DEM-BASED INVESTIGATION ON STREAM NETWORK NODES AND THEIR FEATURES

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ABSTRACT:

Surface runoff is one of dominant factors in hydrological environment, whose spatial pattern and hydrological feature represent the composite factors of its corresponding drainage. And the stream network nodes present spatial structure and attributes of geography and hydrology in a watershed. A quantified method to analyze stream network nodes is proposed in this paper. The typical area of the Loess plateau is taken as study site and Digital Elevation Model（DEM）is chosen as basic dataset. The stream network nodes are extracted based on DEM and the classification of stream network is put out by different rules. Additionally, the basic features are analyzed from the angles of hydrology and GIS, including attribution, spatial-temporal distribution. This attempt reveals relationship between law of stream runoff and other spatial features, which has potentials to enable quantitative comparisons of different landform domestically.

1. INREODUCTION

Surface runoff is one of dominant factors in hydrological environment, whose spatial distribution pattern and hydrological feature represent the composite factors of its corresponding drainage. So research on runoff and stream network is important to hydrology. And the stream network nodes present spatial structure and attributes of geography and hydrology in a watershed. Digital Elevation Model（DEM） digitally demonstrates the earth's surface, in addition, it is the basic data source for terrain analysis and it is an effective analysis method. Now DEM is playing an important role in hydrologic and topographic character analysis. Up to the present, great progress is achieved in river network based on DEM (Horton, 1945; Tang, 2005; Liu, 2003; Jin, 2000) and it is an efficient way to extract river network (Lu, 1998; Ren, 2000; Li, 2001). Some efforts are made to derive terrain features, including peak, pit, ridge, channel, plane, and pass, based on terrain analysis (Moore, 1988; Jenson, 1988; Martz, 1988, 1992, 1995; Tribe, 1992).Moreover, the hydrographical characteristics are extracted, including stream-channel networks, delineation of catchments boundaries, catchments area, catchments length and stream order, based on the flo[*]w accumulation method (O'Callaghan and Mark, 1984).As the confluence of streams, the stream network nodes imply both geographical features and a lot of spatial-temporal messages. So, this paper proposes the concept of stream network node, probes into its features and analyzes relationship between law of stream runoff and other spatial features.

2. EXPERIMENTAL BASIS

As we all know, the Loess Plateau of China has drawn worldwide attention in geographical research for its unique morphological features, abundant natural sources, most serious soil erosion, as well as its potential contribution to economic development and ecological reconstruction. Hence, from north to south of the Loess Plateau, Sui De, Chun Hua and Yijunin are taken as study site, they are the typical areas which supply different types of landform and gully characteristics. Test data are the corresponding 5 m-grid resolution DEM produced according the national standard of China.

3. OBJECTIVE OF STUDY

The structure of stream network is devious, complicated, so it is essential to reveal its feature. The stream network node is proposed to explore the features of stream network. The main objectives of this study are:

(1) to analyze characteristics of stream network node ;

(2) to reveals relationship between law of stream runoff and other spatial features

With the two points being borne in mind, quantitative characterization of stream network node and analysis of their properties is carried out in this study.

4. CHARACTERISTICS AND CATEGORY OF STREAM NETWORK NODES

The stream network nodes (See Figure 1) are considered as the collection of confluence of one stream and its corresponding tributaries in the drainage. For each stream network node, it contains both spatial location and hydrological attribute. But for one specific region (one drainage), stream network node can reflect the distribution of gully or stream network in different orders. The corresponding 5 m DEM resolution is taken as data source. With the support of ArcGIS the stream network nodes are extracted.

