IOP Conf. Series: Materials Science and Engineering **322** (2018) 052047 doi:10.1088/1757-899X/322/5/052047

Threshold Selection of River Network Extraction Based on Different DEM Scales Using ATRIC Algorithm

Liya Chen[1], Yanbin Yuan[1]*, Xiaohui Yuan[2], Xisui Yang[1], Jiejun Huang[1], Yan Yu[1]

[1]School of Resources and Environment Engineering, Wuhan University of Technology, Wuhan, China
[2]School of Hydropower and Information Engineering, Huazhong University of Science and Technology, Wuhan, China

*Corresponding author e-mail: yybjm@126.com

Abstract. The extraction precision of digital network in watershed depends on drainage area threshold. Due to the multi-scale effect of DEM, different scales of DEM would provide different terrain information. Taking Qingjiang watershed as the subject and the DEM under 30m*30m and 90m*90m resolution as the foundation, this research extracts the digital river network and studies the optimal drainage area threshold from DEM with different resolutions through ATRIC algorithm. It's concluded that under the same resolution, the river network becomes sparser with the increase of threshold; the optimal drainage area threshold under higher resolution is larger than that under lower one. Compared with DEM data for 90m resolution, the river network extracted from DEM for 30m resolution enjoys a better goodness of fit with the real river network, with an overlapping rate of 68.8%. ATRIC algorithm is more suitable for DEM data under high resolution.

1. Introduction

As an important factor to determine the digital drainage network, the drainage area threshold directly determines the source of the river and the spatial form of the river network [1]. In general, the threshold was chosen with certain subjectivity and randomness, which would affect the extraction of river network and river basin characteristics. The development of automatic river network extraction technology on DEM plays a significant role in river research and access to hydrological information.

The expression of terrain information and terrain features extraction is affected by the DEM resolution. It is a prerequisite for the accurate river network extraction to get more accurate terrain factors from the high-resolution DEM data source.

This paper is aimed to study the effect of different spatial-resolution DEM on the drainage area threshold and evaluate the applicability of the existing automatic extraction algorithm to the digital DEM with different spatial resolution.

IOP Conf. Series: Materials Science and Engineering **322** (2018) 052047 doi:10.1088/1757-899X/322/5/052047

2. Literature Review

Many scholars have studied the determination of drainage area threshold based on DEM data. The earliest ones were Dennis.L and Johnson, who proposed to use the trial and error method [2] to determine the threshold, which is subjective and computationally inefficient. Then Yi proposed the drainage density method [3], which can only determine the approximate range of threshold in general. Xiong suggested that the point where the change of river's average slope gradient with the drainage area threshold tended to be gentle was the optimal threshold to extract river network [4]. Lin proposed the fitness index method [5] and only considered some of the water network deviation. Yang proposed fractal dimension method based on fractal concept [6], but the method is applicable only in small watershed. In 2015, Bhowmik [7] proposed ATRIC algorithm and applied it to two watersheds with different size, which worked well in automatic river network extraction. At present, the influence of DEM resolution is mainly used in the research on terrain information [8, 9], while there were few researches on threshold done from the perspective of spatial scale. Chen compared river network extraction on different resolutions of DEM [10]. Considering the limitation of some methods, the ATRIC algorithm is studied to determine the threshold from the DEM data with different resolutions and extract the digital river network.

3. Data Preprocessing and Method

3.1 Data and data preprocessing

Qingjiang watershed, the second-class tributary of Yangtze River, is taken as the research object and 30m * 30m and 90m* 90m DEM data are obtained respectively for the extraction of digital river networks. ENVI and ARCGIS software are used to do image splicing, cropping and projection transformation. The river network data is obtained from the interpretation of the flood control situation map in Hubei Province.

3.2 Method

The ATRIC algorithm was proposed by Bhowmik et al. in 2015. We apply the basic idea "in the digital elevation model (DEM), the cell with flow accumulation equal to the drainage area threshold is usually considered as the birthplace of the river [11] "to determine the range of threshold. And then the concept of parallel displacement *d* is introduced to express the deviation between the Mapped Stream Network (MSN) and the DEM-derived Stream Network (DSN) in the spatial position, and established the objective function to determine the optimal drainage area threshold. The specific steps of ATRIC algorithm is expressed in Fig.1.

