Effect of Resolution of Digital Elevation Models on Soil-Landscape Correlations in Hilly Areas

By Wei Wu, Zhengyin Wang, and Hongbin Liu

A study of six different digital elevation model (DEM) grid sizes and their impact on the relationships between soil properties and their physical terrain found that the most accurate model is not always produced at the highest resolution. The knowledge of which DEM resolution produces an appropriate model for a particular landscape can be used as a guideline for optimizing field sampling strategies.

A DEM is a representation of the continuous topography of the Earth in digital format, and is widely used in terrain analysis and other spatial applications (Moore et al., 1991). Use of appropriate spatial resolution within a DEM can be a challenge for researchers involved in topography-based modeling. Most studies have led to the conclusion that as resolution decreases, slope and curvature derived from a DEM decrease and many delicate landscape features are lost. To a certain degree, micro-topography remains very important and must be appropriately preserved according to the specific research goal. The loss of important local landscape features with an increase in DEM cell size may lead to decreased accuracy for a given area. Therefore, it is important to remember that a particular landscape demands an appropriate DEM resolution. The objective of this work was to assess the effects of various DEM resolutions on the relationships between soil properties and their landscape attributes.

The study area was located at 28°28' to 29°28' N and 105°49' to 106°36' E in southwest China **(Figure 1)**. The region's climate is mild sub-tropic, with mean annual temperatures of 16 °C and mean annual precipitation of 1,030 mm. Major soils types are classified as purple humid Cambosols, according to Chinese Soil Taxonomy (2001). The site measures 100 ha and has slopes of 0 to 34 degrees **(Figure 1)**.

Soil was sampled at 121 field locations using a 100 x 100 m grid strategy. At each site, 10 soil samples were taken at a depth of 0 to 20 cm within a 10 m radius of the geo-referenced grid point. Soil pH, OM, Ca, Mg, P, S, and Cu **(Table 1)** were measured by the Systematic Approach developed by Agro Services International Inc. (Portch and Hunter, 2002). Based on a skewness indicator range between -1 and 1, soil pH, OM, and Cu fell into normal distributions, while the remaining soil properties were considered non-normal or skewed. The coefficient of variation decreased in the order: P > Mg = Ca = S > Cu > OM > pH. Soil pH mainly fell between 4.4 and 5.0. The majority of values for OM and P were low, mainly between 0.4 to 0.8% and 1.35 to 10.0 mg/L, respectively. Distributions for other nutrients were mainly between 100 to 300 mg Mg/L, 20 to 60 mg S/L, 1 to 3 mg Cu/L, and 500 to 1,500 mg Ca/L.

Abbreviations: OM = organic matter; Ca = calcium; Mg = magnesium; P = phosphorus; S = sulfur; Cu = copper; L = liter; GIS = geographic information system.

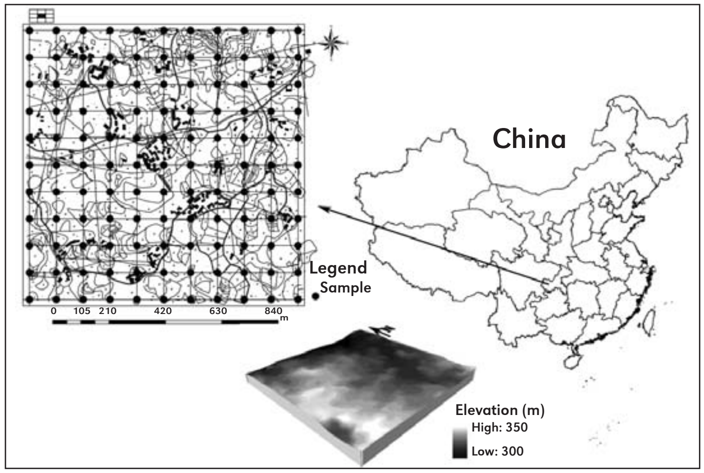

Figure 1. Location of the study area, distribution of sampling sites, and its digital elevation model (DEM).

Table 1. Descriptive statistics of soil properties.