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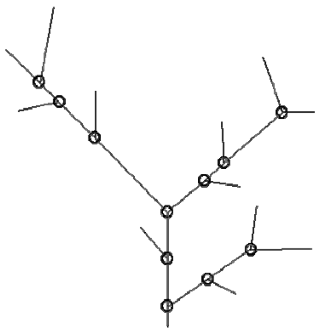


Figure.1 Diagram of stream network node

4.1 Characteristics of stream network nodes

(1) Attribution characteristics

The stream runoff nodes are collection of multiple geographical attribution of controlling watershed, in which hydrological attribution is the most important. The accumulation of each stream runoff node can used to record its daily flow rate; monthly flow rate and annual flow rate .More over, the stream runoff nodes reflect topographical, geological, vegetative and climatic features. So the expressions of stream runoff nodes are flexible and diversified.

(2) Spatial distribution characteristics

According to the basic geographical laws, the spatial distribution of geographic elements is self-correlated. Hence, the distribution of stream runoff node is highly correlated to geographical, geological and surface characteristics. The random distribution is the reflection of multiple factors of its controlling watershed. The morphological feature of stream runoff node distribution is obviously corresponding to their shape of hydrographical net.

(3) Temporal distribution characteristics

Temporal distribution characteristics include temporal attribution variation and temporal variation of different positions in the watershed. From temporal attribution variation, the stream runoff nodes can reveal the changes of daily flow rate, monthly flow rate and annual flow rate. Due to fluvial denudation, transporting action and deposition, river valley changes steadily, hence the position of stream runoff node varies correspondingly. So, temporal position variation of stream runoff node indicates the change and development of river valley, which has potentials to explore the geological laws from hydrological view.

4.2 Category of stream network nodes

A classification of stream network is proposed by follow rules:

1. According to its corresponding river order. As we all know, hydrologic net can be classified into different orders, which are closely related to some features, including flow accumulation, mean length. Consequently, the stream network node could be classified into its different order. It could help us to reveal the relationship between stream network node and river shape conveniently
2. According to its corresponding gully-valley type. As we all know, there are four types of gully, including rill, ephemeral gully, gully and valley. So stream network node could sort according to their gully-valley type, including rill node, ephemeral gully node, gully node and valley node. Correspondingly, the link between stream network node and flow accumulation is built
3. According to composite feature of stream network node. The above two way consider the feature of single stream network node. By the distribution shape of stream network node, there are four types of stream network node. They are random distribution, cluster distribution, belt distribution and ring-like distribution which reflect its corresponding river shape.

5. FLOW ACCUMULATION OF STREAM RUNOFF NODE

As the stream network nodes are considered as the collection of confluence of one stream and its corresponding tributaries in the drainage. For each stream network node, it contains both spatial location and hydrological attribute. From the mechanism of stream runoff node extraction based on DEM, it is known that the flow accumulation of reflects its controlling watershed area. So it is helpful to reveal the feature of gully.

Based on DEM of study site, the stream runoff nodes are derived, whose flow accumulation and corresponding order are included (See Figure 2)

