The Extraction of the Watershed Boundary from DEM Using a Cellular Automata Method

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Abstract: The algorithms to extract watershed boundary from DEM has been developed for many years. However, the depression and flat areas of DEM typically will generate the processing difficulties for most of the algorithms, especially on high spatial resolution DEM. Focus on the difficulty, this study intends to delineate the watershed boundary using a cellular automata method. The method deals with the problem in two particular rules: (1) to examine the flow direction using the D8 Algorithm (O'Callaghan and Mark, 1984); (2) to balance the water-level. After applying these two rules on the cellular automata operation, we can simulate a simple dynamic water flow model by steadily adding rainfall on DEM. Accordingly, each cellular automata operation will generate a flow direction and the following tracing procedure and the region growing method will be used to combine the watershed into regions. The operations will continue until the sinks of the DEM are filled with the water, and the optimal exits of the depression areas are determined. As a result, all the watershed boundaries led the water to the exit of the DEM, and the watershed boundaries are determined. The initial test results indicate that cellular automata method can be used effectively to extract watershed boundaries from DEM. Moreover, the cellular automata operation successfully solves the typical processing difficulties that used to occur in depression and flat areas of DEM. The successful operation of the cellular automata method shows that major application of such a method is in the high spatial resolution DEM.

Keywords: Cellular Automata, watershed, DEM, region growing

1. Introduction

In the early periods, the watershed boundary was extracted by the human's interpretation. Due to the establishment of the digital elevation model and the promotion of the computer processing ability, extracting the watershed boundary automatically with a computer became an important hydrological study. A variety of automated extracting methods and algorithms for watershed boundary has been issued, including Symbolic Approach, Profiling Approach, Tracing Approach, Hydrologic Approach and Hydrologic Gradient Approach (Lin, 2002). The single flow direction algorithms (D8), which was proposed by Mark in 1984, solved the difficulties of flow direction computing for non-depression area. Various computing methods and algorithms for the depression area have been proposed afterward. These methods, however, still lack of the applicability of determining the flow direction over the depression and non-depression area. In this study, we attempt to extract watershed boundary by applying a cellular automata mechanism to simulate rainfall and water flow on DEM.

2. Methods

This study combines D8 algorithms and Cellular Automata mechanisms to simulate the rainfall and to generate a dynamic water flow model on the DEM surface. The framework of extracting whole watersheds is presented as a flow chart (Fig. 1.). The procedure is divided into three steps which are: 1.Importing the DEM and encoding each cell with an identified sequential number, 2.Calculating the Cellular Automata model and examining the flow direction, 3.Connecting flow direction and processing region growing and merging.