Soil property	Mean	Median	Min.	Max.	Stdev	Skewness	Kurtosis	CV%
pH	4.8	4.8	4.1	5.8	0.3	0.98	2.20	6
OM, %	0.7	0.6	0.4	1.1	0.2	0.25	-0.43	22
Ca, mg/L	1,203	1,040	277	3,596	648	1.52	2.34	54
Mg, mg/L	248	208	50	884	140	1.63	3.91	57
P, mg/L	18.3	13	1.4	110.8	19.7	2.60	7.67	108
S, mg/L	51.2	46.6	8.6	153.3	25.7	1.13	1.70	50
Cu, mg/L	2.2	2.2	1.0	5.2	0.8	0.63	1.17	34

A 2 m resolution DEM was created using ANUDEM (Hutchinson, 1995). Six different resolution DEMs (4, 6, 8, 10, 20, and 30 m) were developed through a GIS (ARC/INFO 9.0; ESRI, 1995; **Figure 2**). Terrain attributes of slope, aspect (or slope direction), plan curvature, elevation, specific catchment area (SCA), and topographic wetness index (TWI) were also calculated (Moore et al., 1993). Pearson correlation coefficients (r) were employed to examine the relationships between each soil property and terrain attribute at all DEM resolutions.

The spatial distribution of the terrain indices for each sample location and DEM grid size are shown in **Figure 3**. Changing DEM resolution produced clear variations in most topographic index values, excluding elevation and topographic aspect. Collectively, the observations that follow are mainly attributed to the smoothing of the topography resulting from a lower resolution DEM. In general, the larger grid size caused landscape details, such as shorter slopes, to be lost.

Although the minimum elevation was over estimated by 2 m using the broadest DEM of 30 m, statistical analyses failed to show any significant bias in its estimation of the median or range of elevation **(Figure 3a)**. Based on the 4 m DEM, the site's higher elevations mainly existed in its southwest regions and such general trends were also seen in the 6 to 30 m

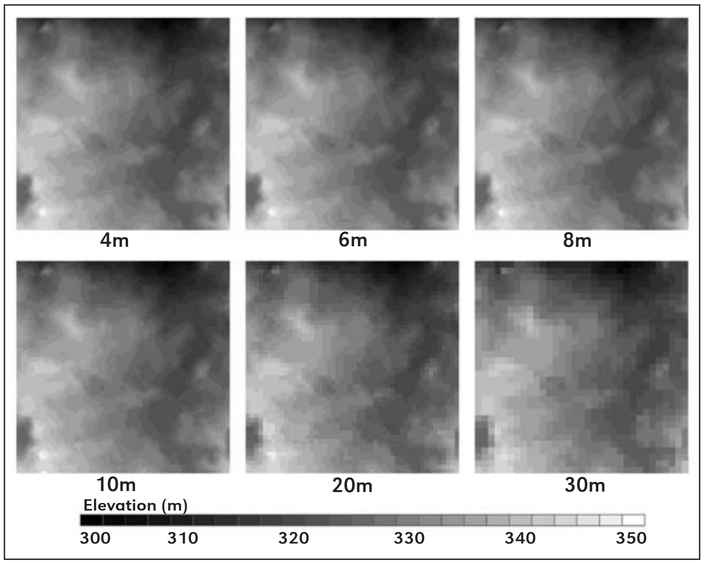

Figure 2. DEMs with grid size from 4 to 30 m.

DEMs **(Figure 2)**. The coarser DEM was unable to accurately estimate the spatial distribution of the mean slope angle. However, a steady decrease of the mean and standard deviation of the mean slope gradient existed as DEM cell size increased from 4 to 30 m as did the range of slope percentage **(Figure 3b)**. No clear trend was found for topographical aspect across the different DEM resolutions **(Figure 3c)**. In general, the range and the standard deviation of plan curvature decreased with an increase in the DEM cell size **(Figure 3d)**. Similar trends were found for maximum and mean of plan curvature when the 6 m DEM was excluded from the analysis. A clear increase in the natural logarithm of the specific catchment area [ln(SCA)] was found with coarser DEM cell sizes **(Figure 3e)**. A similar trend was found in TWI **(Figure 3f)**. Furthermore, the range of ln(SCA) and TWI decreased with a decrease in DEM resolution.

Relationships that remained across the full range of DEM resolutions included elevation which was negatively related to pH, Ca, and S, and positively related to OM and P **(Table 2)**. This is mainly attributed to the narrow range of elevation in this study site (300 to 350 m). Others that were independent of DEM resolution included the consistent relationships between topographical aspect and OM, Ca, and Mg; the negative relationship between slope and S; the positive relationship between plan curvature with S; the positive relationship between SCA and S; and the significant relationships between P (negative) and S (positive) with TWI.