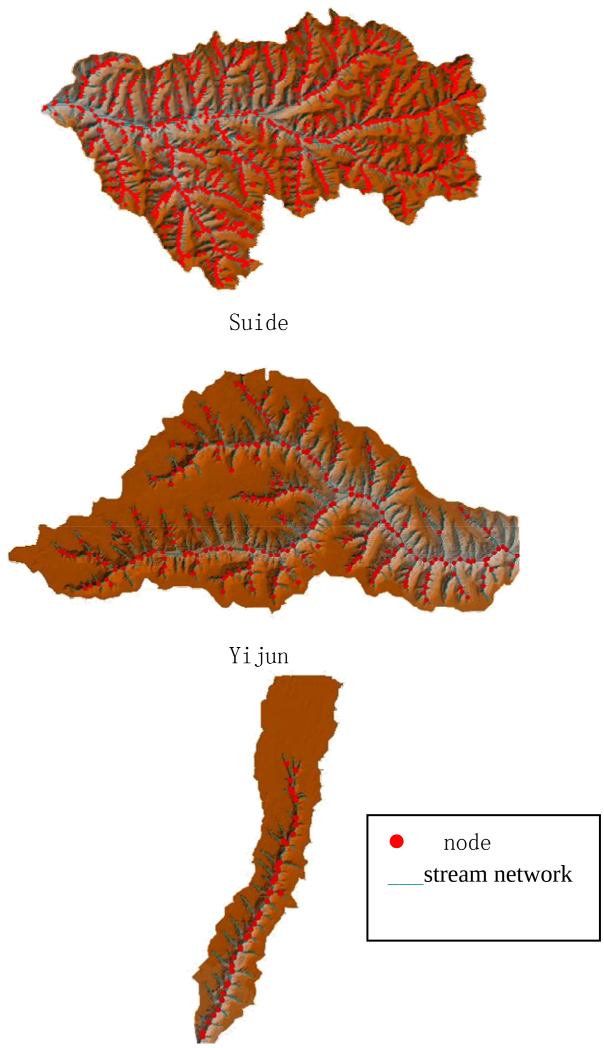
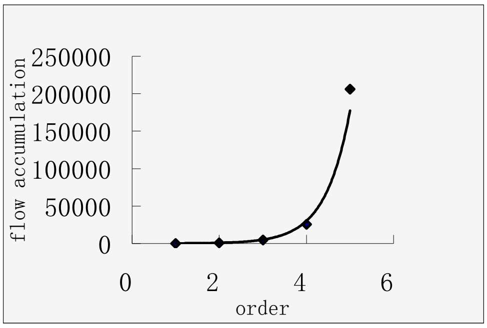
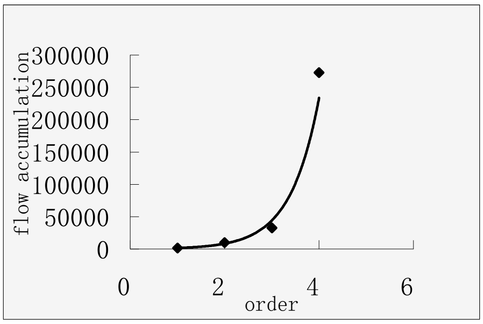


Figure 2. Distribution of stream network node in study site

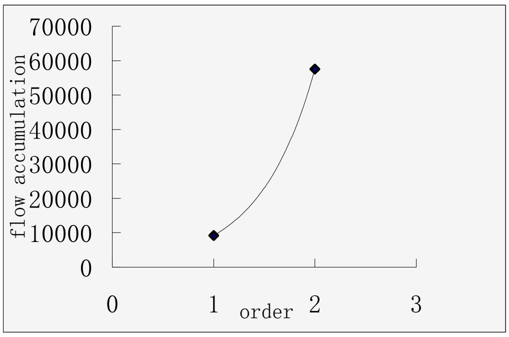
On the analysis of relationship between flow accumulation and corresponding order, the result is shown as Figure 3. So the equation can be expressed as Table 1.



Suide



Yijun



Chunhua

Figure 3. Relationship between order and flow accumulation of the stream network node

According to the results, the relationship between flow accumulation and corresponding order can be computed as formula (1).

$$y = a \times e^{bx} \quad (1)$$

Table 2 shows the value of a and b, in three different areas, which revels that parameter a and b reflect the types of different landforms.

Study site	formula	R^2
Suide	$y = 25.239 \times e^{1.772x}$	0. 998
Yijun	$y = 295.18 \times e^{1.669x}$	0.99
Chunhua	$y = 1470.7 \times e^{1.833x}$	1

Table 1. Formula of Relationship between order and flow accumulation

Study site	a	b
Suide	25.239	1.772
Yijun	295.18	1.669
Chunhua	1470.7	1.833

Table 2. Value of a and b in study site

Study site	Gully density	Parameter a
Suide	5.34	25.239
Yijun	3.67	295.18
Chunhua	1.65	1470.7

Table 3.Comparison of gully density with parameter a in study site

As Suide is the hilly gully area of loess plateau (Mao in Chinese), whose surface is corroded heavily. While Yijun is hilly area of loess ridge (Liang in Chinese), whose surface is relatively less broken. And Chunhua is hilly area of loess hillock (Yuan in Chinese), whose surface is quite flat. So, the parameter a increases as the surface change from broken surface to flat. The density of gully is a significant parameter that describe how broken the surface is. By comparing parameter a with density of gully, the result shows they has the similar change, shown as Table 3. This regular change reveals the development of the Loess Plateau and its erosion.

