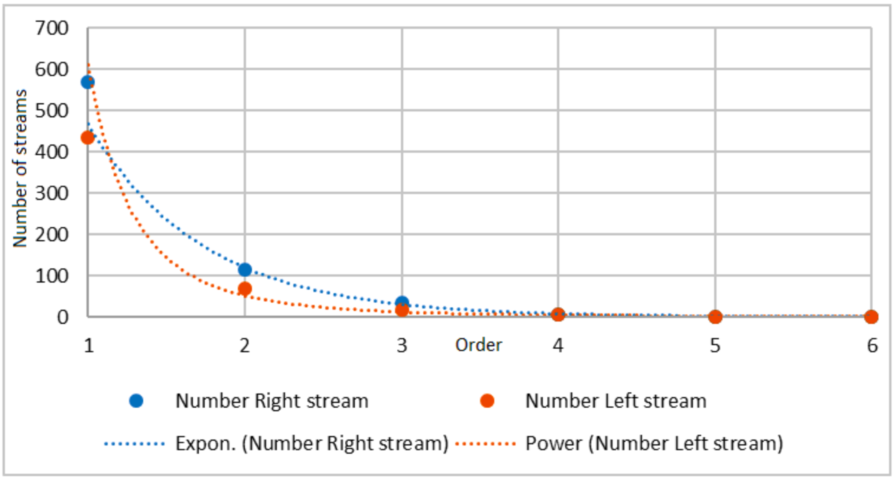

Figure 4- Arrangement of order and number of streams and their fitting line in the research area

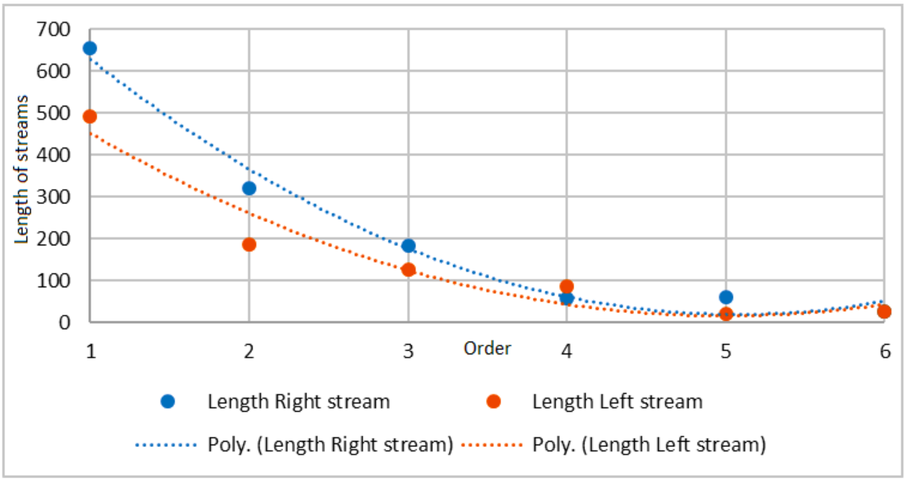

Figure 5- Arrangement of order and length of streams of the research area and their fitting line.

The correlation between the order and the length of the streams of the research area is high (0.984) and is of polynomial type, although the degree of this correlation is less than the correlation between the order and the number of streams on each side (Fig. 5). The determination coefficient between the order and the length of the right side streams is 0.9824, but on the left side, this correlation has decreased to 0.9394.

The process of changes in the average length of streams on the right and left sides of the study area has increased exponentially and has a lower correlation (0.756) than the number and length of streams of the study basin orders. The determination coefficient between the order and the length of the right side streams is 0.8743 but on the left side this coefficient increases and reaches 0.9851. Also, the average length of streams on the right side is more than the left side (17.5 vs. 12.1 km), which indicates the further evolution of streams on this side (Fig. 6).

The results of the Order Matrix model show that the pattern of the drainage network of the basin is not the same in the right and left sides and the number of right streams is about 1.4 times the left, which indicates inequality and disequilibrium on both sides of the basin. In general, in drainage basins located in the Zagros Mountains, such as the study basin, due to active tectonic impact and differences in tectonic status, drainage networks have different patterns and shapes. These results are in accordance with (Elmizadeh & Mohammadkhani, 2017). Based on the model results, the drainage network disorder is reduced at higher orders. There is also a correlation between the number of streams of orders 1 to 6, which indicates that the drainage network of the basin is developing downstream and the exit point. However, the correlation between the length of streams in the right and left sides has slightly decreased compared to the number of streams.

