

The Impact of Resolution on the Accuracy of Hydrologic Data Derived From DEMs*

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ABSTRACT

Hydrologic data derived from digital elevation models (DEM) has been regarded as an effective method in the spatial analysis of geographical information systems. However, both DEM resolution and terrain complexity impacts the accuracy of hydrologic derivatives. In this study, a multi-resolution and multi-relief comparative approach was used as a major methodology to investigate the accuracy of hydrologic data derived from DEMs. The experiment reveals a quantitative relationship between DEM hydrologic derivative accuracy and the variation of resolution and terrain roughness at global level.

DEM terrain representation error affects the accuracy of DEM hydrological derivatives (drainage networks and watershed etc.). Coarser DEM resolutions can usually cause worse results. However, uncertain result commonly exists in this calculation. On the basis of a great deal of experiments, an error mathematical simulation model is put forward in this paper. The derivative errors can be found closely related with DEM vertical resolution and terrain roughness. DEM vertical resolution can be found closely related with the accuracy of DEM hydrological derivatives, especially in the smooth plain area. If the mean slope is less than 4 degree, the derived hydrologic data are usually unreliable. This result may be helpful in estimating the accuracy of the hydrologic derivatives and determine the DEM resolution that is appropriate to the accuracy requirement of a particular user.

By applying a threshold value to subset the cells of a higher accumulation flow, a stream network of a specific network density can be extracted. Some very important geomorphology characteristics, e.g. shallow and deep gully, can be separately extracted by means of adjust the threshold value. However, such a flow accumulation based processing method can not correctly derive those streams that pass through the working area because it is hard to accumulate enough flow direction values to express the stream channels at the stream's entrance area. Consequently, errors will definitely occur at the stream entrance area. In addition, erroneous derivatives can also be found in deriving some particular rivers, e.g. perched (hanging up) rivers, anastomosing rivers and braided rivers. Therefore, more works should be done to develop and perfect the algorithms

Keywords: DEM, resolution, hydrological, accuracy

1. Introduction

Automated extraction of drainage features from DEMs is an effective alternative to the tedious manual mapping from topographic maps. The derived hydrologic characteristic, include stream-channel networks, delineation of catchment boundaries, catchment area, catchment length, stream-channel long profiles and stream order etc. Other important characteristics of river catchments, such as the stream-channel density, stream-channel bifurcation ratios, stream-channel order, number and length, gradient and area of streams of that order, may also be derived. Several methods to extract the above drainage features from DEMs are available (Band 1986; Fairfield and Leymarie, 1991; Jenson and Domingue, 1988; Martz and Garbrecht, 1992; O'Callaghan and Mark, 1984) and have been applied to diverse areas such as hydrology, geomorphology, geology, and biology (Drayton, Wilde, and Harris, 1991; Jenson, 1991; Martz and De Jong, 1991; Moore, Grayson, and Ladson, 1991; Quinn and others, 1991). Studies have investigated the effect of DEM elevation sampling errors on the extracted drainage features (Walsh, Lightfoot, and Butler, 1987), but few works have been done to investigate the impact of

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DEM resolution and terrain complexity on the accuracy of hydrologic derivatives. This section focuses on the implications of DEM Et to the reliability of derived hydrologic derivatives.

To represent the terrain types in plains hills and mountains, three 10km × 10km areas in different relief complexity areas near Xi'an are selected as test sites in this study, Table 1 shows their major topographic parameters.

Table 1 Major Terrain Parameters of the Test Area

<i>Terrain Parameter</i>	<i>Plain</i>	<i>Hill</i>	<i>Mountain</i>
Geographical coordinate at the center of the test areas	109° 27'04''E 34° 35'12''N	114° 30'28''E 27° 25'46''N	116° 19'16''E 40° 32'31''N
Mean elevation (m)	425	227	824
Mean gradient (degree)	2.42	15.1	20.7
Profile curvature (degree)	5.96	15.47	21.24

2. The Accuracy of Hydrologic Data Derived

Let's simply examine ARC/INFO hydrological analysis method first. The program is presented by Jenson S.K and Domingue J.O (1988) and Tarboton D.G.; Bras R.L., Rodriques (1991). The derivation of drainage networks and watershed involves a number of stages.

