CARTOGRAPHIC VISUALIZATION TECHNIQUES FOR COASTAL WATERSHED CHARACTERIZATION

Xiaojun Yang
Department of Geography, Florida State University, Tallahassee, FL 32306, USA; Email: xjyangusa@yahoo.com

ABSTRACT

Coastal watersheds have become the target of numerous interdisciplinary research efforts aiming to assess the condition of these highly dynamic systems in response to intensifying human activities. To what degree that cartography and geographic visualization can contribute to these efforts is an important but neglected research area. The purpose of this paper is to explore the role of cartographic visualization techniques for coastal watershed characterization. The study area, Pensacola estuarine area, is a well-known coastal tourism resort along the Gulf of Mexico in the United States. The data used in this study are quite diverse, which include a variety of biophysical and socioeconomic variables as well as water quality measurements in either discrete (such as points, lines or polygons) or continuous (such as rasters) form. Several cartographic visualization methods are used to help mine the information contained in the large-scale spatial datasets. First, station-based water quality data were transformed into continuous representations by using an ordinary Kriging interpolation algorithm. Second, zonal-based socio-economic data are converted into pixel-based with spatial redistribution through a dasymetric mapping technique. Last, visual analysis of multivariate georeferenced data was conducted by displaying multiple surfaces in an appropriate projection of three-dimensional space and creating fly-over animations. The study concludes that cartographic visualization techniques can increase our ability of interpreting coastal ecosystem data and enhance our understanding of the relationship between landscape conditions and ecological responses.

Keywords: Coastal watershed, dasymetric mapping, three-dimensional perspective, fly-over animation, and visual analysis

1. INTRODUCTION

Coastal areas are the home of nearly 60% of the world’s population. The rapid growth of coastal human population, accompanied by agricultural, industrial, and urban development, has led to an unparalleled acceleration of contaminant and nutrient inputs into coastal estuaries and their watersheds, thus exacerbating environmental stress and degradation of coastal ecosystems throughout the world (Finkl and Charlier 2003; Shi and Singh 2003). Therefore, there is a strong need to find efficient ways to manage and protect these highly sensitive ecosystems (Hobbie 2000).

Starting from 2000, we have been involved in an interdisciplinary research project aiming to develop environmental indicators for integrated estuarine ecosystem assessment in the Gulf of Mexico, USA. Pensacola Bay, as one of the three exemplary large-scale river-driven estuarine systems across the northern Gulf of Mexico, has been selected for detailed research. The study area is actually the Pensacola estuarine drainage area (PEDA) (Figure 1). The PEDA has a total area of 9119 km², including 8643 km² of upstream land and 476 km² of bay waters.

In connection to the above research, we have created a GIS database for environmental and socio-economic conditions in PEDA. The procedures used in the production of this dataset were discussed elsewhere (e.g. Yang and Liu 2005a, 2005b). The current research aims to explore the role of cartography and geographic visualization techniques for mining the information contained in the spatial dataset in order to support coastal watershed characterization. In particular, this research will investigate the casual relationship between

Figure 1: Location of the study area.
watershed landscape and socio-economic variables and estuarine water quality measures. Traditionally, this has been approached by using statistical analysis such as multivariate regression. Here, we will investigate if visual approach could help understand the above relationship.

2. RESEARCH METHODOLOGY

As implied by the scope of this research, the dataset we collected is quite diverse, including a variety of biophysical and socioeconomic variables as well as water quality measurements in either discrete (such as points, lines or polygons) or continuous (such as rasters) form (Table 1). In order to explore the causal relationship between upstream landscape and socio-economic variables and estuarine water quality measurements, we firstly transformed all data layers into continuous representation. This involved the use of two major mapping techniques: spatial interpolation and dasymetric mapping. Spatial interpolation was used to transform water quality data from scattered points into continuous surfaces. This has been done through the use of an ordinary Kriging interpolation algorithm. Dasymetric mapping technique was used to transform census data from discrete into pixel-based continuous form. This involved the use of land use and land cover data for spatial redistribution of zonal-based census measurements.

Table 1: List of major layers in the GIS database.

<table>
<thead>
<tr>
<th>No.</th>
<th>Name of Data Layer</th>
<th>Sources</th>
<th>Format</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Land use and land cover maps (1989, 1996, and 2002)</td>
<td>Created by classifying Landsat imagery</td>
<td>Raster</td>
</tr>
<tr>
<td>2</td>
<td>Landscape pattern and structure measurements (1989, 1996, and 2002)</td>
<td>Created from 1</td>
<td>Discrete form; organized by sub-watershed unit</td>
</tr>
<tr>
<td>5</td>
<td>DEM and Slope</td>
<td>From USGS</td>
<td>Raster</td>
</tr>
<tr>
<td>6</td>
<td>Soil Conservation Service Curve Number (effective runoff)</td>
<td>Computed by using STATGO soil database</td>
<td>Raster</td>
</tr>
<tr>
<td>7</td>
<td>Water quality data (1996 and 2002)</td>
<td>From EPA Gulf Ecology Division</td>
<td>Point</td>
</tr>
<tr>
<td>8</td>
<td>Boundary of sub-watershed</td>
<td>From DEM by using hydrological modeling</td>
<td>Discrete form</td>
</tr>
</tbody>
</table>

