Study on Soil Erosion Systems Simulation of Small Watershed in Loess Area

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Abstract: The loess plateau in China is one of the most serious soil erosion area. And the soil erosion volume of watershed is an important index, which is useful to evaluate correctly the comprehensive management, and weigh the benefit of the comprehensive management. It is also the premise and foundation of arranging the measures of Soil and Water Conservation and conducting watershed management and planning. Based on this, we deemed that simulating the soil erosion systems of small watershed in Loess Area based on computer is essential. The computer-based model of soil erosion of watershed in Loess Area was built in this paper. It is loosely coupled with Geographical Information System. It makes use of DEM's function of providing the topographical feature, and then conducts the hydrological analysis of runoff in watershed. On the basis of this analysis, the USLE sediment model and the routing model were applied to the hydrological analysis of runoff. And then the distributed watershed soil erosion simulation model was built. Using this model, the soil erosion volume with different temporal and spatial characteristic can be computed. At last the research achievement applied to Huangjiaercha Small Watershed of Xi'ji County in Ningxia Hui Autonomous Region. Additionally, the model system was verified to have a definite reliability. This will further heighten the level of small watershed comprehensive management of Loess Plateau in China.
Keywords: loess area, small watershed, soil erosion, geographical information system, cell

In the Loess Plateau, the precipitations cause the most soil erosion. The intensive rainfall hit the soil surface, which cause the severe soil and water loss. When the comprehensive management and planning in the watershed of the loess plateau were conducted, it would be best if the erosion control measure type and the detail spatial position were known. If so, the soil erosion in the detail spatial position within the watershed was calculated and queried. This effective tool is an exact comprehensive distributed parameter model, which divide the watershed into unit (for example the cell) to simulate the effect of these assumed management measure. The distributed parameter model is more and more important in the field of precipitation-runoff-erosion relation, which provides the possibility of considering the spatial change of the various parameters. The project and data of it application into surface runoff and soil erosion are few in China, But a great deal of work was done by the researcher from abroad, and many model such as AGNPS, SHE, TOPMODEL, ANSWER, WEPP were put forward.

That the surface runoff and soil erosion were studied with the GIS's raster analysis method is the basis of the distributed runoff erosion simulation. The algorithm put forward by Smith, M.B. & Brilly, M. (1992), Jenson, S.K. & Domingue, J.O. (1988) and USLE model were drawn in this paper. On base of this, a watershed soil erosion systems simulation was established with Visual C++ program, which loosely coupled the WINGIS software developed by Chinese Academy of Forestry and precipitation-runoff-erosion model. Thus its application into Huangjiaercha Small Watershed in Loess Plateau was conducted to quantitatively analyze the surface runoff and soil erosion. This is an interesting thing for the scientific circles and the local government.

The computer simulation tool for analyzing the runoff erosion system in the loess area's watershed can largely improve the capability of soil erosion prediction in China. And also it provides the basis for the determination of erosion intensity, the comprehensive management planning and management measures assessment in the watershed.

1 Method

The overall structure of the whole soil erosion systems simulation is as below Figure.

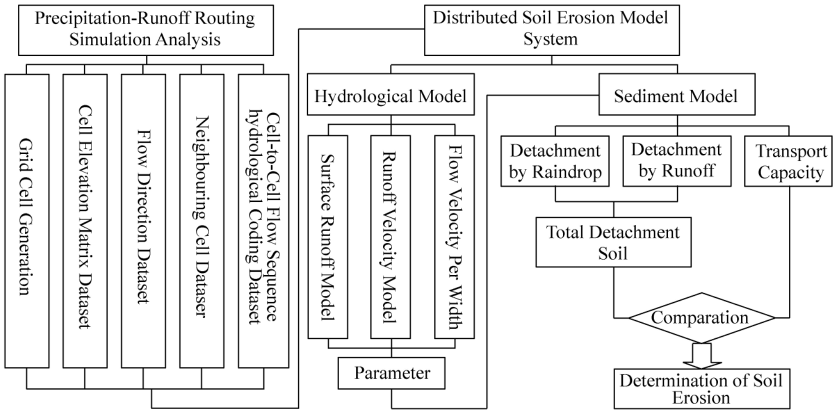


Fig.1 The structural flow chart of soil erosion systems simulation in the watershed