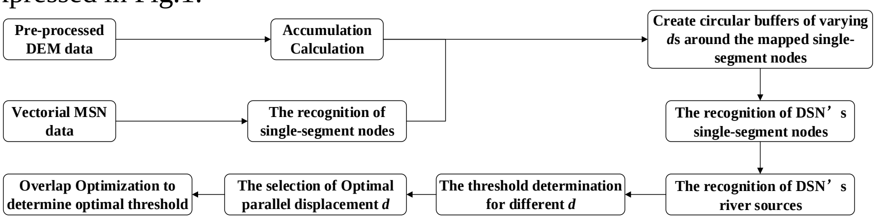

Fig.1 Flow chart of ATRIC algorithm

The river network can be regarded as a network which consists of nodes and arcs, where arcs correspond to rivers, nodes correspond to outlets, meet and crisscrosses. Extract nodes in MSN, nodes corresponding to sources or outlets are treated as "single-segment nodes" and "single segment nodes" are connected to "single segment arcs".

To calculate the optimal parallel displacement *d*, the initial value of *d* is generally taken as two-fold DEM resolution and increases by the resolution size. Extract the digital river network and its cell number (n_{DS}) under different thresholds and compare them with the number cell of MSN (n_{MS}). Then the objective function (1) is established:

$$n_{DS(opt.)}=n_{MS}+\min(n_{DS}-n_{MS}),\quad (n_{DS}-n_{MS})/n_{MS}< 0.05 \qquad (1)$$

$\min(n_{DS}-n_{MS})$ is used to minimize the difference in cell number between DSN and MSN. $(n_{DS}-n_{MS})/n_{MS}< 0.05$ ensures that all river cells of MSN are extracted by DEM and meanwhile reduces the possibility of extracting non-existing streams. *d* corresponding to $n_{DS(opt.)}$ is selected as the parallel displacement between DSN and MSN. And the drainage area threshold AT_d corresponding to the parallel displacement *d* will be the initial value of the overlap optimization.

The parallel displacement *d* is selected as the buffer radius to buffer the MSN. The DSN extracted at different thresholds is overlapped with the buffer. The difference between DSN and MSN is considered to be the smallest when the overlap ratio is higher. The function of the overlap optimization is given by (2):

$$\max \quad n_{DS(ov)}/n_{DS} \tag{2}$$

The drainage area threshold with the highest overlap ratio and satisfying the requirement of equation (1) is the optimal drainage area threshold $AT_{(opt.)}$. The selection of threshold is typically increased or decreased by 10^{n-2} units based on the initial threshold AT_d, AT_d should meet $10^{n-1}<AT_d<10^n$, $n\epsilon N$.

4. Experimental Results

4.1 Extraction of river network with DEM data in different resolution

The two DEM data are dealt with by using ARCGIS's hydrological analysis to explore the influence of DEM resolution on the automatic extraction of digital river network. Digital river morphology under different DEM resolutions is extracted (Fig.2).

For the DEM data with the same resolution, with the threshold increasing, the river networks gradually become sparse, while for different resolution DEM, the river network form extracted at same threshold is affected less by the resolution.

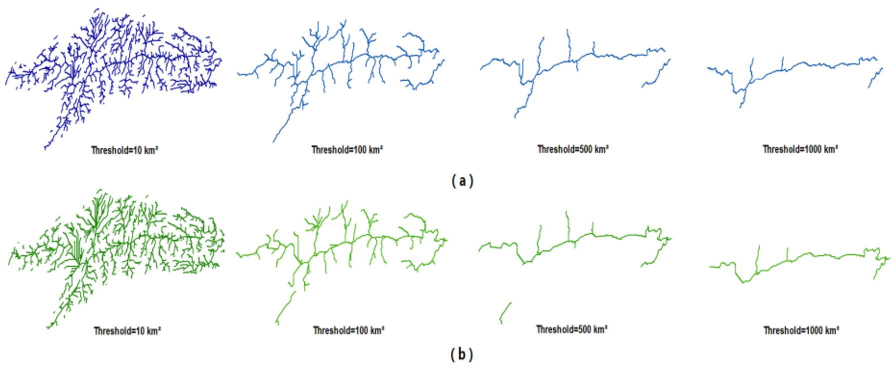

Fig.2 the extracted river network for different resolutions ((a): 30m * 30m; (b): 90m * 90m)

