Research note

Physiological Factors Measured Using Digital Elevation Model Data for Experimental Watersheds of the Taiwan Forestry Research Institute

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【Summary】

Physiographic factors are the most important characteristics in establishing the hydrologic conditions of a watershed. They are crucial for experimental watersheds for model calibration and determining the effects of forest management practices on water yields. Originally those factors of Taiwan's experimental watersheds were analyzed using topographic maps. The accuracy of values for factors obtained from maps and ground surveys has long been criticized due to the scale and man-made errors. With the development of geographical information system (GIS) and digital photogrammetric techniques, it is increasingly common to determine basin characteristics from digital elevation models (DEMs). In this context, the physical characteristics of Taiwan Forestry Research Institute experimental watersheds including those at Fushan, Piluchi, Lienhuachih, and Shanping were examined using WinGrid, computer software which combines techniques of GIS, remote sensing, related theories, and models of soil and water conservation for topographic analysis of watersheds. The results indicated that there were significant differences between physiographic factors measured using topographic maps and DEM data for area and area-related factors such as the circumference of watershed, form factor, compactness, and average slope. Hopefully the adjusted measurements will be helpful in improving watershed and hydrologic studies in Taiwan.

Key words: physiographic factors, experimental watershed, DEM data.

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研究簡報

以DEM資料量測林業試驗所試驗集水區地形因子

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摘　要

地形特徵為決定集水區水文特性的主要因子，對集水區水文模式的驗證及經營作業對集水區水量改變等均有決定性的影響。目前台灣試驗集水區的地形因子分析多沿用地形圖分析結果為藍本；然而由地形圖所取得的地形因子其精確度常因比例尺與人為誤差而遭詬病。隨著地理資訊及數位判圖技術的進步，集水區的地形特性已多改為由數化的地形資料快速萃取而得，除精確度大為提高外更可將誤差減到最低程度。緣此作者將林業試驗所福山、畢祿溪、蓮華池與扇平等目前仍進行觀測的試驗集水區，利用WinGrid系統分析各集水區數位地形資料，重新測定各試驗集水區的地形因子，並與先前餘地形圖獲得的數據相比較。分析結果獲知：集水區面積及與面積有關的地形因子，前後量測的結果差異甚大，足以影響集水區試驗結果。希望藉由精確的量測能對台灣地區試驗集水區研究有所助益。

關鍵詞：地形因子、試驗集水區、數化地形資料。

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Hydrological phenomena are usually studied in experimental watersheds. They are ideally selected on the basis of their representation so that results obtained from them can be transferred (at least qualitatively) to other measured watersheds with similar characteristics. The initiation of the first experimental watershed was in 1909 at Wagon Wheel Gap in Colorado, USA. Experimental watersheds are now used worldwide to determine the effects of forest management practices on water yields. They have contributed considerably to our understanding of hydrologic phenomena and the effects of various land use practices (Hewlett et al. 1969). Following this tend, the first gauged watershed was established in the Shanping Experimental Forest of southern Taiwan in 1964 and managed by the Taiwan Forestry Research Institute (TFRI) following the recommendations of Dils (1964). Academic organizations of Taiwan normally carried out experimental studies at that time. TFRI has consecutively added experimental watersheds at the Lienhuachih, Piluchi, and Fushan research centers and once reached a maximum of 15 gauged watersheds. However, some of these were later abandoned mostly due to leakage. Currently there are 11 gauged watersheds representing several forest types and climatic conditions in northern subtropical, temperature hardwood, conifer forests and southern tropical hardwood forests (Lu et al. 2000, 2001).

Physiographic factors are the most important characteristics in establishing hydrologic conditions which are likely to significantly affect storm regimes in a watershed. The physiographic factors of Taiwan's experimental watersheds were analyzed by Koh and others in 1978 and Hsia and others in 1996. Since then, topographic characters of those watersheds were cited from their measurement in studies regardless of whether for model calibration or hydrologic roles of forests. Measuring the topographic and hydrologic characteristics of TFRI's experimental watersheds by Koh et al. and Hsia et al. was done using topographic maps. The accuracy of values for factors obtained from topographic maps and ground surveys has long been criticized due to the scale and man-made errors. In addition, the results obtained from topographic maps are not detailed or spatially homogeneous enough for large-scale examinations. However, with the development of geographical information system (GIS) and digital photogrammetric techniques, the ability, accuracy, and efficiency of spatial data analyses have greatly improved. With techniques of GIS combined with digital elevation model (DEM) records, the topographic factors of a watershed can be easily calculated with high accuracy and less effort (Chung et al. 2006).