The target of the Basin precipitation-runoff routing simulation was that determine the hydrological flow sequence and runoff convergence and the routing path level. It is based on the division of the watershed into grid cell. In here both the patch map and the topographic map are divided into the same size cells. It is the foundation of the distributed parameter model. On the basis of this, the hydrological model and the sediment model are operated. And the watershed soil erosion systems simulation is achieved.

Additionally, before the soil erosion simulation of loess area’s watershed was conducted, the standard of erosive rainfall in loess area must be determined. In the Loess Plateau, a few rainstorm during the period of flood season cause the most soil losses, most rainfall do not come into being the surface runoff, and thus no soil losses. According to the investigation and former research on the loess plateau, that the rainfall is greater or equivalent to 9.9mm, and the maximum 30 minute rainfall intensity is greater or equivalent to 7.2mm are the standard of the erosive rainfall.

2 Case study

Huangjiaercha Small Watershed locates in the middle reach of Yellow River, also the center area of the Loess Plateau. The administrative location is in the Ma’jian Township of the Xi’ji County, Ningxia Hui Autonomous Region. It is located at 105°29'—105°31'40"E and 35°17'18"—35°58'40"N. The watershed area is 5.7 km^2, and length is 3.75km. It is the source of Lan’ni River that is the largest tributary of the Hu’lu River. Huangjiaercha Small Watershed also locates in the loess hilly and gully area. The annual average rainfall is 402.2mm. The soil erosion in the Huangjiaercha Small Watershed is mainly from the sloping land surface; the type of soil erosion is mainly the hydraulic erosion. The serious soil losses cause the large harm, and so the ecological environment is extremely fragile.

According to the requirement of Erosion Systems Simulation, The attributive database with DBF relative mode database structure was established. Huangjiaercha Small Watershed was divided into 202 patches. The Patch map and topographic map were digitally input into computer with WINGIS. In here, the patch map and the topographic map must be same scale, and when the vector maps were changed into raster map with the same grid cell size (the grid cell size in *X* and *Y* direction). And then one spatial certain grid cell in the patch raster map and topographic raster map present the same spatial location. This is the requirement of systems simulation.

In here, for the presentation of the result, 250m×250m of the grid cell size was selected (In the practical application, the grid cell size selection principles were followed. For example, the size is 30m×30m, the cell number is 124×90). Through the routing simulation, the datasets were as below:

Cell Elevation Matrix Dataset in H Watershed

0	0	0	0	0	0	0	0	0197519651965	0	
0	0	0	0	0	0	0	01965196519651965	0		
0	0	0	0	0	01965196519651890191019101965					
0	0	0	0199519701965189518901875186518651870							
0	02040200019651965196518951890193519351910	0								
0	01985196519651935193519401940194019501965	0								
01980196519651935193519501965197019651965	0	0								
20401980196519651970198019850	0	0	0	0	0					
020402040	0	0	0	0	0	0	0	0	0	0

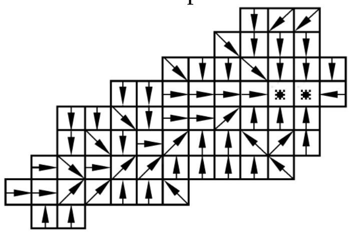
Slope Value of the Cells in H Watershed

0	0	0	0	0	0	0	0	0	2	0	0	0
0	0	0	0	0	0	0	0	12	17	12	12	0
0	0	0	0	0	0	11	16	17	4	10	10	21
0	0	0	0	7	1	16	1	3	2	0	0	1
0	0	12	8	5	7	16	1	2	0	0	0	0
0	0	5	5	7	0	6	0	0	8	6	0	0
0	3	0	7	0	0	0	0	0	0	4	0	0
13	3	0	5	0	0	8	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0