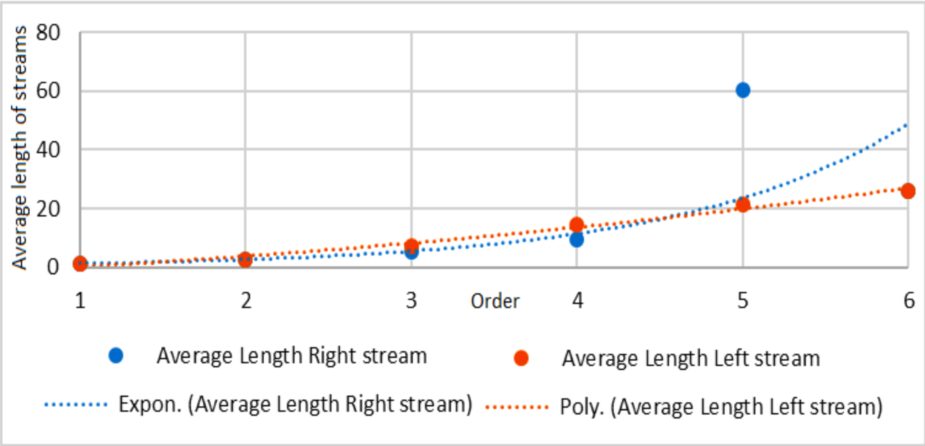

Figure 6- Arrangement of order and the average length of streams in the research area and their fitting line.

due to active tectonic impact and differences in tectonic status, drainage networks have different patterns and shapes. These results are in accordance with (Mohammadi-Khoshoui et al., 2021; Gautam, 2024; Mahato & Nimasow, 2023). Based on the model results, the drainage network disorder is reduced at higher orders. There is also a correlation between the number of streams of orders 1 to 6, which indicates that the drainage network of the basin is developing downstream and the exit point. However, the correlation between the length of streams in the right and left sides has slightly decreased compared to the number of streams. Due to the different functions of geological formations, a drainage pattern is not developed on the left and is formed almost parallel, while on the right, the pattern of streams is closer to a dendritic pattern.

Creating equilibrium in the river profile requires establishing a state of equilibrium between the transport force and sediment load on the one hand and excavation and sedimentation on the other, and the geological structure and type of rocks and their strength ratio play a decisive role in justifying the water network route and the drainage pattern.

In this regard, the streams that join the main river in the left side, pass less distance and join the Beshar River with a steeper slope than the right side and enter more sediments into the river when it rains, because there is no opportunity for the accumulation of sediments, and on the other hand, the predominant use of rangelands in this area and the sunny slopes increase the rate of evaporation and with decreasing moisture, it has less dense vegetation and does not have much ability to absorb water. Also, the short distance to the main river has limited the opportunity to form a stream with higher order and has caused disorder and lack of development in this area of the basin. Conversely, in the streams on the right side of the basin, the distance to the main river is longer and causes the accumulation of sediments before entering the main river. In this area, the Hillsides are mostly behind the sun and snow can be found at the highest heights up to eight months of the year. Snow-covered heights in the right side of the study basin cause the formation of more streams (especially order 1) and melting of snow in the hot season causes the continuation of water flow in the streams of this area, this has led to less erosion intensity during rainfall and consequently less sediment to the river and Seymareh dam.

Also, in the study basin with an average annual temperature of about 14 degrees Celsius and an annual rainfall of 650 mm, an important part of precipitation is snow and for this reason, stream networks have a lower density than warmer areas with the same amount of rainfall or less. On the other hand, the density of streams on both sides of the main river is not balanced; the number of river orders and the density of streams on the right side are higher, hence the snow melts faster and the response time is shorter, which leads to a greater density of streams and a greater number of rivers.

It can be well understood that due to the environmental complexities, in order to better study and analyze the behaviors of the drainage network pattern, there is a need to use new methods such as Order Matrix. Based on the results obtained from this model, Beshar watershed basin is active in terms of geomorphological changes and has disorder and disequilibrium and the reason is due to the influence of various factors such as tectonics and lithology in the basin.

The Order Matrix Model revealed significant disequilibrium in the Beshar River basin’s drainage network, driven by tectonic activity and unequal rock strength. The left side exhibits a near-parallel pattern, while the right side approaches a dendritic pattern, reflecting distinct geomorphological processes. The model’s quantitative approach offers valuable insights for basin management and hazard assessment. Recommendations include high-resolution mapping and tectonic monitoring to inform sustainable planning. Further studies should explore temporal network evolution and integrate advanced geospatial techniques.

The results show that the Order Matrix model, as a valuable tool, offers a method that quantifies the complexity and degree of disorder and equilibrium of river networks. In general, drainage networks, in addition to material and energy transfer paths and various forms and patterns of streams, express important geomorphic issues in terms of permeability, runoff threshold, response time, type of precipitation and etc.

Finally, it is concluded that the change in the basin indicates a kind of disorder, which indicates the existence of the disequilibrium in the form of the drainage network. The cause of the disequilibrium in the form of the drainage network is the basin tectonic activity and the lag time to equilibrate the form resulting from the tectonic process and the factors affecting this equilibrium has occurred with a long time delay, as a result, there is a kind of inconsistency between the form and processes of the basin; because, the form is resistant to the processes imposed on the form of the basin, and causes a longer delay time and has created a kind of disorder in the form of the basin.

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