Once the data transformation was completed, the next step was to conduct visual analysis. To support this analysis, four cartographic and visualization techniques were applied. First, three-dimensional visualization of spatial data in an appropriate projection; this can give us new perspective and provide insights that would not be readily observable from a planimetric map of the same data. Examples of 3-D perspectives can be found from Figures 2 and 5. Figure 2 is a 3-D perspective of terrain surface with a vertical exaggeration of approximately 70 times. The boundary of sub-watersheds is overlaid on the terrain surface. From this view, it is clear that the terrain in the study area is relatively flat but the difference in height between the stream channels and ridges can be well perceived. Figure 5 is a 3-D perspective of pixel-based population surface with a vertical exaggeration of 6000 times.

Second, image draping technique was used to mathematically "drape" an image over a digital terrain model and then renders the resulting scene from a variety of viewpoints. Since all data layers within the database are at the same projection space, the draping process has been quite straightforward. Examples are given in Figures 3 and 4. Figure 3 was created by draping land use and land data over a digital elevation model. Figure 4 was created by draping the Soil Conservation Service Curve Number map over a digital elevation model.

Third, image overlay technique was used to relate different map layers together so that their visual relationship can be perceived. Examples are given in Figures 6, 7, and 8. The Total Nitrogen surface is overlaid with the terrain surface (Figure 6), or land use and land cover map (Figure 7), or population surface (Figure 8).

Last, several fly-over animations were created by defining some fly paths and navigating over different 3-D surfaces such as the digital terrain model, several image draping surfaces, and some image overlay surfaces. Later on, these
Figure 2: Three-dimensional perspective of terrain surface in the study area. The vertical exaggeration is approximately 70 times. Note that the boundary of four sub-watersheds is shown in white. The image covers an area of approximately 140 X 151 km$^2$.

Figure 3: The 2002 land use and land cover map draped over a digital elevation model. The vertical exaggeration is approximately 70 times. The boundary of four sub-watersheds is shown in white. The image covers an area of approximately 140 X 151 km$^2$.
Figure 4: Soil conservation service curve number (SCS CN) map draped over a digital elevation model. The vertical exaggeration is approximately 70 times. The boundary of four sub-watersheds is shown in black. The image covers an area of approximately 140 X 151 km$^2$.

Figure 5: Three-dimensional population surface that was produced by using dasymetric mapping technique. The vertical exaggeration is approximately 6,000 times. The boundary of four sub-watersheds is shown in black. This image dimension is approximately 140 X 151 km$^2$. Note that several major residential clusters can be clearly identified from this 3-D surface.
Figure 6: The 1996 Total Nitrogen (TN) surface for the Pensacola Bay that is overlaid with a digital terrain model. The TN surface was created from the 1996 annual average of station-based surface water measurements by using kriging interpolation algorithm. This image dimension is approximately 140 X 151 km$^2$.

Figure 7: The 1996 Total Nitrogen (TN) surface for the Pensacola Bay that is overlaid with the 1996 land use and land cover map. The TN surface was created from the 1996 annual average of station-based surface water measurements by using kriging interpolation algorithm. This image dimension is approximately 140 X 151 km$^2$. 
animations were merged to form a movie with other effects added by using a professional movie production software package (Figure 9).

3. RESULT AND CONCLUSIONS

The visual products are very useful for analyzing the relationship between different variables. For example, from Figure 6, we can see that much higher concentration of Total Nitrogen is found near the mouths of several large rivers discharging into the Pensacola Bay. This implies the possible sources of nutrients in the Pensacola Bay. From Figure 7, it is clear that higher concentration of Total Nitrogen can be found along the area where urban land use dominates. This suggests the relationship between land use/cover and the concentration of nitrogen in the Bay. Similarly, Figure 8 offers an insight that the relationship between urban residential clusters and higher concentration of Total Nitrogen. These results are comparable to the analysis we conducted by using multivariate regression (Yang 2005). In conclusion, we found that visual analysis through 3-D viewing, image draping, map overlay, and fly-over animation is quite effective in mining the information contained in the dataset. This can enlarge our understanding of the complex human-environmental interaction in coastal areas.

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REFERENCES

Figure 9: Major technical procedures used in the production of animation: creation of several individual animations by using ArcScene and editing of these animations to create an integrated movie by using Window Movie Maker.


**AUTHOR’S SHORT BIOSKETCH**

Xiaojun Yang received undergraduate and graduate training in geology and geography from China, the Netherlands and United States. He is currently an Assistant Professor of Geography and Environmental Studies at the Florida State University. His research interests are GIS-based spatial data analysis, modeling, and visualization; remote sensing and aerial photography; urban indicators and spatial growth dynamics; environmental indicators and landscape dynamics; and coastal and estuarine ecosystem studies. Xiaojun has been a guest editor for three journals, namely *Photogrammetric Engineering and Remote Sensing (PE&RS)*, *International Journal of Remote Sensing (IJRS)*, and *Computers, Environment and Urban Systems (CEUS)*. He can be reached via email (xjyangusa@yahoo.com) or phone (850-644-8379).