Cell Flow Direction Matrix Dataset in H Watershed

-1	-1	-1	-1	-1	-1	-1	-1	-1	8	16	16	-1	
-1	-1	-1	-1	-1	-1	-1	-1	4	8	8	8	-1	
-1	-1	-1	-1	-1	-1	4	8	8	4	8	8	8	
-1	-1	-1	-1	8	8	2	2	2	2	0	0	32	
-1	-1	8	8	4	8	2	2	1	128	128	128	-1	
-1	-1	8	4	8	2	1	128	128	64	1	128	-1	
-1	2	4	2	1	1	128	128	128	128	64	-1	-1	
2	2	1	1	128	128	64	-1	-1	-1	-1	-1	-1	
-1	12	8	128	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1

Cell Flow Direction Map in H Watershed



Adjacent Cell Matrix Dataset in H Watershed

-1	-1	-1	-1	-1	-1	-1	-1	-1	0	0	0	-1
-1	-1	-1	-1	-1	-1	-1	-1	0	2	1	0	-1
-1	-1	-1	-1	-1	-1	0	0	0	2	1	1	0
-1	-1	-1	-1	0	0	0	3	2	3	4	3	1
-1	-1	0	0	1	1	0	3	3	0	0	2	-1
-1	-1	1	1	0	3	3	1	1	2	0	0	-1
-1	0	2	1	5	2	0	0	0	0	0	-1	-1
0	2	2	1	0	0	0	-1	-1	-1	-1	-1	-1
-1	0	0	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1

Cell Flow Routing Frequency Matrix Dataset

0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	2	0	0	0
0	0	0	0	0	0	0	0	0	3	0	0	0
0	0	0	0	0	0	0	3	4	23	28	4	0
0	0	0	0	0	0	0	15	18	0	0	2	0
0	0	0	0	0	10	13	0	0	2	0	0	0
0	0	2	0	8	2	0	0	0	0	0	0	0
0	2	3	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0

The Starting Cell Path Coordinate List

Path NO.	Cell NO.	Row	Col
1	1	1	10
	2	2	10
4	1	1	11
	2	2	10
5	1	1	12
	2	2	11
	3	3	11
	4	4	11
6	1	2	9
	2	3	10
7	1	2	12
	2	3	12
	3	4	12
8	1	3	7
	2	4	8
12	1	3	8
	2	4	8
13	1	3	9
	2	4	9
14	1	3	13
	2	4	13
	3	4	12
15	1	4	5
	2	5	5
	3	6	6
20	1	4	6
	2	5	6
	3	6	6
21	1	4	7
	2	4	8
22	1	5	3
	2	6	3
	3	7	3
25	1	5	4
	2	6	4
	3	7	5

Path NO.	Cell NO.	Row	Col
26	1	5	7
	2	5	8
27	1	5	10
	2	4	10
28	1	5	11
	2	4	11
29	1	6	5
	2	7	5
30	1	6	11
	2	5	12
32	1	6	12
	2	5	12
33	1	7	2
	2	7	3
34	1	7	7
	2	6	7
35	1	7	8
	2	6	8
	3	5	8
36	1	7	9
	2	6	9
	3	5	9
37	1	7	10
	2	6	10
39	1	7	11
	2	6	10
40	1	8	1
	2	8	2
43	1	8	5
	2	7	5
44	1	8	6
	2	7	6
46	1	8	7
	2	7	6
47	1	9	2
	2	8	2
48	1	9	3
	2	8	3