It is increasingly common to determine basin characteristics and drainage networks using DEMs. Therefore, the authors feel that it is timely and necessary to reexamine physiographic factors of Taiwan's experimental watersheds using techniques of GIS with DEM data.

The software WinGrid, which was developed by Chao-Yuan Lin and Wen-Tzu Lin, was adopted for the physical characteristic analysis of watersheds in this study. It is combined with techniques of GIS, remote sensing, related theories, and models of soil and water conservation for topographic analyses of watersheds (Lin and Lin 2000, Lin et al. 2006, 2008). The theory of automated extraction of watershed geomorphologic and hydrologic factors by WinGrid is based on the concepts of drainage direction and accumulative flow proposed by O'Callaghan and Mark (1984). Techniques for extracting stream channel links, delineating the boundaries of watersheds, and determining the direction of flow for each grid developed by Jenson and Domingue (1988) are also applied in WinGrid.

Highlights of the analysis of physiographic factors in this study were as follows.

1. Prepare DEM data of the experimental watersheds of TFRI. Except for the Piluchi watershed which is composed of 40×40-m raster data, the other watersheds are composed of 5×5-m raster data that are believed to provide the required accuracy for watershed analyses.
2. Obtain longitude and latitude of the location of weir in each experimental watershed by GPS (global positioning system).
3. Compute vectors of flow paths, basins, and ridges lines.
4. Control the drainage network density and basin size use flow accumulation thresholds for outlets, upstream limits, and branch points.
5. Automatically fill spurious small depressions in the DEM and set thresholds to leave large, deeper depressions unfilled.
6. Compute the upstream catchment area and downstream flowpath at the location of weir.
7. Determine the slope of each grid by calculating the angle between the grid plane and its normal axis (line).
8. Determine physiographic factors of a watershed such as the area, circumference, main stream length, mean watershed width, form factor, compactness, average slope, average elevation, and aspect through arithmetic operations or taking the mode from the corresponding values of stream lines or basin polygons.

The topographic characteristics of Fushan, Piluchi, Lienhuachih, and Shanping obtained from DEM data combined with these obtained from topographic maps are tabulated in Tables 1 to 4, and the locations

Table 1. Physiographic factors for Fushan experimental watersheds

Item	No. 1 watershed		No. 2 watershed	
	DEM	Maps	DEM	Maps
Watershed area (ha)	36.59	37.98	67.55**	94.15
Circumference (m)	3410**	2526	5550*	4975
Main stream length (m)	892*	758	1797*	2058
Mean watershed width (m)	410*	501	376*	457
Form factor	0.46**	0.66	0.21	0.22
Compactness	0.63**	0.85	0.52**	0.69
Average slope (%)	60.2*	54.0	63.3**	85.0
Average elevation (m)	836	842	858	922
Maximum elevation (m)	998	1000	1000*	1230
Minimum elevation (m)	663	670	667	675
Aspect		SSE		S

Table 2. Physiographic factors for Piluchi watersheds

Item[1)]	No. 11 watershed		No. 12 watershed	
	DEM	Maps	DEM	Maps
Watershed area (ha)	145.12	144.0	239.52	238.0
Circumference (m)	6720**	5335	9440**	7550
Main stream length (m)	2251	2450	3367	3325
Mean watershed width (m)	645	587.8	711*	715.8
Form factor	0.29	0.24	0.21	0.22
Compactness	0.63**	0.80	0.58*	0.72
Average slope (%)	62.6**	82.0	64.5*	74.0
Average elevation (m)	2525	2530	2641	2622
Maximum elevation (m)	3040	3060	3193	3205
Minimum elevation (m)	2092	2105	2112	2105
Aspect		W		W

[1)] Measured using 40-m DEM records.

