Journal of the Arkansas Academy of Science

Volume 64 Article 25

2010

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Abstract

Digital Elevation Models (DEMs) represent the elevation of the earth's surface. Scientists and decision makers have used DEMs to address questions relating to the earth's landscape. This study assessed the vertical accuracy of Arkansas 5-meter raster DEM dataset produced in 2006 photogrammetrically, for three physiographic regions that represented a variation of elevations. The vertical accuracy of the DEM datasets was assessed by comparing their elevations to elevations collected using a surveying carrier phase Global Position System (GPS). To make comparisons between physiographic regions, paired t-tests using absolute elevation value difference and elevation difference along with the Absolute Mean Range Value (AMRV) was also computed. The results of the study revealed that 5-meter DEM is statistically different from the true elevation for the state with a mean absolute difference elevation error of 2.90 meters. The mean absolute elevation error for the Boston Mountains, the Ouachita Mountains, and the Mississippi Alluvial Plain physiographic regions are 4.98, 2.81, and 1.06 meters, respectively. The absolute mean range value (AMRV) revealed that in the Mississippi Alluvial Plain, the DEM might be problematic, since there is more error fluctuation (AMRV = 12.421%) across a smaller distribution of true elevation values compared to 1.283% for the Boston Mountains and 1.271% for the Ouachita Mountains physiographic regions.

Introduction

With the increased demand for the earth's limited resources, reliable assessments of landscapes are needed for natural resource conservation and for the understanding of human impacts on natural resources (Smith and Atkinson 2001). In the past, Geographic Information Systems (GISs) were used primarily as a descriptive tool, but now, they are also used as a tool for decision-making (Weih and Smith 1990). With a GIS it is possible to examine a host of realistic decision-making scenarios, from solid-waste disposal to location of schools and fire stations, zoning, land use decisions, and evaluation of development plans (Goodchild and Palladino 1995). When decisions are made based on GIS analysis, one should not only consider the validity of the decision formulated, but also the accuracy of the data used to derive the decision. Because these decisions directly affect the public, making sure that the highest quality data is used for decision-making may be the most important step in any decision-making process.

A GIS can model surfaces in three general ways: as contour lines or isolines, as a triangulated irregular network (TIN), or as a raster surface (Zeiler 1999). An example of a dataset that uses contour lines to enhance surface visualization is a United States Geological Survey's (USGS) quadrangle map. Triangulated irregular networks consist of vector data that partition geographic space into contiguous, non-overlapping triangles such that the vertices of each triangle are data points with x, y, and z values (Kennedy 2001). A surface raster is a spatial data model made of rows and columns of cells where each cell contains an attribute value and location coordinates that are contained in the ordering of the matrix. An example of a surface raster is the DEM data product produced by the USGS (Weih and Smith 1996). Raster surfaces are the most common representations of surfaces because elevation data is widely available in this format (Zeiler 1999).

With the increased availability of DEMs and the advancement of computerized terrain analysis tools, it is possible to quantify the topographic attributes of a landscape (Gallant and Wilson 1996). Digital elevation models are 2-D representations that describe elevations of the earth's surface, and through manipulation in a GIS, they may be converted into 2.5-D representations to enhance visualization. From these DEMs, calculations such as slope and aspect may be modeled. The resolution of the DEM and the accuracy affects the results of these models (Weih and Mattson 2004). With the increased use of DEMs in GISs for decision-making, the accuracy of the data is an important issue that should be examined. All published maps and datasets produced by the USGS must adhere to the National Map Accuracy Standards (United States Geological Survey 2010). Even though USGS DEMs adhere to the National Map Accuracy Standards, one must realize that errors do exist in the datasets and must be examined to realize the limitations of the information obtained from the datasets and the magnitude of these errors. The objective of this study was to determine if a significant difference exists and to quantify the differences between GPS field elevations taken with survey grade Global Position System (GPS) units and elevations obtain from the Arkansas 5-meter DEM created in 2006.