(1) Depression and plateaux processing: Depressions and plateaux create difficulties when attempting to extract river-channel flow paths. "Fill" function should be used firstly to identify the depression and plateaux features in the DEMs. Mark (1984) and O'Callaghan and Mark (1984) proposed an algorithm for automatically detecting of drainage networks from DEM, and has been extended by Band (1986), Jenson and Domingue J.O (1988) and McCormack et al. in 1993. Plateaux are identified using a recursive neighbour algorithm. Neighbours of a cell are examined to see if they are at the same elevation. If so, the neighbours of each neighbour are examined in turn until the cells comprising the plateaux have been collected. Depressions are identified by simulated filling until overflow occurs. The perimeter of a simple depression expands during filling until an overflow point is found. Such a point will have a lower neighbour, which is not inside the perimeter and which defines the direction of water flow.

(2) Calculate the flow direction: The flow direction is determined by finding the direction of steepest descends from each cell. The stream-channel network can be completed by joining feature inflows to outflows. This is done by drawing a straight-line path from an inflow to the nearest outflow point.

(3) Calculate the flow accumulation: Flow accumulation is calculated then. The results of flow accumulation can be used to create a stream network by applying a threshold value to the subset cells with a high accumulation flow. Figure 1 shows the above three procedures.

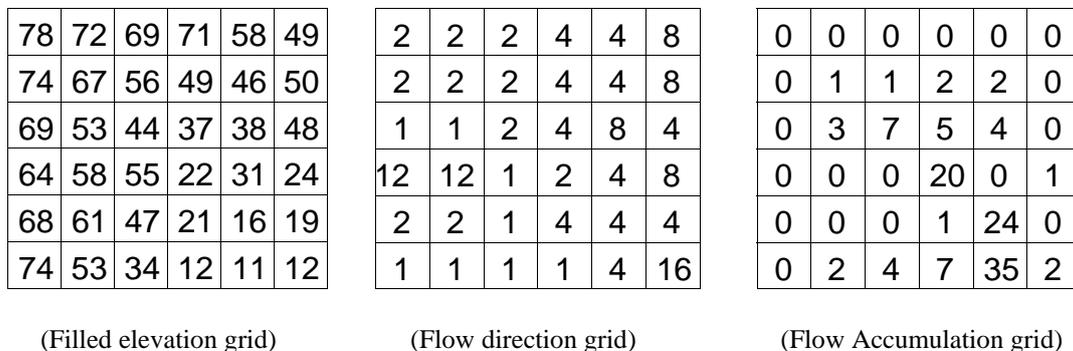


Figure 1 An illustration of calculating flow direction and flow accumulation

(4) Finally, river catchment divisions can be derived by climbing the stream-channel network of the flow links from the end points and calculating the upslope areas contributing to every point. Figure 7.15 gives an illustration of the last three processing stages.

This investigation is conducted in the form of a sensitivity analysis. Drainage properties are extracted from DEMs of a increasing grid cell size. Drainage networks and watershed derived from different resolutions DEMs are compared to those derived from the original 50m resolution DEM to assess the effect of the DEM Et.

2.1 The effect of "Fill Processing" in deriving drainage properties

A set of tests is made to investigate the specific characteristics of the depressions. Table 2 shows the statistic result. This investigation shows that the filled depressions can be found commonly in smooth areas. No doubt, this pre-processing will definitely cause some representation errors. Many real depression and lowland areas will also be filled. So a careful visual comparison with corresponding topographic maps to check the fill processing effect is encouraged.

Table 2 A comparison of relevant depression values

		<i>Plain</i>	<i>Low-hill</i>	<i>Hill</i>	<i>Mountain</i>	<i>High-mountain</i>	<i>Mixture</i>
Dep.	1m	6.35	1.76	0.37	0.14	0.53	3.96
Area	2m	2.52	0.81	0.14	0.09	0.38	0.98
(km ²)	3~4m	1.35	0.51	0.07	0.17	0.34	0.46
	> 5m	0.35	0.22	0.01	0.06	0.26	0.11
Maximum value		21m	9m	9m	14m	18m	11m
Mean value		0.18m	0.063m	0.0097m	0.0128m	0.049m	0.081m
S.D. value		0.65m	0.418m	0.15m	0.225m	0.577m	0.412m

Above table show that along with the increase of terrain complexity, there are relatively less depressions and plateaux existing, so the continuity of the derived drainage lines is getting better.

Anyway, there are still some depressions that make it difficult to get a integrate drainage system. Consequently, identifying and filling the depression and plateaux features in the DEMs are indeed a basis and necessary pre-processing work in hydrologic analysis.

