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The Three Gorges Dam from Space

This image was created from merging 15-m resolution panchromatic data with 30-m resolution multispectral data collected by Landsat-7 satellite on November 6, 2000. The dam is under construction near Sandouping in Hubei Province, China.

Constructing an Urban Sphere of Influence Model Using GIS: An Instructional Module

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Abstract

A major concept in urban geography deals with determining the spheres of influence for urban centers. This paper describes an instructional module used in two different geography courses showing students how a model might be developed to measure spheres of influence for multiple urban centers within a given region. A geographic information system (GIS) is employed throughout the development of the model. This module is incorporated into a traditional undergraduate urban geography course and a beginning GIS course. The software packages used are MapViewer and Grapher. The region is the Mississippi Lowlands with five urban centers: New Orlenas, Memphis, Little Rock, Jackson, and Baton Rouge. Keywords: GIS, spheres of influence, MapViewer, urban geography.

Introduction

This paper deals with an instructional module designed to introduce students to how a geographic information system (GIS) can be used to develop a spatial model showing urban spheres of influence. The module is used in two undergraduate geography courses using two different instructional formats. The first course is a junior/senior level GIS course where students receive a large amount of hands on computer work. The second course is a sophomore level urban geography course based on lecture type instruction. The module is built around the Mississippi Lowland region, a large flat alluvial plain extending from the southern tip of the state of Illinois to the Gulf of Mexico and delimited on three sides by hill lands. The region does not have a complex urban environment, which keeps the module relatively simple for student use. The module can be developed around other regions to relate to other courses and instructional environments.

Before being introduced to this module students in the GIS course receive considerable background work on the use of certain GIS software packages and data files. They are also provided with certain established files in order to reduce or eliminate several routine, time-consuming tasks. The problem on how to measure an urban place's sphere of influence is presented to them along with the mathematical/statistical procedures to be followed. Only a limited amount of discussion is given on the topic of urban spheres of influence. The students are to generate a series of maps progressively showing each major step in developing the model. To complete the module takes about four class periods for these students and the class is limited to fifteen students. The students in the urban geography course have been introduced to the concepts and issues associated with urban spheres of influence before the module is presented. These students generally have little or no knowledge about GIS. The instructor using a computer with a projector works the class through the development of the model. The instructor does all of the computer work in class with the results being projected on a large screen. If an instructor does not want the students to view the various mathematical/statistical steps being performed in developing the model, then a series of PowerPoint slides can be developed beforehand and presented to the class. With time for discussion, the module can be generally covered in two one-hour class periods. The enrollment in this class is limited to around thirty students and a number of the students are business majors with interest in marketing.

Mississippi Lowlands - Urban Centers

The study area centers on the Mississippi Lowlands and surrounding hill regions. Figure 1 is a false color image of the study area with the rich agricultural alluvial lowlands appearing in blue and white colors and the forested and hill lands in red. Urban development within the area is not complex in comparison with other regions. Two major urban centers exist, namely New Orleans with a 1994 estimated Metropolitan Statistical Area (MSA) population of 1,309,000 and Memphis with a MSA population 1,056,000.* New

* The MSA population figures mentioned throughout this section were obtained from the U.S. Department of Commerce's *Statistical Abstract of the United States, 1995.*

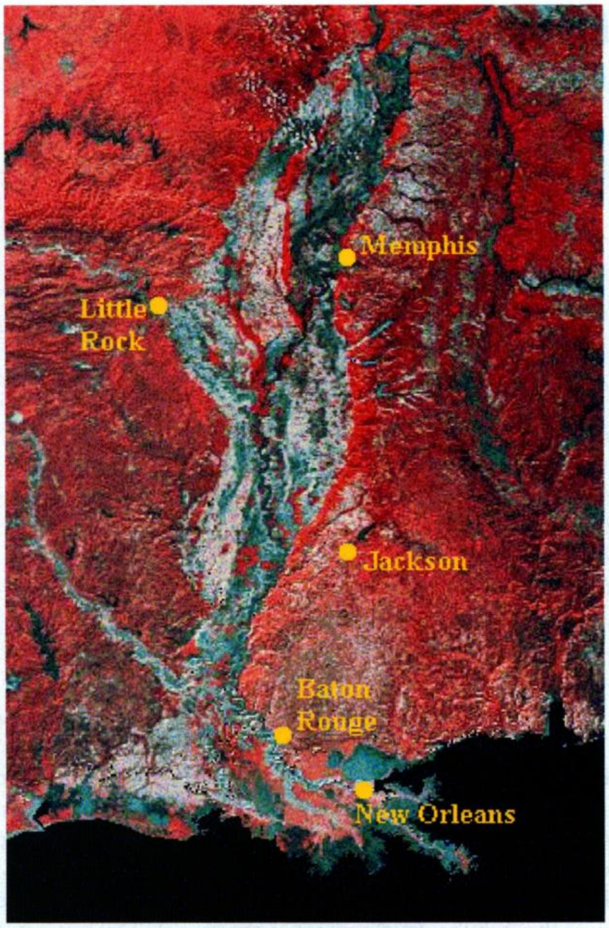

Figure 1 A Satellite View of the Mississippi Lowlands

Orleans represents the port of entry into the region with its major port facilities and break-in-transportation position between ocean going ships and river based boats. Also, nearly everything which flows up or down the Mississippi River eventually goes through New Orleans. Memphis occupies the center of the Mississippi Lowlands, and thereby, attracts a large number of people and activities. Thus, the one urban center controls the major entry path into the area and the other controls the central location. No other urban centers within the region rival these two places in size and importance.