*4.2 The determination of optimal threshold at 30m * 30m resolution*

The initial parallel displacement *d* is set to 50 cells after trial, and *d* is increased in 10-cell units. The error between the DSN cell number (n_{DS}) at different thresholds and the cell number of MSN (n_{MS}) is obtained by calculating the corresponding threshold AT for different parallel displacements *d*. The results are shown in Table 1:

Table.1 determination of *d* using the ATRIC algorithm under 30m resolution

d(cell)	Threshold(km^2)	n_{DS}	n_{MS}	$(n_{DS}-n_{MS})/n_{MS}$
50	15	99626	89725	0.110
60	18	91320	89725	0.018
70	19	88487	89725	-0.014
80	20	85957	89725	-0.042
90	23	80430	89725	-0.104

From Table 1, when *d* = 60 cells, the corresponding threshold ATd = 18km2. The error between DSN's and MSN's cell number is minimal, satisfying the requirements of equation (1). Take *d* = 60 cells as the parallel displacement between DSN and MSN.

Then the overlap optimization is tested. The buffer area is obtained when d = 60 cells are selected as the buffer radius. Take ATd = 18km^2 as the initial value of threshold, the DSN with different thresholds is extracted at 1km^2 as the increment / decrement interval. Then the overlap ratios n_{DS}(ov) are calculated and shown in Table.2:

Table.2 the results of overlap optimization under 30m resolution

Threshold(km^2)	n_{DS}	n_{DS}(ov)	n_{DS}(ov)/n_{DS}	(n_{DS}-n_{MS})/n_{MS}
16	96519	64758	0.671	0.076
17	93673	63674	0.680	0.044
18	91320	62646	0.686	0.018
19	88487	61796	0.698	-0.014
20	85957	60807	0.707	-0.042

As the threshold increases, n_{DS} becomes smaller, but the overlap ratio with MSN buffers is increasing. When AT=18km^2, the requirements of equations (1) and (2) are satisfied. Therefore, take AT = 18km^2 as the optimal threshold for extracting the digital river network from the 30m resolution DEM in Qingjiang River Basin, and the extracted river network has a better goodness-of-fit with MSN.

*4.3 The determination of optimal threshold at 30m * 30m resolution*

For the 90m resolution DEM data, the initial value of *d* which is set as 1 cell is more appropriate after trial. The thresholds AT corresponding to different parallel displacements d are calculated by the increment interval of 1 cell. The results of parallel displacement calculation and overlapping optimization are shown in Table.3 and 4:

Table.3 determination of *d* using the ATRIC algorithm under 90m resolution

d(cell)	Threshold(km^2)	n_{DS}	n_{MS}	(n_{DS}-n_{MS})/n_{MS}
1	1	150978	89725	0.683
2	2	98290	89725	0.096
3	3	78110	89725	-0.129
4	3	78110	89725	-0.129
5	5	60602	89725	-0.325

Table.4 the results of overlap optimization under 90m resolution

Threshold(km^2)	n_{DS}	n_{DS}(ov)	n_{DS}(ov)/n_{DS}	(n_{DS}-n_{MS})/n_{MS}
1	150978	13846	0.092	0.683
2	98290	10881	0.111	0.096
3	78110	9758	0.125	-0.130
4	67435	9126	0.135	-0.248
5	60602	8724	0.144	-0.325

From the above results, the change of parallel displacement *d* has little effects on the selection of threshold for the DEM data with 90m resolution. When *d* = 2 cells and the threshold AT = 2km^2, the DSN and MSN have the smallest cell error equal to 0.096, which does not meet the requirement of equation (1). This is because the larger the DEM resolution, the rougher the terrain information described and the larger the extraction error is. So (n_{DS}-n_{MS})/n_{MS}< 0.05 is altered and the relative error is limited to 0.1. Then the optimal threshold is set to 2 km^2 for 90m resolution DEM data.

4.4 The comparison of the optimal threshold determination for different resolution

By comparing the optimal threshold calculated from DEM with different resolution, the optimal threshold in the same region increases with the increase of DEM resolution, that is, the optimal threshold for 30m resolution is 18km^2, which is much higher than the optimal threshold 2km^2 for 90m resolution.

