COMPARISON OF USGS AND SHUTTLE RADAR TOPOGRAPHY MISSION DIGITAL ELEVATION MODELS

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ABSTRACT

The main purpose of this study was to compare accuracies of three Digital Elevation Model (DEM) data sets, 10m and 30m USGS DEMs and 30m Shuttle Radar Topography Mission (SRTM) DEM. BASINS program of US EPA was used for automatic watershed delineation. A USGS Hydrological Unit Coverage (HUC) and a satellite image were used for an accuracy assessment. The watershed boundary delineated by the 10m USGS DEM provided the best fit to the HUC. While the 30m USGS DEM showed a relatively accurate watershed boundary, the 30m SRTM DEM provided a more accurate delineation. The 30m SRTM DEM also showed a better correlation with the 10m USGS DEM than the 30m USGS DEM in estimating four watershed parameters: subbasin area, stream reach length, subbasin slope, and reach slope. The 10m USGS DEM had the most accurate terrain parameters as compared to the 30m DEM datasets. An interesting finding was the closer correlation of the estimated terrain parameters of the 10m USGS DEM to the SRTM than to the 30m USGS DEM. This study showed that the 30m SRTM DEM provided better accuracies than the 30m USGS DEM in automatic watershed delineation.

INTRODUCTION

Digital Elevation Models (DEM) provide essential information for watershed related studies. Geographic Information Systems (GIS) make it possible to implement automated methods to delineate basins and drainage networks to extract several terrain parameters from DEMs (Tribe, 1992; Martz and Gabrecht ,1998). Despite its wide use, it is difficult to create an accurate DEM because of the high cost of the acquisition and processing of aerial photography or other high resolution remotely sensed data. To minimize this problem, stereo pairs of satellite images, such as SPOT, have been used to generate DEM data. SPOT-derived DEM data have provided adequate accuracy for basin-wide hydrogeomorphology but failed to match the equivalent accuracy of the 7.5-minute USGS DEMs at scales finer than 100m (Endreny et al. , 2000). According to Walker and Willgoose (1999), the accuracy of published DEM data (Cartometric and Photogrammetric DEMs) is unreliable for estimating the topographical and geomorphologic parameters necessary for hydrological modeling.

Shuttle Radar Topography Mission (SRTM) provides a global scale DEM coverage at 30m spatial resolution, which is compatible to the 7.5-minute USGS DEMs. The strength of the SRTM data is the relatively high spatial resolution and the global coverage. Unlike the aerial photography-based USGS DEM data, the global coverage of the SRTM DEM provides an opportunity for landscape research especially when data availability is an issue. Usually it is difficult, if not impossible, to obtain aerial-photography of remote landscapes in a developing country. Although the SRTM DEM provides critical terrain information about landscapes where the terrain data are not available or difficult to obtain, caution should be exercised using the SRTM DEM data in a watershed study because of the accuracy of the SRTM DEM in deriving terrain information has not been fully verified. Due to the nature of the shuttle radar sensor, the SRTM DEM is subject to more significant sensor problems than the aerial-photograph-based DEM. Most of sensor-related problems are corrected in a DEM generating process. For example, the radar sensor tends to create speckle noise that can significantly affect watershed boundary or stream channel delineation.
The effects of spatial resolution of the DEM on delineation of watershed boundaries and channel networks are well documented (Hutchinson and Dowling, 1991; Veregin, 1997; Bates et al., 1998; Graham et al., 1999; Zhang et al., 1999; Ma et al., 2000; Wolock and McCabe, 2000). Flow-routing algorithms utilizing DEMs has also been studied (Quinn et al., 1991, 1995; Costa-Cabral and Burges, 1994; Desmet and Govers, 1996; Moore, 1996; Wilson et al., 2000). The choice of an appropriate flow-routing algorithm is a significant factor affecting the terrain parameters for watershed modeling.

The objective of this study was to compare the accuracy of the estimated primary topographic factors obtained from 10m and 30m USGS DEMs and 30m SRTM DEM using the automated watershed delineation algorithm of USEPA BASINS.