Conclusion

Soil properties are highly variable across hilly landscapes in Southwest China, but attempts to assess these properties across various DEM grid sizes revealed many consistent relationships. Thus, regardless of a measurable loss in the detail of the landscape with coarser DEMs, the expectation for significant change in the interpretation of how soil properties vary within this landscape should be small. An understanding of the effect of DEM grid size on soil-landscape relationships provides useful information for optimizing grid-based field sampling designs, which can be prohibitive in their adoption at practical scales due to excessive costs associated with time and labor. BC

Table 2. Soil-landscape relationships based on different DEM resolutions.

Topographic index	Soil variable	DEM Resolution, m 4	6	8	10	20	30
Elevation	pH	neg**	neg**	neg**	neg**	neg**	neg**
	OM	**	**	**	**	**	**
	Ca	neg*	neg*	neg*	neg*	neg*	neg*
	Mg	ns	ns	ns	ns	ns	ns
	P	**	**	**	**	**	**
	S	neg**	neg**	neg**	neg**	neg**	neg**
	Cu	ns	ns	ns	ns	ns	ns
Aspect	pH	ns	*	ns	ns	ns	ns
	OM	neg*	neg**	neg**	neg**	neg**	neg**
	Ca	*	**	**	**	**	**
	Mg	**	**	**	**	**	**
	P	ns	ns	ns	ns	ns	ns
	S	ns	ns	ns	ns	ns	ns
	Cu	ns	ns	ns	ns	ns	ns
Slope	pH	ns	ns	ns	ns	ns	ns
	OM	ns	ns	ns	ns	ns	ns
	Ca	ns	ns	ns	ns	ns	ns
	Mg	ns	ns	ns	ns	ns	ns
	P	ns	ns	ns	ns	ns	ns
	S	neg**	neg**	neg**	neg**	neg**	neg**
	Cu	ns	ns	ns	ns	neg**	neg**
Plan curvature	pH	ns	ns	ns	ns	ns	ns
	OM	ns	ns	neg*	ns	ns	ns
	Ca	ns	ns	ns	ns	ns	ns
	Mg	ns	ns	ns	ns	ns	ns
	P	ns	ns	neg**	neg**	neg**	neg*
	S	*	**	**	**	**	**
	Cu	*	ns	ns	**	*	ns
Specific Catchment Area (SCA)	pH	ns	ns	ns	ns	ns	*
	OM	ns	ns	ns	ns	ns	ns
	Ca	ns	ns	ns	ns	ns	neg*
	Mg	ns	ns	ns	ns	ns	ns
	P	ns	ns	ns	ns	ns	neg*
	S	**	**	**	**	**	**
	Cu	ns	ns	ns	ns	ns	ns
Topographic Wetness Index (TWI)	pH	ns	ns	ns	ns	ns	ns
	OM	ns	ns	ns	ns	ns	ns
	Ca	*	*	*	*	ns	ns
	Mg	ns	*	*	ns	ns	ns
	P	neg*	neg**	neg*	neg**	neg**	neg**
	S	**	**	**	**	**	**
	Cu	**	**	**	**	ns	ns

** and * refer to 0.01 and 0.05 levels of significance, respectively; "neg" refers to a negative correlation; "ns" refers to a non-significant correlation.

Dr. Wu (wuwei_star@163.com) is Associate Professor, College of Computer & Information. Mr. Wang and Dr. Liu (lhbin@swu.edu.cn) are Professors, College of Resources & Environment, Southwest University, Chongqing, China.

