Study on the statistical characteristics of soil crack based on complex network

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Abstract. In the References [1], we found the two typical soil-crack network (SCN) in Yuanmou Dry-hot Valley Region (YDVR) were not only the topological characteristics of the fracture network itself, but also more important study the reflected characteristics of the soil crack under different network topologies. On basis of the above research, we put our research on our attention and energy to their statistical characteristics. In this paper, according to complex network theory, we analyse the degree distribution properties of the two SCN in YDVR, that is, vertisols soil crack network (V-SCN) and dry-red soil crack network (DR-SCN), which includes not only their topological characteristics, but also more important study the reflected characteristics of the soil crack under different network topologies. In this paper, we have studied the betweenness centrality (BC) distribution and characteristic spectral density distribution of the two SCN. We found the power-law dielectric index of DR-SCN is bigger than V-SCN. The V-SCN is vulnerable overall damage, but the DR-SCN are more prone to dismemberment erosion. And we can observe how the crack development mechanism from “small” to “big”, and it can provide continuous visualization to study the growth process of soil crack.

1. Introduction

The past decade has seen a dramatic surge of interest in the study of networks, with much of it in fields outside the “traditional” areas of mathematics, computer science, and the social sciences [1]. By providing a formal mechanism for representation, measurement, and modeling of relational structure, the use of network analytic methods in these new domains (including physics, biology and medicine) has arguably paved the way for a range of advances. Especially, in recent years, the scientific community set off a wave of research on complex networks, and even called “The New Networks Science”.

Now, many scholars have studied on the possibility of using predictive models for crack pattern formation and also the possibility of using statistical methods in characterizing such patterns [2,3], such as multiphysics model [4] and Tsallis Q-statistics [5]. In this paper, according to complex network theory, we analysis the complexity of two typical SCN in YDVR, which includes not only the the topological characteristics of the fracture network itself, but also more important study the reflected characteristics of the soil crack under different network topologies. At the same time, people gradually realized that to solve the problem of soil erosion mechanism must conduct a comprehensive analysis to network as an object. And the topological fracture of soil crack with static and dynamic entity itself
is not static [1]. Due to human activities such as external effects or the formation of crack in its mechanism, it makes the continuous evolution over time. We carry out research in this area, which can help us understanding the internal mechanism and evolutionary operation law, and then provide a theoretical basis for an effective method propose solutions to soil erosion and other issues. This paper study the complexity of other soil cracks’ statistical characteristics mainly based on complex network theory through the integration of some of its own soil cracks’ networks characteristics.

2. Study area
The YDVR is located on the lower reaches of the Longchuan River, a first-level tributary of the Jinsha River in the northern part of the Central Yunnan Plateau and is enclosed between latitudes 25°25’-26°07’N and longitudes 101°35’-102°05’E (Figure 1). It borders Wuding County in the east, Lufeng County in the south, Southwest and Great Yao and Luding County adjoin, northwest bordering with Yongren County, north and Huili County at the border [1].

![Figure 1. Scope of YDVR in Jinsha River and location diagram of Yuanmou.](image)

Table 1. The number of nodes and degree of two typical SCN.

| Degree | the number of nodes for the V-SCN | the number of nodes for the DR-SCN |
|--------|-----------------------------------|-----------------------------------|
| 1      | 631                               | 858                               |
| 3      | 1401                              | 892                               |
| 4      | 17                                | 14                                |
The author has taken 167 V-SCN and 27 DR-SCN photographs, based on the typical SCN data in YDVR. The two representative maps are selected (Table 1 and 2), and their general situation are shown in Table 1 and 2, in which their vectorization using ArcGIS software are shown in Figure 2 and 3.

| Situation | Quadrat number | Location | Altitude | Terrain | Aspect | Slope | Slope position |
|-----------|----------------|----------|----------|---------|--------|--------|----------------|
| V-SCN     | 189#          | N 25°36′09.8″ E 101°51′56.3″ | 1287m     | hilly-sloppy lands | E 79°  | 8°~9°  | upper part     |
| DR-SCN    | 86#           | N 25°36′31.9″ E 101°51′43.6″ | 1296m     | hilly-sloppy lands | W 273° | 11°~12° | upper part     |

| Situation  | Vegetation types | Coverage | Dominant species   | Sample areas | Development degrees | Soil water status | Vegetation Growth |
|------------|-----------------|----------|--------------------|--------------|---------------------|------------------|------------------|
| V-SCN      | wild grass       | 30%      | dodonaea viscosa   | 80m²         | the light and moderate level | Moist | Poor |
| DR-SCN     | brush grass      | 40~50%   | espino             | 80m²         | The moderate level    | Moist | good |

3. Result and discussion

3.1. The correlation of degree and clustering coefficient (CDC)
The CDC is the relationship between degree k of nodes and their average clustering coefficient (c(k)) [6]. As can be seen from Figure 4, both two networks present a negative correlation, indicating that nodes with a degree of 3 tend to cluster into groups, which means that both networks are hierarchical. This could be caused by the special geographical factors of the YDVR, such as deep valleys, significant wind-burning effects, dry climate and fragile ecological environment. Together with strong disturbance of human activities, they have made the two typical SCN lack obvious layers. However, these models do not consider the geometric effects of the networks. For the networks model with well-defined geometric locations of nodes, since the hierarchical system research on this network has not been seen. So, this paper provides reference to development of SCN.
3.2. Betweenness centrality

Betweenness centrality (BC) is a fundamental and useful index for measuring the importance of a vertex within a graph, because it is primarily defined as the ratio of shortest paths between vertex pairs that pass through the vertex of interest, the nodes or edges with high median are often more important [7-9]. In soil cracks, the nodes or edges with high betweenness are generally important, which are related to the starting point of crack development and the formation of surrounding crack. This is because these nodes are the starting point of crack development generally, which there are many associated edges around the fracture, and their BC are very high. On the other hand, although the degree of cracks’ endpoints is small, they are the beginning of the development of the entire crack networks, and many cracks will follow them and begin to develop. Figure 5 shows a logarithmic distribution of nodes betweenness for the two SCN, that is, $P(BC)\sim BC^{-\gamma}$, which power-law exponents are $\gamma_{V-SCN}=1.4$ and $\gamma_{DR-SCN}=1.7$.