Materials and Methods

Study Sites

Because topographic surface roughness may affect the accuracy of DEMs, three physiographic regions with a wide variation of terrain characteristics were chosen for the study. The variation in topographic relief provided a means to determine how different gradients of terrain variation affected the vertical accuracy in DEMs. The physiographic regions were the Boston Mountains, the Ouachita Mountains, and the Mississippi Alluvial Plain. Figure 1 shows the location of the three physiographic regions in Arkansas. In each physiographic region, three study sites were selected, each in an individual USGS quadrangle. Each study site is approximately 4.8 x 4.8 km in area consisting of approximately 2,330 hectares. In summary, there were three physiographic regions, with each one having three study sites, or nine study sites sampled.

The Boston Mountains province covers the northwestern corner of Arkansas. This physiographic region covers an area of 103,599 sq. km and includes parts of four states: Arkansas, Kansas, Missouri, and Oklahoma (U.S. Department of Agriculture, Forest Service 1999). The most striking feature of the Boston Mountains is the rugged topography, which consists of flat-topped mountains that are more than 610 meters higher than the lowlands of the southern half of the state (Foti and Hanson 1992). This highly variable landscape was intended to describe how DEMs respond to areas of significant elevation changes over short distances. The Boston Mountains study sites were in the Oark, Boston, and Ozone quadrangles.

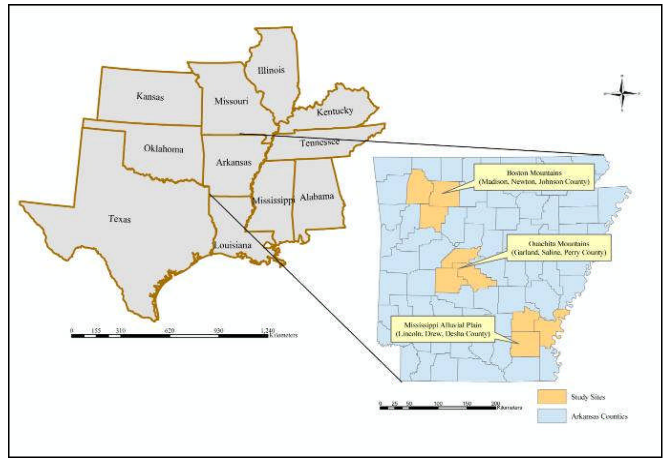

Figure 1: Locations of physiographic regions in Arkansas

The second region is located in the Ouachita Mountains, which is south of the Boston Mountains. Although this area is considered a mountainous region, the topography is considerably different from the Boston Mountains in respect to landform. While the Boston Mountains have flat-topped mountains, the Ouachita Mountains consist of long, narrow ridges running from east to west (Foti and Hanson 1992). Altitudes of land in the Ouachita Mountains range from less than 91 meters to more than 838 meters above sea level. This region was intended to reveal how DEMs respond to areas of intermediate and constant elevation. The Ouachita Mountains study sites were in the Jessieville, Nimrod SE, and Paron SW quadrangles.

The third region was located in the Mississippi Alluvial Plain. This area, when compared with the previous two, consists of gently rolling hills to flat bottomlands (Foti and Hanson 1992). Because this area has small elevation differences, it was intended to answer how DEMs respond to areas of low and constant elevation over large distances. The Mississippi Alluvial Plain study sites were in the Winchester, Kelso, and McArther quadrangles.

Digital Elevation Model

The Arkansas 5-meter DEM used in this study was collected as an ancillary product of a statewide orthophoto acquisition using a Lecia ADS40 digital pushbroom sensor. EarthData International processed the data. The coordinate system used was Universal Transverse Mercator projection (UTM) on the North American Datum of 1983 (NAD83). The aerial imagery acquired between January 15 and March 31, 2006 was used to create the 5-meter DEM. EarthData processed a Digital Surface Model (DSM) dataset to identify and remove the majority of elevation points falling on vegetation, buildings, and other above ground structures to generate the 5-meter Digital Terrain Model (DTM) or Digital Elevation Model (DEM) as referenced in this study.