**STUDY AREA**

The study area is the drainage basin of the Little River of western Kentucky and Tennessee (Figure 1). The man-made lakes, Kentucky Lake and Lake Barkley, in the area are very important for recreation, flood control, power generation, and transportation. Little River is the largest watershed surrounding the Land Between Lakes (LBL) and contains little urban land use (Figure 1). The gentle landscape of this watershed with intensive agricultural land use provides an ideal situation to compare the accuracy of three different DEM data sets. The study area belongs to the Mississippian System (McFarlan, 1943) with many basins and sinkholes, characteristics of karst topography. There are some surface branches and streams, but much of the runoff from rainfall enters underground streams through sinkholes and basins. The elevation in the area ranges from about 360 to 550 feet (109.73 to 167.64m).

![Figure 1. The image showing the Little River Drainage Basin of western Kentucky and Tennessee](image)
METHODS

Although DEMs are available from a variety of sources, USGS DEMs have been the most widely used, reasonably accurate digital elevation data employed in the US. For this study, three digital elevation data sets, 10m- and 30m USGS DEMs, and 30m SRTM DEM, were used. The vertical accuracy of the 30m USGS DEM dataset was 15 meters or better (USGS, 1994). The absolute horizontal and vertical accuracy of SRTM DEM is 20 meters (circular error at 90% confidence) and 16 meters (linear error at 90% confidence), respectively (USGS, 2005).

The ArcView-based BASINS extension program was utilized to delineate stream line and watershed boundaries automatically. The DEM data sets were preprocessed to fill sinks in the digital elevation data. The sink-filled elevation data were processed to compute flow direction and accumulation to delineate streamlines and watershed boundaries. The minimum pixel number for stream initiation was set to 3000 pixels for the comparison of the stream line delineation and 10000 pixels for the comparison of the subbasin boundary and the USGS 14-digit HUC boundary. Different numbers for stream initiation were set because subbasins delineated with a 3000 pixel setting for stream initiation were too small to compare to the USGS 14-digit HUC subbasin polygons. Moreover, the stream lines delineated with a 10000 pixel setting for stream initiation were too simplified.

Correlation analyses of the three DEM data sets was used to determine the relationship among the three DEM data sets. To compare the results of the automatic delineation of the DEM data sets visually, the streamlines and drainage basin boundaries of the DEM data sets were overlaid on a SPOT 10m panchromatic image and 10m USGS DEM for accuracy assessment(Figures 2 and 3). USGS 14-digit Hydrological Unit Coverage (HUC) polygon data were used to assess the accuracy of the automatic delineation of the watershed boundaries. For the reference data of the streamlines, the ideal data set was USGS National Hydrography Dataset (NHD); however, since the drainage basin had typical karst topography, many streamlines in the NHD coverage were discontinuous line segments. Thus, it was difficult to use the NHD data as a reference dataset because the automatically delineated streamlines of the DEM data sets were produced from the sink-fill preprocessed DEM data with no discontinuous streamlines.

To quantify the difference of the delineated streamlines, the shortest distances between the delineated streamlines of the three DEM data were measured and randomly sampled to compare the results. The sampled random points with three distance values between the streamlines of the DEM data sets were tallied for three groups based on the shortest distance value of each random point. The difference values were compared to show the relative magnitudes of the difference among the streamlines of the DEM data sets.

Subbasin areas and the total stream length for the three DEM data sets were also compared. Despite the same settings used for the DEM data sets and the similar total delineated subbasin polygons (about 100 subbasins), the automatically delineated subbasin polygons were significantly different from the USGS 14-digit HUC in a lower drainage area. It was quite difficult to compare all subbasin polygons directly, so 40 subbasin polygons that showed close shape similarity were selected and compared using correlation coefficients and scatter plots for four parameters of each subbasin (area (ha), stream reach length (m), subbasin slope (%), reach (longest path) slope (%)).

RESULTS AND DISCUSSION

The correlation coefficients (all greater than 0.97) suggested the closeness among the three DEM data sets, an expected result as the target landscape was rather flat and the spatial resolution of the source DEM data was relatively close. The correlation coefficient of the 10m USGS DEM – SRTM 30m DEM pair was the highest (0.998). The difference between the correlations for the 10m and 30m USGS DEMs vs. the 30m SRTM DEM was just 0.021. This was unexpected because it was thought that the 10m and 30m USGS DEMs would have the highest correlation coefficient (Table 1).