2.2 The Impact of resolution and terrain on the accuracy of derived stream-channel networks and watershed

A stream-channel network is one of the most important hydrologic and topographic factors. It builds up a basic topographic configuration in geographic analysis and mapping. To investigate the impact of DEM resolution and terrain complexity on the derived accuracy, three sets of drainage network maps are presented (see figure 3). It is assumed that the networks from 5m resolution DEMs be truth and can be regarded as a criterion for assessing the derived drainage network accuracy from a coarser resolution. By mean of a careful comparison and analysis, following conclusions can be drawn.

(1) By applying a threshold value to subset cells, a high accumulation flow, stream networks can be extracted. Experiment result shows if the mean value of flow accumulation is taken as the threshold value, ideal stream-channel networks can be derived. Although the mean flow accumulation values are different at different resolution levels, the derived drainage system by this threshold can make a same effect.

(2) In smooth terrain areas, drainage networks are extremely easy to change their structure and pattern with the increase of grid size. This error is pictorially like the "river capture" phenomenon in geomorphology. The main reason of this phenomenon can be reasoned that aspect errors happened in smooth area will cause the error of flow direction, where errors will definitely lead to erroneous flow accumulation and hence get erroneous drainage networks. This kind of error is most apparent in the plain and low-hill test sites and the uniform part of a mixture test site. In the hill, mountain and high-mountain test areas, this kind of error will be greatly limited because of the less aspect error.

(3) In order to make a quantitatively analysis, the rate of correct stream-channels in different test areas and at resolutions is calculated. If a stream-channel from a coarser resolution is integrally conform to the corresponding stream-channel from the original 50m resolution, it is defined to be a correct stream, and vice versa.