Ground Elevation Sampling

Since accurate elevation measurements were needed to determine the accuracy of the DEM datasets, the study sites were sampled with survey grade Global Positioning Systems (GPS). Dual-frequency carrier phase GPS was chosen rather than mapping-grade GPS due to inaccuracies of mapping-grade GPS in determining elevation. Dual-frequency GPS can model and remove not all, but a significant portion of the ionosphere bias, and it is not affected by selective availability because actual phase measurements are used for the GPS measurements (Van Sickle 2001).

These measurements allowed comparisons to be made between the elevations of the observed field point positions and the corresponding locations found in the DEM. For this study, a post-processed, fast static survey using Trimble Model 4700 GPS receivers in combination with a Micro Centered L1/L2 antenna, and a TCSI data collector was used. The data was processed to determine the horizontal position and vertical elevation of all ground control points. All horizontal GPS measurements were converted to Universal Transverse Mercator (UTM) coordinates and elevation data converted to topographic surface elevation represented in meters. This was assumed the true location and elevation for this study. A minimum of 90 sample points were collected per physiographic region, meaning there were approximately 30 sample points per study site. All GPS observations were located at least 100 meters from any other sample point. The Survey GPS elevation values were considered the true elevation for each location.

Results

A paired t-test was used to determine if there was a significant difference between DEM elevation values and true elevation values. A significance level of $\alpha = 0.05$ was used for tests in this study. The absolute elevation difference value was tested. However, inferences about the magnitude of elevation error in relation to overestimation and underestimation could not be determined with this particular test. To gain an understanding of the magnitude of elevation error in relation to overestimation and underestimation elevation difference analyses were done using paired t-tests. Tests were performed for each physiographic region (global basis), per physiographic region (regional basis), and per study site (study site basis). This approach was used instead of using the root mean square error so comparisons could be made with the mean difference.

The AMRV measurement allowed the absolute mean elevation difference found for each DEM dataset to be normalized relative to the range of true elevation values so that comparisons could be made between physiographic region datasets. It was assumed that a population with a large range of true elevation values tended to have a larger absolute mean difference (AMD) value due to the variability in the population. However, this does not necessarily mean that datasets with smaller absolute mean elevation differences have less error.

The following formula was used for AMRV:

$$\text{AMRV} = \left(\frac{\text{AMD}}{\text{Range}}\right)(100\%) \qquad (1)$$

where:

AMD = the absolute mean difference computed by subtracting true elevation values from the 5-meter DEM elevation values and calculating the mean of the absolute value difference

Range = the difference between the maximum and minimum true elevation values in the study area

AMRV = absolute mean range value.

When true elevation values were subtracted from corresponding 5-meter DEMs to determine absolute elevation difference on a global basis, statistically (Table 1) there was a difference in elevation. The mean absolute difference determined on a global basis was 2.899 meters (Table 2). Mean absolute differences found on a regional basis varied. The mean absolute difference for the Mississippi Alluvial Plain was found to be quite small (1.057 meters) when compared to the Boston Mountains (4.976 meters) and Ouachita Mountains (2.807), on average, had larger mean absolute differences (Table 2). Study sites in the Ouachita Mountains, except Paron SW, had less mean

Table 1 Comparison of true elevation values and 5-meter DEM elevation values

Area	Number of Samples	Absolute Difference[1] (meters) t-value	Absolute Difference[1] (meters) p	True Difference[2] (meters) t-value	True Difference[2] (meters) p
Combined physiographic entities	303	13.887	<0.0001*	-0.326	0.7445
Boston Mountains	96	9.850	<0.0001*	-1.900	0.0605
Ouachita Mountains	104	10.335	<0.0001*	3.426	0.0009*
Mississippi Alluvial Plain	103	10.504	<0.0001*	-1.954	0.0534
Oark	33	6.749	<0.0001*	-0.200	0.8425
Boston	31	5.963	<0.0001*	0.550	0.5863
Ozone	32	5.780	<0.0001*	-2.866	0.0074*
Jessieville	34	5.012	<0.0001*	-0.847	0.4029
Nimrod SE	31	6.463	<0.0001*	1.738	0.0925
Paron SW	39	8.454	<0.0001*	3.940	0.0003*
Winchester	39	7.254	<0.0001*	-2.193	0.0345
Kelso	34	8.346	<0.0001*	6.708	<0.0001*
McArthur	30	6.751	<0.0001*	-3.778	0.0007*