6. FRACTAL GEOMETRY OF STREAM RUNOFF NODE

Based on the above analysis, it is obvious that parameter a is the mirror of gully development. In Chunhua and Yijun, the surfaces are corroded less heavily and the gullies are not maturely developed. So Chunhua ang Yijun are mainly comprised of loess ridge and loess hillock and filled with flat areas. The parameter a is relatively great. However, in Suide, the surface is well developed and heavily corroded. The surface is broken, hence the parameter a is less than that of Chunhua and Yijun. Therefore, parameter a reveals the erosion of surface, development of gully and type of landform. Different from parameter a, parameter b is relative steady, it varies around 1.5. So it demonstrates the variation of different gully, and it shows that the mechanism of development and erosion of the Loess Plateau are similar.

The fractal geometry is common in nature, especially for stream network. The stream networks are composed of main streams and branches and they are self-similar, which means that each part of a structure is similar to the whole shape at many scales. Thus, seemingly, random and transformed shapes can repeat themselves across scale, and are fractals in the formal sense. So, fractal geometry is an effective way to explore the feature of stream networks.

6.1 Calculation of Box Dimension

Fractal shapes can have dimensions between the 0, 1, 2,0r 3 to which we are accustomed. Groups of points that follow a line are fractal dust, which has a dimension between 0 and 1, a terrain has dimension greater than 2 but less than 3 , and cross-sections through terrains generate fractal lines with dimensions between 1 and 2, but they are described either 2-manifold pattern or 3-d structures. So the dimension of stream network is between 1 and 2, which reflects the structure of stream network. Boxing-counting is applied to calculate the dimension of stream network node. The dimension D_0, which is given by the power relation between the number of pieces and the reduction factor, is:

$$D_0 = \lim_{r \to 0} \frac{\ln N(r)}{r} \quad (2)$$

where N(r) is the number of pieces and r is the reduction factor. For stream network node, it is the collection of the collection of confluence of one stream and its corresponding tributaries in the drainage. Its spatial distribution is the compound result of geology, landform and development of gully. The dimension D_0 can be calculated by following steps:

(1) Cover all the stream network nodes with square whose length of side is r (See Figure4)
(2)Get the amount of squares, N(r)
(3) Change the reduction factor r and repeat step (1) and step
(4) Compute the relationship between ln(r) and ln (N(r))

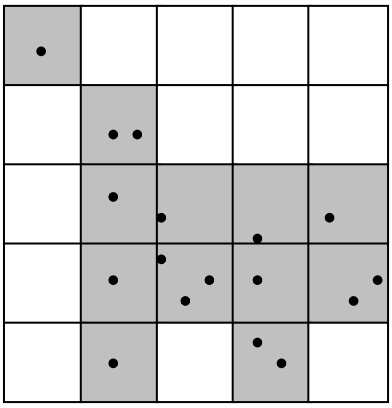


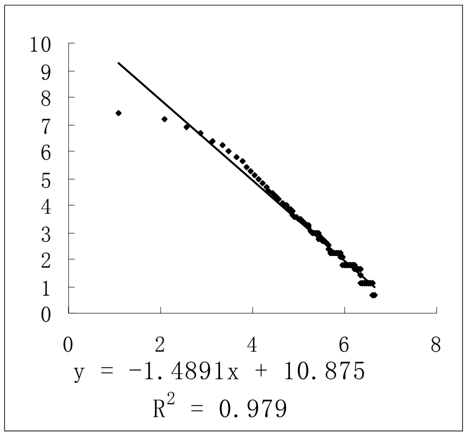
Figure 4. Diagram of covering stream network