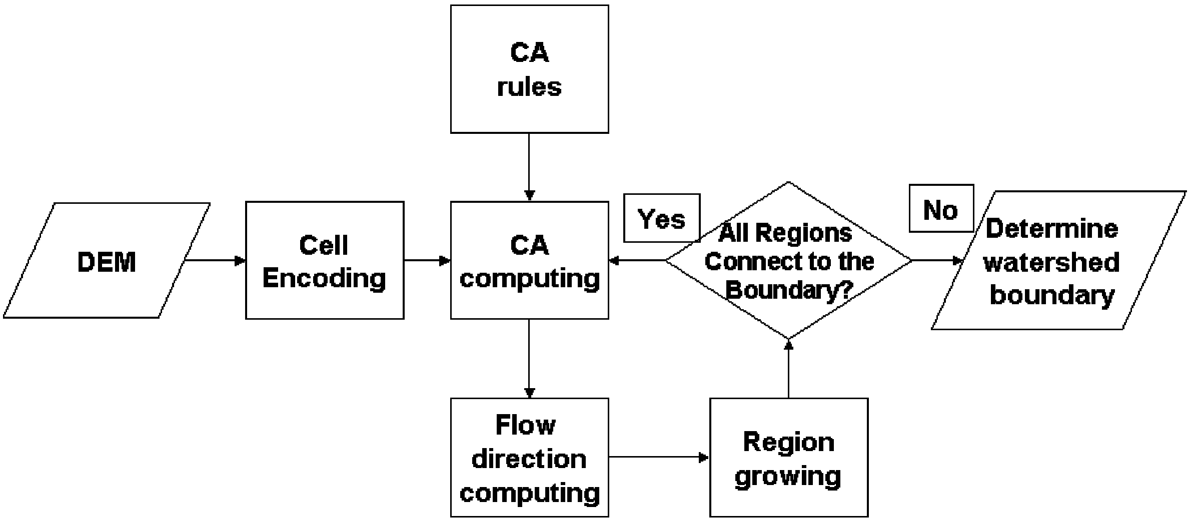


Fig. 1 The flow chart of extracting the watershed boundary

1. Importing the DEM and encoding each cell with an identified sequential number

The latticed DEM has been chosen in this study, and we give each cell an identified sequential number. The rule is to assign each cell a sequential number from left to right and then from top to bottom (Fig. 2).

01	02	03	04	05	06	07	08	09	10
11	12	13	14	15	16	17	18	19	20
21	22	23	24	25	26	27	28	29	30
31	32	33	34	35	36	37	38	39	40
41	42	43	44	45	46	47	48	49	50
51	52	53	54	55	56	57	58	59	60
61	62	63	64	65	66	67	68	69	70
71	72	73	74	75	76	77	78	79	80
81	82	83	84	85	86	87	88	89	90
91	92	93	94	95	96	97	98	99	100

Fig. 2 Assign each cell a sequential number

2. Calculating the Cellular Automata model and examining the flow direction

The steps of simulating water flow mechanism by applying Cellular Automata method are as follows:

a. Add fixed rainfall to each cell. In this study, we add 0.5mm rainfall in each iteration and each cell height is defined as DWM (DWM=DEM+ rainfall height).
b. Find the lowest adjacent cell. If there are many cells that have the same lowest value, the cell with the largest sequential number will be selected as the single flow direction. The flow direction encoding rule is defined in Fig. 3. Therefore, the flow direction in each cell can be recorded in an iteration.
c. While determining the flow direction, it is critical to balance the water level between the central cell and the lowest adjacent cell. We apply the rule, “water flows downward,” to the Cellular Automata mechanism. After that, these two cells’ DWM should be equivalent. If the depression height is larger than accumulated water height, then the water within the central cell needs to be poured out to the lowest cell. After balancing the water level, the condition, DWM $\geq$ DEM, has to be satisfied.
d. The new DWM will be determined by balancing all the cells’ water level in each iteration. After that, we go back to step a and add rainfall to each cell.

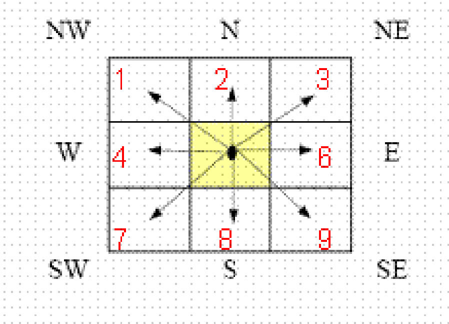


Fig. 3 The flow direction encoding rule

3. Connecting flow direction and processing region growing and merging

This step is to connect the chains among the cell's relation of pouring in and out in each iteration, and replace the flow direction that points to the final pouring-in cell with the final pouring-in cell's sequential number. It is a process of region growing. So the cells are growing and becoming small regions. After steadily adding rainfall to each cell in each iteration, the water in each cell will find the way out. The tiny region can be merged during each iteration, which will never stop until each region connect to the DEM boundary. That is to say, the water within each region will flow out of the boundary.

3. Results

The DEM has 40 m resolution. The study area locates in the upper course area of Lanyang River, where is the boundary of I-lan County, Hsinchu County, and Taoyuan County (Fig. 4).