[1] Absolute differences were computed by subtracting true elevation values from corresponding 5-meter DEM elevation values and taking the absolute value

[2] True differences were computed by subtracting true elevation values from corresponding 5-meter DEM elevation values

* Significantly different at $\alpha = 0.05$

absolute differences when compared to the Boston Mountains (Table 2). Study sites in the Mississippi Alluvial Plain had a mean absolute difference less than one meter except for Winchester.

Based on the results found by performing an elevation error magnitude analysis on the true elevation difference, it was found that 5-meter DEMs underestimated elevations for the Mississippi Alluvial Plain and Boston Mountains while overestimating elevations for the Ouachita Mountains.

Absolute mean range value (AMRV) was computed on a global, regional, and per study site (Table 2). On a regional basis, the AMRV was consistently higher for the Mississippi Alluvial Plain in comparison to the other physiographic regions, with AMRV being similar for the Boston and Ouachita Mountains (Table 2). This same trend was also found on a per study site basis.

Discussion and Conclusions

The 5-meter DEM statistically did not accurately model surface elevations for all the study areas when considering just absolute elevation value differences (Table 1). Examining just the elevation differences, elevation was underestimated by the 5-meter DEM except for the Ouachita Mountains. The reason the Ouachita Mountains were overestimated could be that the 5-meter DEM was created photogrammetrically and the conifer trees were not effectively removed from the DEM. This physiographic region had a higher density of pine trees than the other regions.

The objective of this study was not only to examine accuracy, but also to examine the magnitude of the errors. One can expect to be within mean absolute elevation difference of 2.90 ± 0.41 meters statewide using the 5-meter DEM (Table 3). The error will be highest in the Boston Mountains (4.98 ± 1.00 meters) and lowest in the Mississippi Alluvial Plain (1.06 ± 0.41 meters). Even though the lower error was in the Mississippi Alluvial Plain, the magnitude of the error will be greater with an AMRV of 12.421% (Table 2). A substantial amount of elevation error existed in a smaller range of true elevation values. It was observed that as variability in topographic elevation increased, error in the 5-meter DEM elevation values also increased.

This hypothesis was also supported in a study performed by Isaacson and Ripple (1990). They compared only 30- and 100-meter DEMs for the Echo Mountain SE quadrangle in the Cascade Mountains of Oregon. Isaacson and Ripple (1990) calculated the mean elevation difference between 100- and 30-meter DEMs for their entire study area was 31 meters. They also stated most of the higher differences appeared to be associated with steeper slopes.

It has been emphasized that the use of accurate data must be the most important function in the decision-making process. This study demonstrated that 5-meter DEM has different magnitudes of elevation

Table 2. Mean, minimum, and maximum attributes for absolute and true differences for 5-meter DEM

	Absolute Difference[1] (meters)			AMRV[2] %	True Difference[3] (meters)		
Area	Mean	Min	Max		Mean	Min	Max
Combined physiographic entities	2.899	0.021	33.621	0.425	-0.0872	-33.621	19.014
Boston Mountains	4.976	0.200	33.621	1.283	-1.339	-33.621	19.014
Ouachita Mountains	2.807	0.067	12.203	1.271	1.258	-7.441	12.203
Mississippi Alluvial Plain	1.057	0.021	5.318	12.421	-0.279	-3.439	5.318
Oark	4.739	0.695	18.189	1.963	0.219	-18.189	10.447
Boston	3.465	0.200	15.197	2.064	0.470	-7.542	15.197
Ozone	6.684	0.613	33.621	2.742	-4.248	-33.621	19.014
Jessieville	1.507	0.067	8.531	1.331	-0.334	-5.666	8.531
Nimrod SE	2.176	0.078	8.855	2.579	0.863	-3.746	8.855
Paron SW	4.443	0.184	12.203	2.665	2.961	-7.441	12.203
Winchester	1.539	0.071	5.318	18.085	-0.677	-3.439	5.318
Kelso	0.596	0.034	1.608	19.669	0.550	-0.672	1.608
McArthur	0.952	0.021	2.615	26.817	-0.699	-2.615	1.694