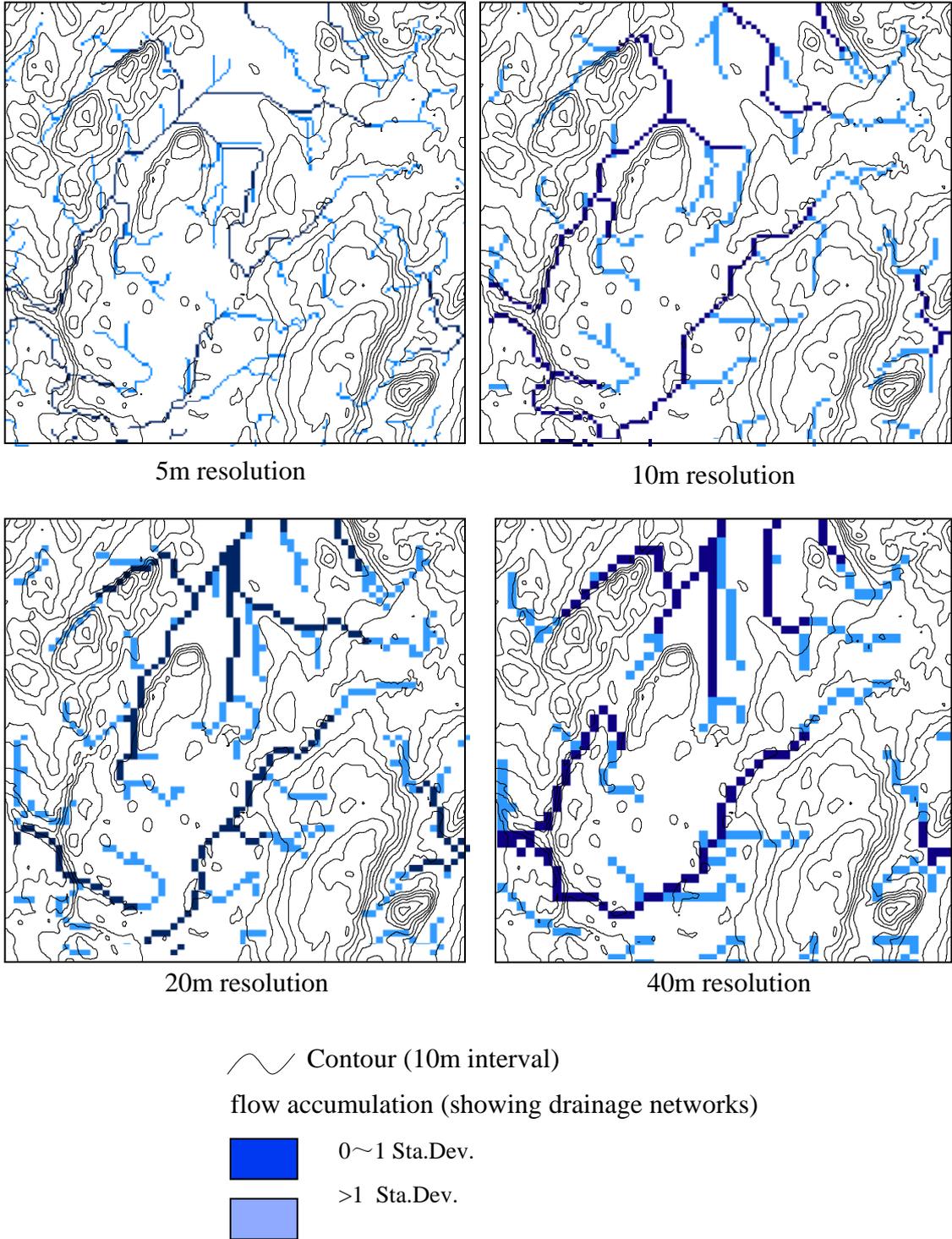
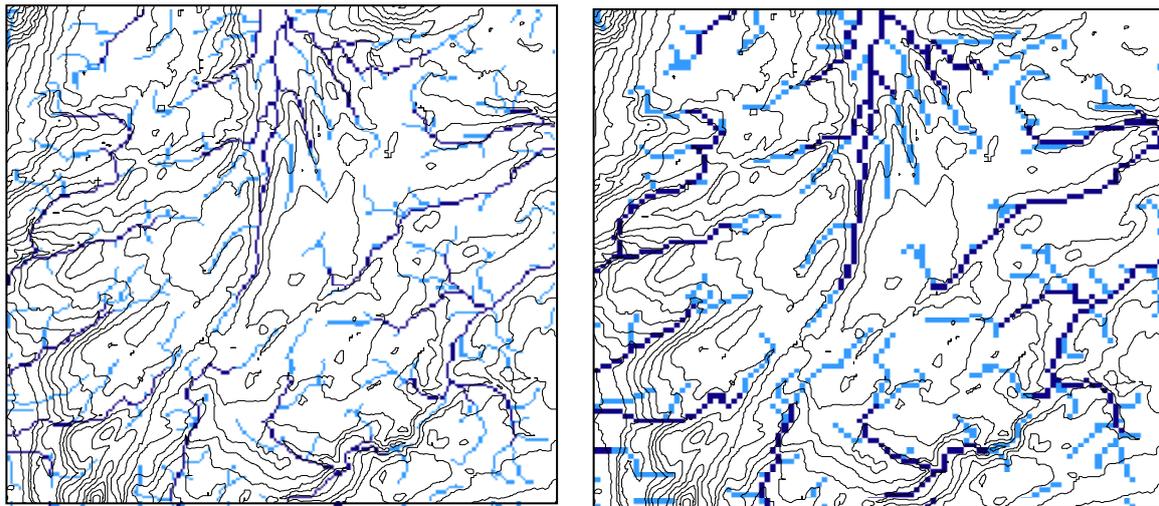
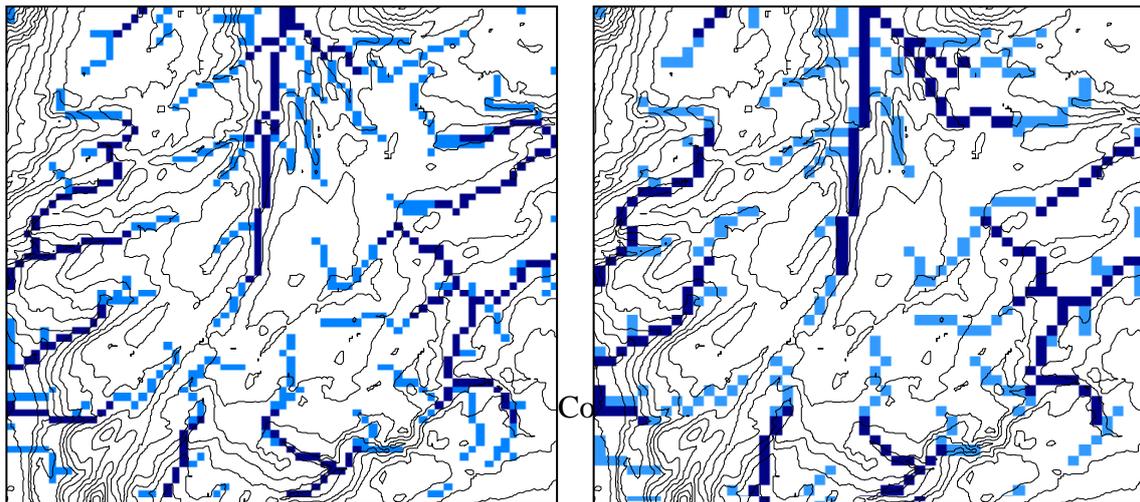