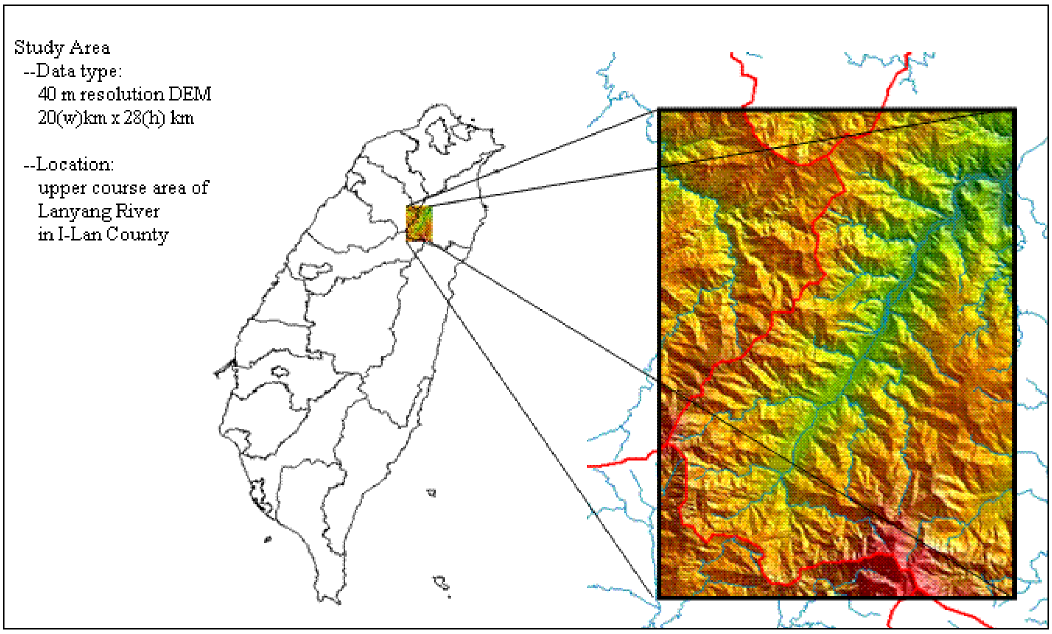


Fig. 4 The study area

A system has been developed by the procedure design. In the interface, we can set up each parameter including rainfall and the minimum visible water volume to show the situation of the flow direction (Fig. 5). Besides, the situation of water flow, the region growing and merging can be set up in this system (Fig. 6).