Table 3. Physiographic factors for Lienhuachih experimental watersheds

Item	No. 2 watershed		No. 3 watershed		No. 4 watershed		No. 5 watershed	
	DEM	Maps	DEM	Maps	DEM	Maps	DEM	Maps
Watershed area (ha)	16.73	16.13	4.10**	3.40	6.16	5.86	8.40	8.39
Circumference (m)	2730**	1910	1230**	780	1470**	1000	1790**	1300
Main stream length (m)	552	603	142**	270	302**	380	289**	420
Mean width (m)	303*	272.5	289**	125.9	204**	154.2	291**	199.7
Form factor	0.55**	0.45	2.03**	0.46	0.67**	0.40	1.00**	0.47
Compactness	0.53**	0.75	0.58**	0.84	0.60**	0.86	0.57**	0.79
Average slope (%)	46.3*	56.0	57.5*	69.0	43.7	40.0	33.5*	41.0
Average elevation (m)	811	812	729	723	768	763	765	757
Maximum elevation (m)	888	889	810	781	798	797	789	788
Minimum elevation (m)	728	726	659	666	722	728	741	735
Aspect		NE		SE		SE		SE

Table 4. Physiographic factors for Shanping experimental watersheds

Item	No. 1 watershed		No. 2 watershed		No. 4 watershed	
	DEM	Maps	DEM	Maps	DEM	Maps
Watershed area (ha)	58.04*	51.8	49.95	50.8	29.54**	21.4
Circumference (m)	4770**	3330	3980**-	3030	3080**	2050
Main stream length (m)	1286	1360	909**	1170	583*	715
Mean watershed width (m)	451*	381	550**	434	507**	299
Form factor	0.35**	0.28	0.60**	0.37	0.87**	0.41
Compactness	0.57**	0.77	0.63**	0.83	0.62**	0.80
Average slope (%)	58.6*	51.0	74.0	69.0	62.5*	55.0
Average elevation (m)	926	937	1047	1064	1047	1057
Maximum elevation (m)	1252	1250	1362	1363	1255*	1235
Minimum elevation (m)	646	675	693	725	819	845
Aspect		SW		NW		SW

obtained from the DEM for those watersheds are shown in Figs. 1 to 4, respectively. Differences between DEM-measured data and original data of > 10% are marked with an asterisk (*) and those of > 20% are marked by 2 asterisks (**). It can be seen that the major discrepancies of physiographic factors measured between topographic maps and DEM data are area and circumference of the watersheds. There are some important relationships between basin area and hydrologic performance. The area of an experimental watershed is crucial for model calibration, validations, and hydrologic process investigations especially for small watersheds. In addition, many physiographic factors such as the circumference of watershed, form factor, compactness, and average slope are also significantly related to area. Therefore if the area of a watershed changes, the related factors are also affected. The circumference of a watershed is closely related to the boundary of a watershed. It also reflects the shape of the watershed. We carefully delineated the boundaries of those watersheds in order to obtain the maximum accuracy for both area and circumference. Hopefully the adjusted area of TFRI's experimental watersheds will contribute to improvements in watershed and hydrologic studies in Taiwan.

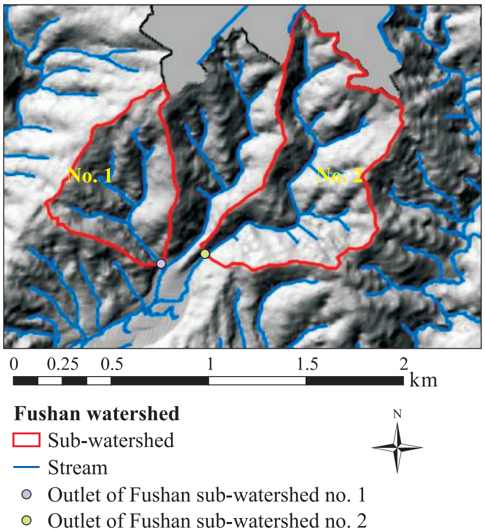

Fig. 1. Location of sub-watersheds in the Fushan Experimental Forest.