[1] Absolute difference were computed by subtracting true elevation values from corresponding 5-meter DEM elevation values and taking the absolute value
[2] AMRV represents the absolute mean range value
[3] True differences were computed by subtracting true elevation values from corresponding 5-meter DEM elevation values

error. Even though errors exist in this DEM, scientists and decision-makers must realize these datasets are important, and must consider the trade-offs when choosing datasets of higher accuracies. Even though the 5-meter DEM did not statistically represent the true elevation surface, it is still a valuable data set. It is currently the highest spatial resolution DEM available for the state of Arkansas.

Table 3. Comparison of 95% confidence intervals of the mean absolute elevation differences.

Area	95% Confidence Interval (m)
Combined physiographic entities	2.90 ± 0.41
Mississippi Alluvial Plain	1.06 ± 0.20
Ouachita Mountains	2.81 ± 0.54
Boston Mountains	4.98 ± 1.00

Acknowledgments

This project would not have been possible without the help of many people. Special thanks to David General, Alan Procell, and David Dickson for collecting the GPS data. Also, thanks to the Arkansas Forest Resources Center and the School of Forest Resources at the University of Arkansas at Monticello for its support of this study.

Literature Cited

Foti T and **G Hanson**. 1992. Arkansas and the land. Fayetteville: The University of Arkansas Press. 113 p.

Gallant JC and **JP Wilson**. 1996. Tapes-G: a grid-based terrain analysis program for the environmental sciences. Computers and Geosciences 22:713-22.

Goodchild MF and **SD Palladino**. 1995. Geographic information systems as a tool in science and technology education. Speculations in Science and Technology 18:278-86.

Isaacson DL and **Ripple WJ**. 1990. Comparisons of 7.5-minute and 1-degree digital elevation models. Photogrammetric Engineering and Remote Sensing 56:1523-7.

Kennedy H. 2001. Dictionary of GIS terminology. Redlands, CA: Environmental Systems Research Institute, Inc. 116 p.

Smith DP and **Atkinson SF**. 2001. Accuracy of rectification using topographic map versus ground control points. Photogrammetric Engineering & Remote Sensing 67:567-70.

United States Department of Agriculture, Forest Service. 1999. Ozark-Ouachita Highlands Assessment: aquatic conditions. Report 3 of 5. Gen. Tech. Rep. SRS-33. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 317 p.

United States Geological Survey. 2010. USGS Map Accuracy Standards: USGS Map Accuracy Standards Fact Sheet FS-171-99. Available at: erg.usgs.gov/isb/pubs/factsheets/fs17199.html. Accessed 2010 July 20.

Van Sickle J. 2001. GPS for land surveyors. Chelsea, MI: Sleeping Bar Press. 284 p.

Weih RC and **TJ Mattson**. 2004. Modeling Slope in a Geographic Information System. Journal of the Arkansas Academy of Science. 58:100-8.

Weih RC and **JL Smith**. 1990. Characteristics and Limitations of USGS Digital Elevation Models. Proceedings of the 1990 Landuse Management Conference: 139-47.

Weih RC and **JL Smith**. 1996. The Influence of Cell Slope Computation Algorithms on a Common Forest Management Decision. Proceedings, Seventh International Symposium on Spatial Data Handling. Delft, Netherlands. Taylor & Francis. 13A.29-13A.48.

Zeiler M. 1999. Modeling Our World, The ESRI Guide to Geodatabase Design. Redlands, CA: Environmental Systems Research Institute, Inc. 199 p.