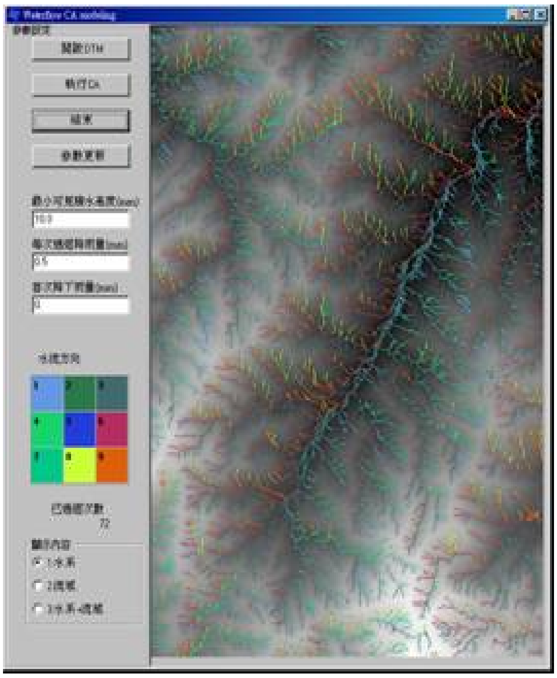


Fig. 5 System interface

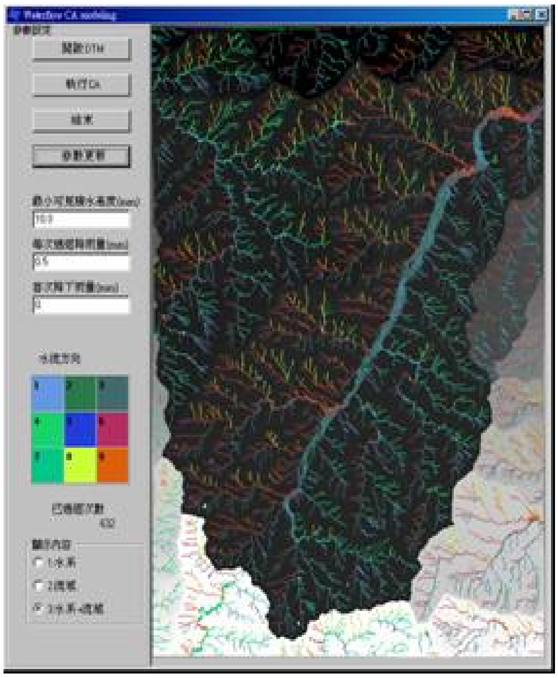


Fig. 6 System interface

Fig. 7 The color shaded relief map in the study area.

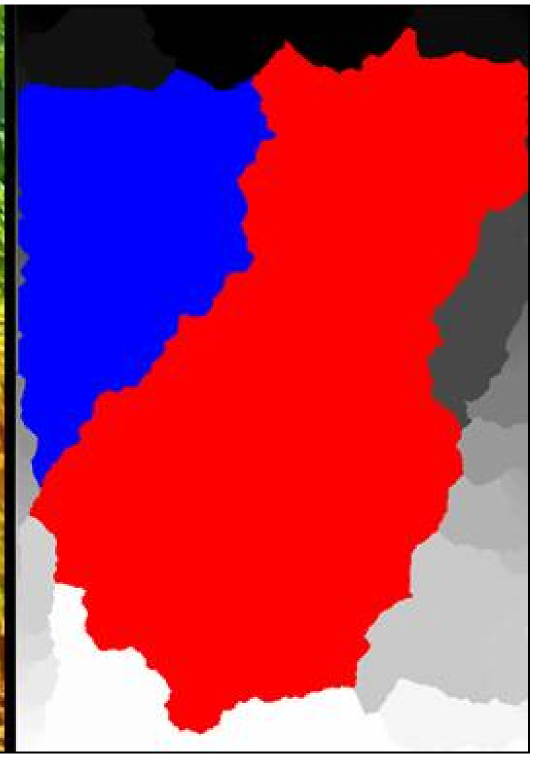


Fig. 8 The determined watershed boundary by using the CA method

The iteration will never stop until all the regions' boundaries connect to the boundary of the DEM. Therefore, the watershed boundary will be determined once the water within each region can flow out of the boundary. Fig. 7 is the DEM of the study area which is displayed in a color shaded relief map, and Fig. 8 is the determined watershed boundary result by using the proposed Cellular Automata method.

This study applies different DEM resolution (10m, 20m) as well. The study area locates in Shei-Pa national park in Taiwan. ESRI ArcGIS 9.0 Hydrology module and our method of extracting the watershed boundary are used. The comparison map is presented in Fig. 10, and the results match with the original drainage maps (Fig. 9). Besides, a comparison map with different DEM resolutions using Cellular Automata method is created (Fig. 11). In the study, a consistency phenomenon can be found that the watershed boundary does not change with different DEM resolutions. Furthermore, ArcGIS Hydrology module will have the same result by adjusting the minimum area combination parameter. Therefore, using cellular automata method to extract watershed boundary is feasible.