The river network extracted from 30m resolution DEM corresponding to the optimal threshold has a better goodness-of-fit, and the overlap ratio is up to 68.8%. But the error between network extracted from 90m resolution DEM and MSN is larger, with an overlap ratio of 11.1%. Therefore, the ATRIC algorithm is more suitable for the higher resolution DEM data. The river network extracted from the two DEMs is compared with MSN (Fig.3), which shows the extraction accuracy for 30m resolution DEM is better. More non-river network parts are extracted for the 90m resolution DEM.

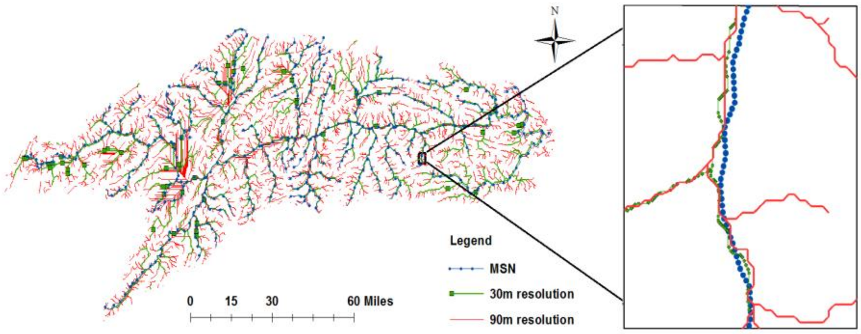

Fig.3 Comparison between river networks for different resolution and the actual river network

5. Conclusion

Taking Qingjiang watershed as the subject, this research studies the thresholds under 30m and 90m resolution respectively and extracts the digital networks through ATRIC algorithm. The network density under the same resolution decreases with the increase of threshold. The river network with the same threshold is affected less by the DEM resolution. The 30m DEM presents a higher optimal threshold than 90m, and enjoys a better goodness of fit with MSN. ATRIC algorithm is more suitable for DEM with higher resolution. The study is conducted solely from spatial scale, without considering factors including climate, temperature and so on. Further research is called for to improve the precision of drainage area threshold and extracted river network.

Acknowledgments

The research was sponsored by the National Natural Science Foundation of China (Project No.41571514, Project No. 51379080 and Project No. 41471339).

References

[1] YANG B, REN L L. Identification and comparison of critical support area in extracting drainage network from DEM [J]. Water Resources and Power, 2009, 27(5):11-14.
[2] Dennis L, Johnson, Arthur C, et al. A spatially distributed hydrology model utilizing raster data structures [J]. Computers &Geosciences, 1997, 23(3):267-272.
[3] YI W H, YANG P. Determination of drainage area threshold for extraction of DEM-based digital drainage network [J]. Jiangxi Hydraulic Science & Technology, 2008, 34(4):259-262.
[4] XIONG L H, GUO S L. Distributed hydrologic model [M]. Beijing, China: China WaterPower Press. 2004.
[5] Lin W T, Chou W C, Lin C Y, et al. Automated suitable drainage network extraction from digital elevation models in Taiwan' s upstream watersheds[J]. Hydrological Processes, 2006,20(2): 289-306.
[6] WU T B, XIA D Z, ZHANG X N. Identification of critical contributing area based on improved fitness index method [J]. Water Resources and Power, 2011, 29(4):18-20.
[7] Avit K B, Markus M, Ralf B S. An automated, objective and open source tool for stream threshold selection and upstream riparian corridor delineation [J]. Environmental Modelling&Software, 2015, 63:240-250.
[8] WANG T T,YANG X, YE J J, et al. Identification of Fluvial Knick points and Analysis of Its Scale Effect Based on DEMs[J].Journal of Geo-information Science.2014.16(6):882-889.
[9] DONG L, LAI Y C. Study on Slope Orientation Extraction Based on DEM from Different Scales [J]. Modern Horticulture.2012, 12:13+16.
[10] CHEN D F, GONG L B, LI Z. Study on principle of threshold selection of river network extraction based on different DEM scales [J]. Journal of Water Resources & Water

IOP Conf. Series: Materials Science and Engineering **322** (2018) 052047 doi:10.1088/1757-899X/322/5/052047

Engineering.2015, 26(2):109-113.
[11] ZHOU J D, MA J, SONG M, et al. Threshold value research about catchment area of drainage network of Hetao irrigated area [J]. Water Conservancy Science and Technology and Economy, 2012, 18(2):25-27.