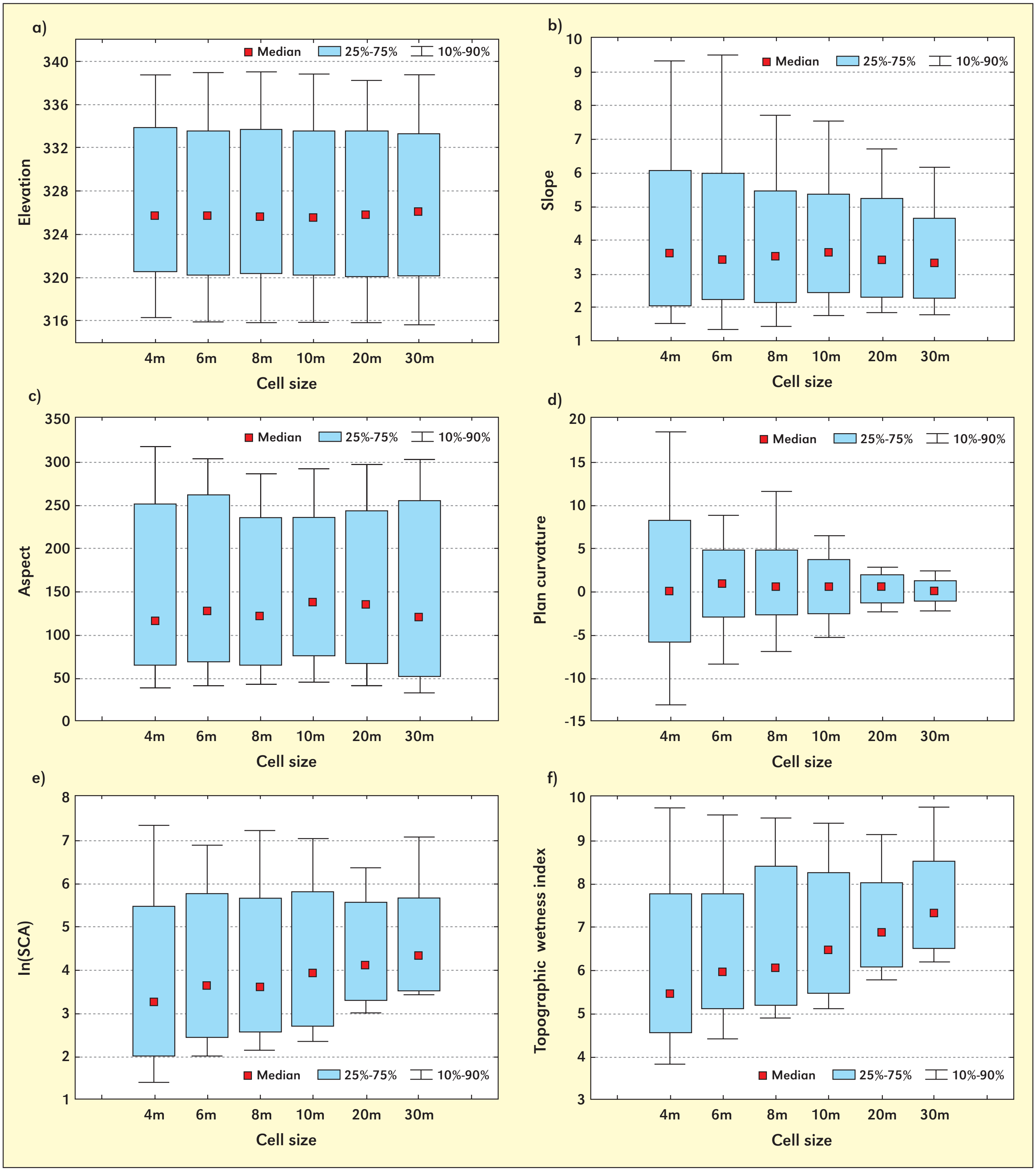

Figure 3. Values of topographic indices for different DEM resolutions a) Elevation, b) Slope, c) Aspect, d) Plan curvature, e) Natural logarithm of Specific Catchment Area (SCA), f) Topographic wetness index, respectively (median and percentiles).

References

ESRI. 1995. ARC/INFO Software. Environmental Systems Research Institute, Redlands, California, USA.

Hutchinson, M.F. 1995. Centre for Resource and Environmental Studies, Australian National University, Canberra.

Moore, I.D., R.B. Grayson, A.R. Ladson. 1991. Hydrol. Processes 5, 3-30.

Moore, I.D., P.E. Gessler, G.A. Nielsen, and G.A. Peterson, 1993. *In* P.C. Robert et al. (Eds.) Soil Specific Crop Management. ASA, CSSA, and SSSA, Madison, WI. 27-5.

Portch, S. and A. Hunter. 2002. Special Publication No. 5, PPI/PPIC China Program. pp. 1-62.