The Junction Cell Path Coordinate List

Level	Counter	Path No.	Cell No.	Row	Col
2	1	2	1	2	10
			2	3	10
2	2	31	1	5	12
			2	4	12
2	3	38	1	6	10
			2	5	9
2	4	23	1	7	3
			2	8	4
			3	7	5
2	5	45	1	7	6
			2	6	7
2	6	41	1	8	2
			2	8	3
3	1	3	1	3	10
			2	4	11
3	2	9	1	4	8
			2	4	9
3	3	42	1	8	3
			2	7	4
			3	7	5
4	1	10	1	4	9
			2	4	10
8	1	24	1	7	5
			2	6	6
10	1	16	1	6	6
			2	6	7
13	1	17	1	6	7
			2	5	8
15	1	18	1	5	8
			2	5	9
18	1	19	1	5	9
			2	4	10
23	1	11	1	4	10
			2	4	11
28	1	49	1	4	11
4	1	50	1	4	12

Some analysis values were counted during the routing simulation process. The result is in Tab.1.

Table 1 The statistical result of runoff path in huangjiaercha small watershed

Cell Number		
	X	13
	Y	9
Cell Number within whole watershed		117
Starting Cell Number		32
Junction Cell Number		18
Starting Cell Path Number		32
Junction Cell Path Number		18
Total Path Number		50

Based on the Routing simulation, the soil erosion in Huangjiaercha Small Watershed in 1996 was calculated. The rainfall volume of each month in 1996 in Huangjiaercha Small Watershed is as below:

Table 2 The rainfall of every months of huangjiaercha small watershed in 1996 Unit: mm

Month	1	2	3	4	5	6	7	8	9	10	11	12	Year
Rainfall	4.1	0.8	13.3	10.1	19.6	4.2	134.7	45.1	32.5	41.5	6.9	0	312.8

According to the erosive rainfall standard, four erosive rainfalls happened in 1996 in Huangjiaercha Small Watershed, respectively in July, August and September. Their rainfall data were as following table:

Table 3 The erosive rainfall data in 1996 in huangjiaercha small watershed

Rainfall Sequence	1	2	3	4
Rainfall Date	1996.7.7	1996.7.27	1996.8.9	1996.9.17
Rainfall Time Length (min)	962	230	450	175
Rainfall Volume (mm)	93.7	28.4	14.3	18.7
Max. 30-min. Rainfall Intensity (mm/min)	0.330	0.240	0.287	0.373
Average Rainfall Intensity (mm/min)	0.097	0.123	0.032	0.107

Through simulating each precipitation of the whole year, the one-year distribution of soil erosion was reported.

Table 4 The soil erosion volume for each rainfall in 1996 in Huangjiaercha Small Watershed

Rain Sequence	1	2	3	4
Soil erosion Volume for each rainfall (kg)	1,551,027	222,984	88,122	131,898
Soil erosion modulus for each rainfall (t/km^2)	272.11	39.12	15.46	23.14
Soil erosion modulus for one-year rainfall ($t/km^2.a$)	349.83			

From the above table, the first rainfall happened in July 7,1996 was an especially big rainfall, which caused the most soil erosion during the whole year.

For testing the reliance and accuracy of the erosion systems simulation and the further parameters revision, the runoff plot observation data, the formerly erosion model and the on-the-spot measuring data were applied synthetically to test the systems simulation. The result showed that the systems simulation have higher reliance. It can be used to simulation and calculation of the soil erosion in the loess area's watershed.

3 Result and discuss

An algorithm has been developed that computes a hydrologically ordered flow sequence of grid cell elements for input into a distributed parameter runoff-erosion model. The algorithm is loosely coupled with the WINGIS software. That is significance for the watershed comprehensive management and planning and the decision-making. The erosion systems simulation relies on the accuracy of DEM and the size of the grid cell. It is easy to conduct the spatial analysis that this grid system combines with GIS and the investigated data. And the same time, it is necessary that the some algorithm of drawing the surface runoff information based on the DEM be improved to enhance the accuracy.

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