Figure 3a A comparison of the drainage networks derived from different resolution DEMs (the plain test area)



5m resolution

10m resolution



20m resolution

40m resolution

~ Contour (10m interval)

Flow accumulation (showing drainage networks)

 0~1 Sta.Dev.

 >1 Sta.Dev.

Figure 3b A comparison of the drainage networks derived from different resolution DEMs (the hill test area)

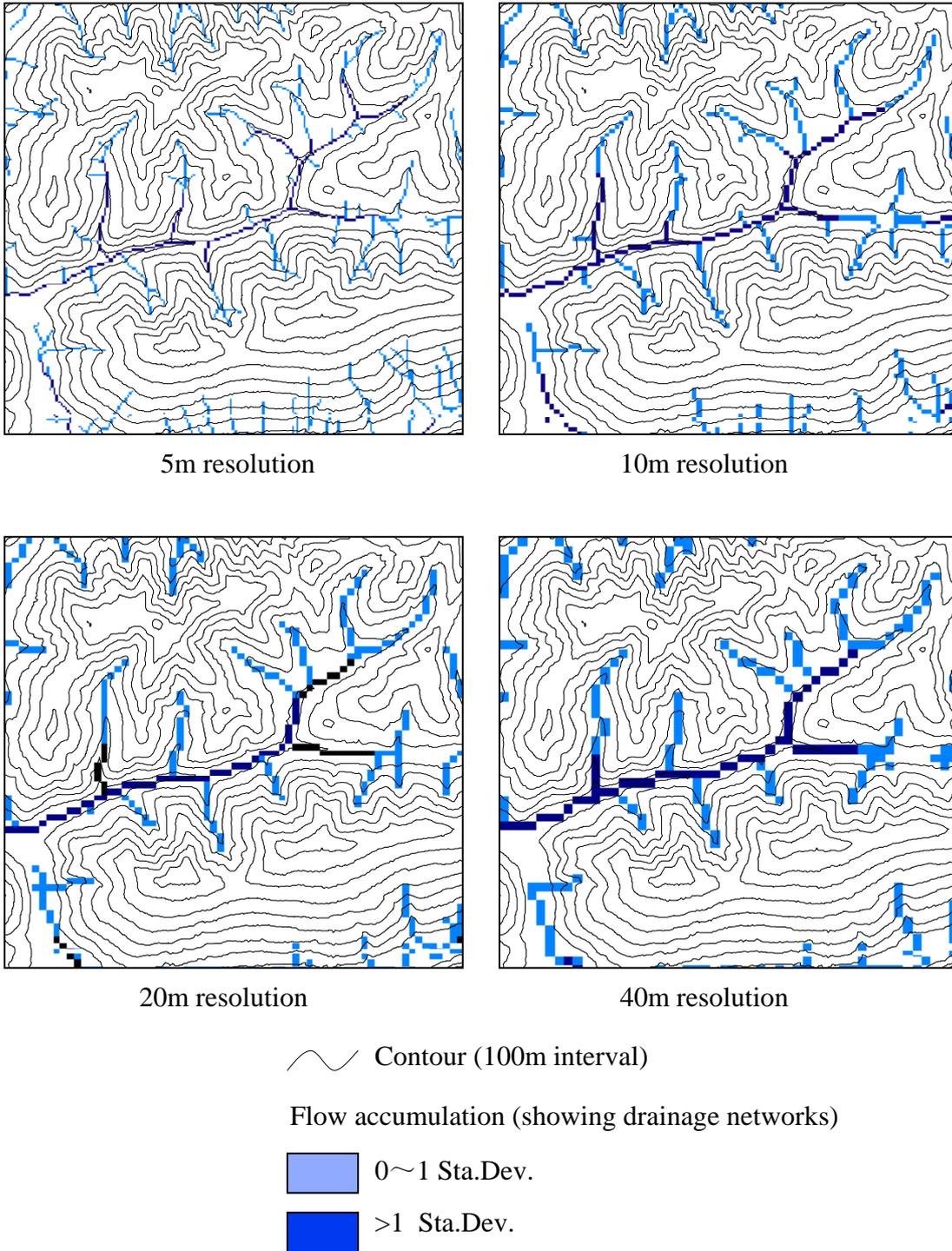


Figure 3c A comparison of the drainage networks derived from different resolution DEMs (the mountain test area)