6.2 Reflection of fractal dimension

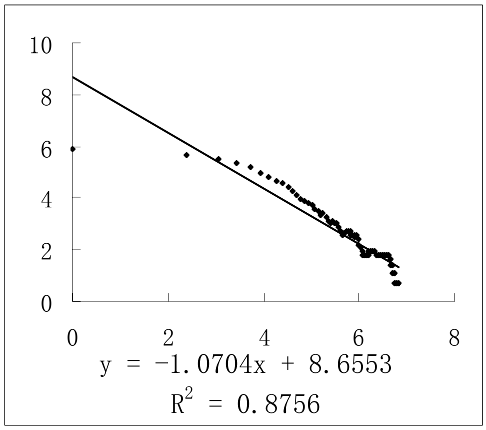
Study site	Gully density	D_0
Suide	5.34	1.489
Yijun	3.67	1.070
Chunhua	1.65	0.773

Table 4. Comparison of gully density with D_0 in study site

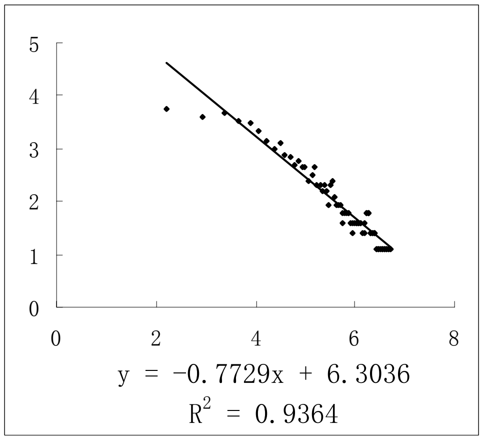
The fractal dimension of gully and hydrologic net is the hot issue, and a lot of efforts are made to reveal its innate laws. Empirically, fractal dimension of gully and hydrologic net is the reflection of development and erosion. The more maturely developed gully has the greater fractal dimension and has denser gully distribution. For the gully, the variations of fractal dimension indicate the erosion changes. When calculation D0, if the box that used to cover the watershed scale out, the stream network can be considered as a node. With the reduction of r, the node expands. Hence, the dimension D0 is the indication of gully complexity. The more complicated the gully is, the greater D_0 is. The values of D_0 are respectively 1.4891, 1.0704 and 0.9364, shown as Figure 5. As Suide is the hilly gully area of Loess Plateau (Mao in Chinese), whose surface is corroded heavily. The stream network is quite complicated, D0 is the highest. While Yijun is hilly area of loess ridge (Liang in Chinese), whose surface is relatively less broken. So value of D0 is a little lower. And Chunhua is hilly area of loess hillock (Yuan in Chinese), whose surface is quite flat with the lowest value of D_0.



Suide



Yijun



Chunhua

Figure 5. Values of D_0 in study site

By contrast with gully density (See Table 4), the result fit the above analysis. The more complicated surface is, the greater D_0

is, vice versa. It proves that value of D_0 reveals the erosion and development of stream network.

7. CONCLUSION

The remarkable character of stream network is the hot issue in geography and hydrology. So as the collection of confluence of one stream and its corresponding tributaries in the drainage, the stream network node has great significance in geology and hydrology and has plenty information. With GIS, it can be extracted easily and efficiently. The category of the stream network node provides more view to study its features and reveal relationship between other spatial features. The analysis shows that the order of stream network node it belongs to determines its flow accumulation and the relationship can be expressed by formula. More over, the stream network is fractal geometry. By measuring dimension of the stream network node and compared with other parameter, it finds that dimension of stream network node is the reflection of development and erosion of the watershed. Study on stream network node is a new way to investigate the laws of stream network node.

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