In addition to area, the length of a stream is also extremely sensitive to the map scale used. Although main stream lengths measured using DEM data were not all greater than those measured using topographic maps, the total length of a stream in a watershed is generally greater when measured from maps of a larger scale. Many ephemeral rills and

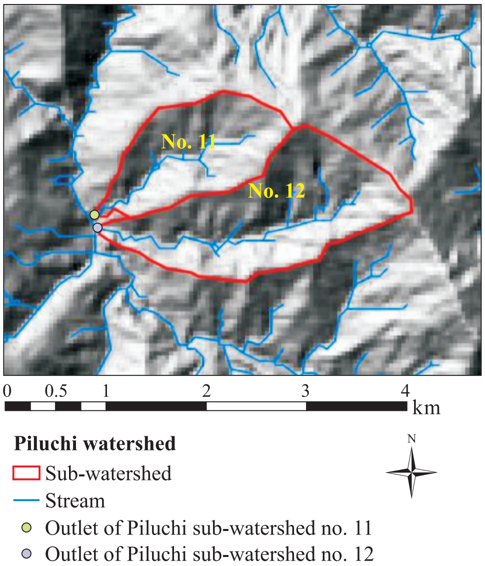

Fig. 2. Location of sub-watersheds in the Piluchi watershed.

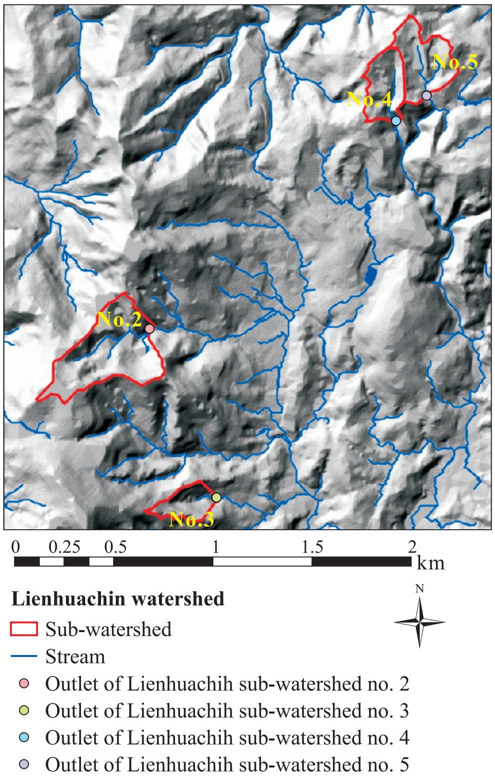

Fig. 3. Location of sub-watersheds in the Lienhuachih Experimental Forest.

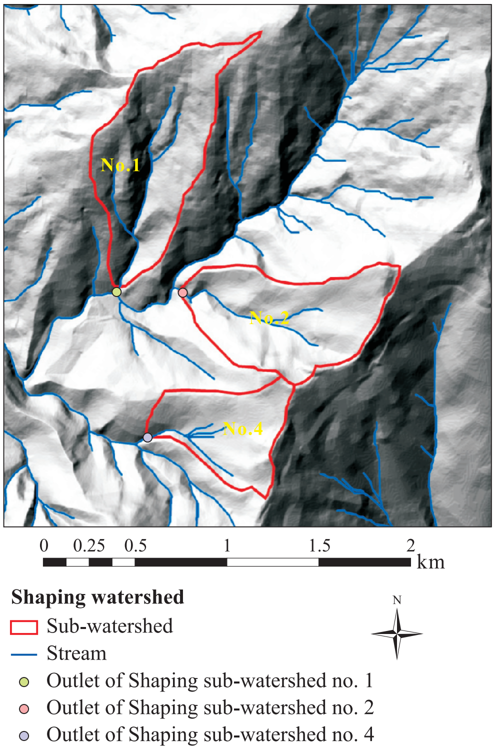

Fig. 4. Location of sub-watersheds in the Shanping watershed.

channels are not indicated on a 1:5000-scale topographic map. It is important to delineate streams with consistency for basin studies. DEM data with a 5×5 resolution are believed to have the required accuracy.

Results also indicated that there was a significant difference in the average slope between DEM-measured and map-measured data for the Lienhuachih no. 3 watershed. The reason for the great discrepancy is landslides which occurred in July 1998 and cut back the top boundary of the watershed. In fact, landscapes incessantly change on a geological time scale. Many upstream watersheds in Taiwan also showed significant landscape transformations after the big earthquake on September 21, 1999. Whether those transformations affect values of physiological factors for upstream watersheds of Taiwan or not should to be reevaluated.

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