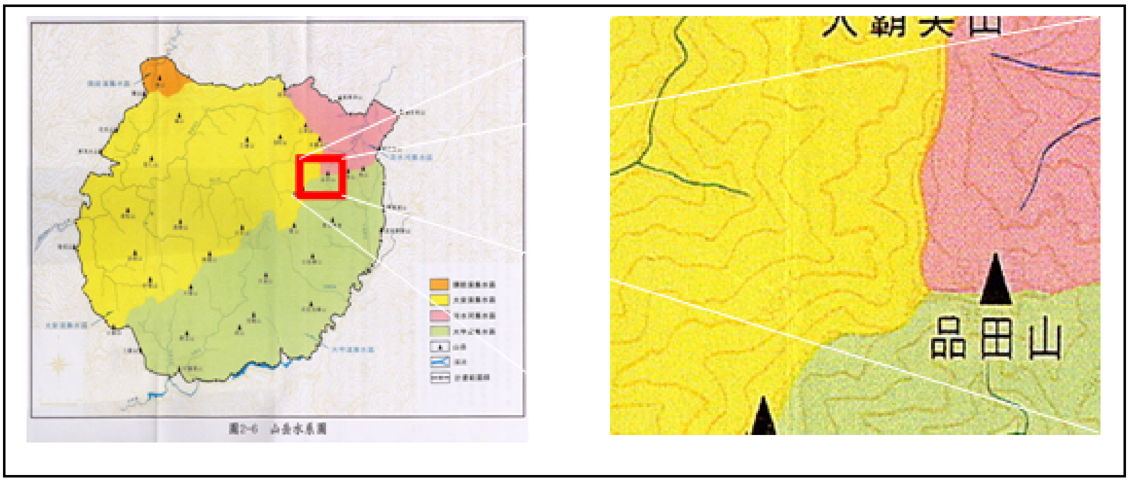
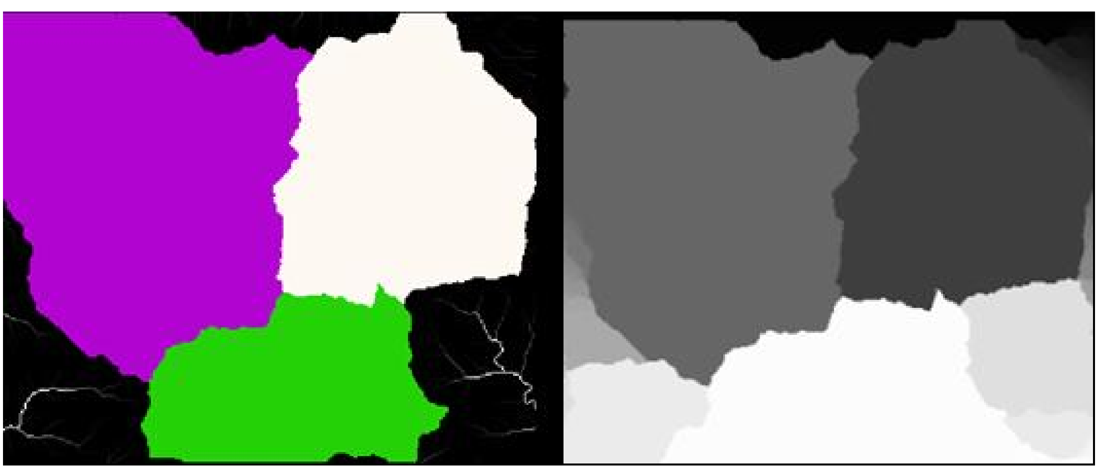


Fig. 9 Shei-Pa National Park drainage maps



The extraction of watershed boundary in using the ArcGIS Hydrology module

The extraction of watershed boundary in using CA method

Fig. 10 A comparison map of watershed boundary extraction with 10 m resolution DEM

Fig. 11 Using CA method in different resolution DEM

4. Conclusions

Using a Cellular Automata method to extract watershed boundary from DEM is feasible in this study. Water in the depression and flat areas can find the way out after steadily adding rainfall to the surface model. These areas of DEM cause the processing difficulties for most of the algorithms, especially on high spatial resolution DEM. Therefore, a cellular automata mechanism was applied to this study. The focus is on the conception of water that will find a way out while steadily filling the depressions and this concept is applied in this study to determine the watershed boundary in depression and flat areas.

There is still a problem of determining the watershed boundary on the flat and depression areas. If there are more than two exits (lowest exit cells) in a depression area, the determination of watershed boundary will become difficult in the future work. The further research will emphasize on the problem to achieve the goal of full automatic extraction of watershed boundary from DEM.

References

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