When the delineated streamlines of the DEM data sets were overlaid, all the streamlines showed close matches in general, while the streamlines of the coarser spatial resolution DEMs, the 30m USGS DEM and the SRTM DEM, showed quite similar discrepancies to the stream line of the 10m USGS DEM in some areas.
Figure 2. Watershed boundary of the Little River Basin generated using the 10m and 30m USGS DEMs, and the 30m SRTM DEM

Figure 3. Three sub-watershed areas with the significant difference in the delineated watershed boundaries using the 10m and 30m USGS DEMs, and 30m SRTM DEM
Table 1. Correlation coefficients for the three DEM datasets

<table>
<thead>
<tr>
<th>DEM Dataset</th>
<th>Correlation Coefficient</th>
</tr>
</thead>
<tbody>
<tr>
<td>30m USGS DEM – 30m SRTM DEM</td>
<td>0.977</td>
</tr>
<tr>
<td>30m USGS DEM – 10m USGS DEM</td>
<td>0.989</td>
</tr>
<tr>
<td>10m USGS DEM – 30m SRTM DEM</td>
<td>0.998</td>
</tr>
</tbody>
</table>

The overlaid streamlines generally did not show any significant discrepancies in the lower watershed but, when they were compared for the upper watershed area, the discrepancies of the overlaid streamlines became significant in some areas. The relatively flat topography of the study area made it difficult to delineate the precise streamlines automatically, except using the 10m DEM data set. While both streamlines of the 30m USGS and SRTM DEMs showed similar discrepancies with the SPOT image, the 10m USGS DEM showed the best stream line matching with the SPOT image, so we used the delineated stream lines of the 10m USGS DEM as a reference. In some areas, the 30m USGS DEM showed much closer streamlines to the 10m USGS DEM but the visual comparison of the delineated stream lines of the three DEM data sets was difficult to quantify.

To get around this problem, the shortest distance between the streamlines produced from each DEM data set was measured and random points were sampled to compare the accuracies of the 30m USGS DEM and the 30m SRTM DEM. As mentioned above, the 10m USGS DEM was used as a reference because the delineated streamline of the 10m USGS DEM was well matched with the SPOT image. Table 2 shows that more random points had the least shortest distance between the delineated streamlines of the 30m SRTM – the 10m USGS DEMs and the total distance difference value of these random points was the smallest one. Contrary to this result, fewer random points had the smallest shortest distance between the delineated streamlines of the 30m USGS – the 10m USGS DEMs and the total distance difference value of these random points was much larger than that of the 30m SRTM – the 10m USGS DEMs. The results shown in Table 2 clearly suggested that the delineated streamlines of the 30m SRTM – the 10m USGS DEMs were the closely matched to each other and the streamlines of the 10m USGS – the 30m USGS DEMs were showing the greatest difference in terms of the sampled random points, if not in terms of the total distance difference. Despite more random points with the shortest distance between the 30m SRTM – the 30m USGS DEMs than between the 30m USGS – the 10m USGS DEMs, the largest total distance difference of the 30m SRTM – the 30m USGS DEMs suggested that the relative difference of the streamlines was more significant between the 30m SRTM – the 30m USGS DEMs than between the 30m USGS – the 10m USGS DEMs.

Table 2. Distance discrepancy of the delineated stream lines

<table>
<thead>
<tr>
<th>Distance</th>
<th>Number of points with shortest distance among three measurements of stream line</th>
<th>Total distance difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>30m USGS DEM – 30m SRTM DEM</td>
<td>0.977</td>
<td>0.977</td>
</tr>
<tr>
<td>30m USGS DEM – 10m USGS DEM</td>
<td>0.989</td>
<td>0.989</td>
</tr>
<tr>
<td>10m USGS DEM – 30m SRTM DEM</td>
<td>0.998</td>
<td>0.998</td>
</tr>
</tbody>
</table>