3. Result

Table 3 shows that, in most cases, resolution is positively related with the ROC values, but random results could exist in this tendency. For example, in the mixture test area, 150m resolution DEM gets a worst result. On the contrary, 200m resolution DEM gets the best one.

Table 3 The rate of correctness (ROC) of the derived drainage networks

	<i>Plain</i>	<i>Hill</i>	<i>Mountain</i>
ROC (10m reso.)	11%	93%	99%
ROC (20m reso.)	11%	87%	99%
ROC (40m reso.)	8%	82%	99%

In term of the experiment result, it is also empirically concluded that if the mean slope of a working area is less than 4 degree, the derived drainage networks will be unreliable. In addition, if there exist a very smooth plain area in a working area, more attention should be paid to check the errors of the derived drainage networks, even if the mean slope of the whole area is over 4 degree. For example, the mean slope in the mixture test area is over 9 degree, big drainage error still occurs in this area because there are over 50 percent of the whole area is smooth area (the mean slope is less than 2 degree), where great erroneous drainage causes a great confusion of their stream system.

The flow accumulation method can not correctly derive those streams that pass through the working area, because it is hard to accumulate enough flow direction values to express the stream channels at the stream's entrance area. Consequently, errors will definitely occur at the stream entrance area. For example, in the mixture terrain test area, Salzach river was misrepresented for this reason. No river entrance can be extracted at the south border of the test area. In addition, erroneous derivatives can also be expected in deriving some particular rivers, e.g. perched river, anastomosing rivers, braided rivers etc. Therefore more work should be done to develop and perfect the algorithms.

Watersheds (river catchments) are important geographical units in geo-analysis and the relevant production planning and management. Figure 4 presents a set watershed area statistic result derived from three sets of watershed maps to reflect the impact of resolution and terrain to the derived watershed accuracy. In a smooth area, especially if the mean slope is smaller than 4 degree, the derived watershed can be found unreliable. Extremely great discrepancy of derived watersheds (both the area and the shape) will happen with the decrease of resolution.

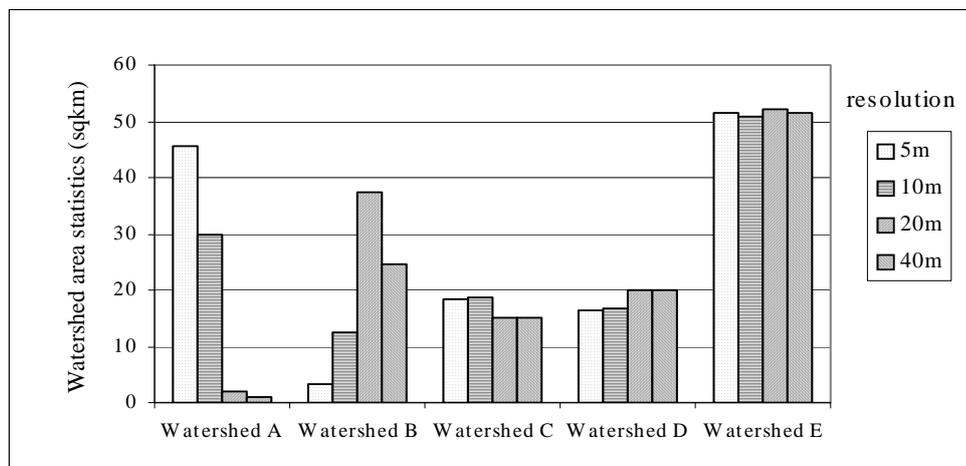


Figure 4 A comparison of the variation rates of watershed derived in different test areas

In sum, the method for extracting watershed and drainage networks from grid DEM is based on a similar principle and method. As a matter of fact, a derived drainage system builds up a basis for watershed. Consequently the accuracy and the error of the both derivatives have the same characteristics. In plain areas, especially if the mean slope of the working area is less than 4 degree, the derived hydrologic data are usually unreliable. Coarser DEM resolution can usually cause worse results.

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