Figure 4. The CDC of V-SCN (a) and DR-SCN (b).

Figure 5. Bilogarithmic profile of betweenness of V-SCN (a) and DR-SCN (b).
4. Conclusions and future work

Through conducting research on statistical properties for the typical soil cracks in YDVR, such as degree distribution, average path length and clustering coefficient, the following results have been obtained:

The Reference [1] has pointed out the topological properties of two typical SCN which include degree and its distribution, average path length and clustering coefficient, which show the two typical SCN have both scale free and small world characteristics. That means they are both scale-free network and small world network. Furthermore, the larger the degree of the node indicates that the more cracks pass through the node. These nodes with a degree 3 have obvious network connection advantages for two typical SCN of YDVR, especially in the V-SCN. Although nodes with a degree 1 in the DR-SCN are more than that of V-SCN, the nodes with 3 degree is obviously less than that of vertisoils by nearly half. And these nodes with degree 4 of V-SCN, is also slightly more than that of DR-SCN.

On the soil surface, it may first develop into a crack network with a degree 1, that because the nodes development has preference and its average degree is larger than that of dry-red soil. So the vertisoils develop faster than those of denatured soils, and it takes the lead in development of the network for nodes with degree 3. However, vertisoils crack is unresponsive. This can be understood from the physic-chemical properties of soil: Because of there are many cracks, the soil is relatively heavy and the organic matter content is lower than that of dry-red soil for vertisoils, the expansion and contraction are strong and the most vertisoils location has been destroyed by manned activity [10-12]. The internal and hydrostatic stress of the soil change rapidly, which result in both stress redistribution, so presents the stage of fracture propagation. At this stage the destruction mechanism transforms the confining pressure and breaks it when it is affected by external forces (such as human farming, animal trampling, rain erosion, etc.), then the cracks continues development to develop and it is taken for granted. However, the dry-red soil is acidic and its bedrock is unsaturated, and there is almost no expansion and contraction. Although its surface cracks are more, it is more stable, and erosion is also dismembered, so its cracks development is obviously slower.

The CDC of two typical SCN indicate that these nodes with a degree 3 tend to gather together. Although the SCN continue to develop, new nodes and edges (cracks) continue to increase, the degree is hard to increase. It can therefore be said that the degree 3 is already the “stability degree” of the networks. This may be due to they are controlled by the physic-chemical properties of soil and the formation mechanism of SCN

The BC shows the DR-SCN has more stronger developmental continuity and perfect in the original network. Since cracks formed by nodes with lager BC is more, then more new nodes are generated. Therefore, there are wider cracks along these nodes, and it is easy to cause soil dismemberment and collapse. This are very consistent with the field observation.

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References

[1] Liu Z H 2019 Study on the degree distribution properties of soil crack 3rd International Conference on Geoscience, Energy and Materials (I-GEM 2019) 289 012007
[2] Hu P, Wang B, Xiao D and Aifantis K E 2019 Capturing the differences between lithiation and sodiation of nanostructured TiS2 electrodes Nano Energy 63 103820
[3] Réthoré J R, Zheng H, Li H, Li J, Aifantis K E 2018 A multiphysics model that can capture crack patterns in Si thin films based on their microstructure Journal of Power Sources 400 383-391
[4] Aifantis E C 2016 Internal Length Gradient (ILG) material mechanics across scales and disciplines, Adv. App. Mech. 49 1-100
[5] Cong J, Liu H T 2014 Linguistic complex networks: Rationale, application, interpretation, and directions Physics of Life Reviews 11 644-649
[6] Crucitti P, Latora V, Marchiori M 2004 Model for cascading failures in complex networks Physical Review E 69 045104
[7] Li Y, Li W G, Tan Y L, Liu F, Cao Y J and Lee K Y 2017 Hierarchical decomposition for betweenness centrality measure of complex networks Scientific Reports 7 46491.
[8] Brandes U 2008 On variants of shortest-path betweenness centrality and their generic computation Social Networks 30 136-145
[9] Kourtellis N, Morales, G D Fand Bonchi F 2015 Scalable online betweenness centrality in evolving graphs 2016 IEEE 32nd International Conference on Data Engineering (ICDE). IEEE 27 2494-2506
[10] Chen A Q, Zhang D, Xiong D H, Liu G C 2012 Effects of mechanical properties of surface soil on soil anti-scourability in Yuanmou dry-hot valley Transactions of the Chinese Society of Agricultural Engineering 28 108-113
[11] Xiong D H, Zhou H Y, Yang Z, Zhang X B 2005 Studies on revegetation in the dry-hot valley of Jinsha river Southwest China Journal of Agricultural Sciences 18 337-342
[12] Yang Z X, Duan Y T, Lu H E, Jin J, Zhao Q L, Liu H G, Li L, Sha Y C 2011 Preliminary report on disease and insect pests of Tamarindus indica L. in dry-hot valley of Jinsha river Journal of Southern Agriculture 42 627-630