In terms of the subbasin delineation, the 10m USGS DEM again showed the best match with the USGS 14-digit HUC subbasin polygon, while both the 30m USGS DEM and SRTM DEM showed some degree of discrepancy. The major watershed boundaries of the three DEM data sets matched generally well with the USGS HUC polygons, especially the 10m DEM. While the 30m USGS DEM and SRTM DEM showed very similar watershed boundaries, both DEM data sets differed somewhat from the USGS HUC polygon in the southern part of the watershed. From the overlay it was difficult to determine which DEM data set, the 30m USGS DEM or SRTM DEM, was more accurate because the subbasin delineated on both DEM data sets did not show significant differences. The total subbasin area of the 30m USGS DEM was closer to that of the 10m USGS DEM than to the SRTM DEM, but the
Table 3. The total subbasin areas and stream reach lengths

<table>
<thead>
<tr>
<th>DEM Dataset</th>
<th>Total Subbasin Area (hectares) (40 subbasin subset)</th>
<th>Total Stream Reach Length (40 subbasin subset)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10m USGS DEM</td>
<td>154975.05 (73599.89)</td>
<td>926372.28 (405258.17)</td>
</tr>
<tr>
<td>30M USGS DEM</td>
<td>155158.74 (74201.04)</td>
<td>852095.29 (372181.22)</td>
</tr>
<tr>
<td>30M SRTM DEM</td>
<td>155630.52 (73615.95)</td>
<td>884602.78 (387635.61)</td>
</tr>
</tbody>
</table>

difference between the 30m USGS DEM and the SRTM DEM was less than 500 hectare (Table 3). The 30m USGS DEM and the SRTM DEM did not delineate the watershed boundary in the southern part of the watershed accurately (Figures 2 and 3). Table 3 shows the delineation problem in terms of the total subbasin area. Contrary to the total subbasin area results, the total stream reach length of the 30m USGS DEM showed a wider difference with the 10m USGS DEM than the SRTM DEM.

As described before, to compare the subbasin delineation, we selected 40 subbasin polygons with higher similarity. When the 40 subbasin polygons were compared (Table 3), the 30m SRTM DEM showed closer values of the total subbasin area and the total stream reach length than that of the 30m USGS DEM values to those of the USGS 10m DEM.

The scatter plots of the 40 polygons with four different parameters (area, stream reach length, subbasin slope, reach (longest path) slope) showed similar accuracies for the 30m USGS DEM and SRTM DEM, while the SRTM DEM provided significantly lower correlation coefficients than the 30m USGS DEM (Figure 4a). In stream reach length, despite of the better correlation coefficient of the 30m USGS DEM, both DEMs showed similar spread pattern (Figure 4b). For subbasin slope (Figure 4c), the SRTM DEM showed consistently higher slope than the 30m USGS DEM, except for two subbasin polygons. Compared to the 10m USGS DEM, while the 30m USGS DEM provided lower slope in all 40 subbasins, the SRTM DEM showed higher slope in 10 subbasins of the 40 subbasins. The total absolute difference in slope was half that of the 30m USGS DEM suggesting that the SRTM DEM estimated slope much better than the 30m USGS DEM when compared to the 10m USGS DEM. The SRTM DEM provided higher correlation coefficients than the 30m USGS DEM for reach slope (Figure 4d).

**CONCLUSIONS**

In summary, the utility of the available SRTM DEM data set for watershed modeling was evaluated by comparing it to conventional 10m- and 30m USGS DEMs. The 10m USGS DEM had the most accurate terrain parameters as compared to the 30m DEM datasets. An interesting finding was the closer correlation of the estimated terrain parameters of the 10m USGS DEM to the SRTM than to the 30m USGS DEM, unlike our initial expectation. The primary topographic factors including slope showed that the estimates using the 30m USGS DEM showed more discrepancy than the SRTM DEM when compared to the 10m USGS DEM. This study also showed that the SRTM DEM dataset could be used to estimate the topographic factors at least as accurately as the 30m USGS DEM.
**Figure 4.** Scatter plots of the four subbasin parameters (r: Correlation Coefficient)

### REFERENCES


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