Below New Orleans and Memphis are the urban centers of Little Rock, Arkansas, Jackson, Mississippi, and Baton Rouge, Louisiana. Each of these centers has approximately half the population of the two principal centers. Little Rock's 1994 estimated MSA population was 538,000, Jackson's 412,000, and Baton Rouge's 555,000. Little Rock is centrally located in Arkansas, at the point where the Arkansas River flows out of the Arkansas River Valley onto the Mississippi Lowlands. Jackson is situated on the Pearl River, which is not part of the Mississippi system. Both Little Rock and Jackson are the largest urban centers in their respective states. Baton Rouge is located just north of New Orleans and is often viewed as a continuation of the New Orleans port. All three urban centers are state capitals for the three states, which make up the core of the Mississippi Lowlands.

Three other MSAs exist within the study area. They are Biloxi-Gulfport, Mississippi (1994 estimated MSA population: 339,000), Lafayette, Louisiana (361,000), and Shreveport, Louisiana (378,000). These cities were not included in the instructional module. They are slightly smaller MSAs and they might be viewed as being situated on the edge of the study area. In addition, getting students to work through the module based on five urban centers represents a major challenge with respect to both time and error free results. Increasing the number to eight urban centers might be pushing the limits. Those students who want to incorporate more urban centers are permitted to do so but their additional work is not incorporated in the evaluation process.

Software and Data Set

The primary software package used with this instructional module is MapViewer, developed by Golden Software, Inc. in Golden, Colorado. This package is designed to create several different map types including choropleth maps. It is an easy package for students to use and it has the ability to create some very sophisticated products. A companion package called Grapher is also used. This package, also created by Golden Software, Inc., produces various statistical results. Both packages use the same type data files.

MapViewer comes with a geography file and an attribute file for every state in the United States. Each geography file contains sets of latitude and longitude coordinates that delimit every county within a state. Since the same coordinate system is used in creating each state's geography file, states can be combined to form a larger region. Several states were initially combined to show the Mississippi Lowlands but only three states - Arkansas, Louisiana, and Mississippi - fell completely within the region. Large sections of the other states such as central and northern Missouri and Illinois, and central and eastern Kentucky and Tennessee were outside the region. MapViewer makes it possible to easily delete these areas and form a new geography file, which can be saved and retrieved for future use. Using this approach a geography file was created to cover the Mississippi Lowlands and surrounding hill regions. By creating this file beforehand and having it available for all students in the GIS course to use eliminated a certain time-consuming task for the students, which was not essential to the instructional goals of the project. The students in this course had been introduced already to the process of combining geography files in an earlier exercise. In the urban geography course having the geography file for the study area prepared beforehand was also essential since showing students in this course how to create such a file was not directly relevant to demonstrating the construction of the model.

In addition to the new geography file, the attribute files for each of the states involved were combined to form an attribute file for the region. This file contained basic demographic data on the region by county.** It did not contain x and y coordinates defining the centroid point of each county, essential information needed to determine distances between points. MapViewer provides an on-screen digitizing function. Using the geography file, an outline map of the region along with its counties was displayed on the computer monitor. It was easy to digitize a centroid for each county, which was stored in a separate file and later transferred to the attribute file. The centroids are defined by the x and y coordinates used to create the basic map, which in this case were latitude and longitude coordinates. Again, this process was done beforehand making it possible for the students to center their attention on the project.

Straight-Line Distance Model

The first step in developing the model is to determine the straight-line distance between each of the five MSAs and the center of each county. This step is accomplished by first ascertaining the x and y coordinates for the MSAs. In order to employ the same coordinate system used to collect the coordinates for the counties, the base map for the Mississippi Lowlands is displayed through MapViewer. One can view the coordinate values on the map while moving the mouse across the monitor screen. The students have to determine what they consider to be the center of the MSAs. Making this decision can generate some discussion as to what constitutes the center of an urban area. For example the geographic center for the New Orleans' MSA is in Lake Pontchartrain and not near the built-up center of the city. Once these coordinate values are collected, they are used in the transformation function of MapViewer's worksheet to calculate the straight-line distance values. The following formula is given to the students to complete this step.

$$((\text{X-MSA} - \text{X-County})^2 * (\text{Y-MSA} - \text{Y-County})^2)^{.5}$$

X-MSA = X-Coordinate for Metropolitan Statistical Area
Y-MSA = Y-Coordinate for Metropolitan Statistical Area
X-County = X-Coordinate for County
Y-County = Y-Coordinate for County

The study area has 288 counties and with this formula the straight-line distance for each of the five MSAs to each of the 288 counties can be quickly calculated. These calculations are stored in five separate columns of the attribute file's worksheet. Figure 2 shows the straight-line distances from New Orleans and Memphis to each of the counties.*** By mapping the distance values, students can view spatially what they might find hard to comprehend by just scanning numerical values in a worksheet. The maps also provide them with an initial idea of what the spheres of influence might look like.

The second step is to calculate the inverse of the distance values and add these values together to show how two or more urban areas relate to each other with respect to straight-line distance. The inverse is determined by dividing the distance between two places into one. This calculation results in the counties close to an MSA having higher distance factors than those counties located farther away. Figure 3 shows how New Orleans and Memphis compare to each other as well as all five MSAs. In the comparison of New

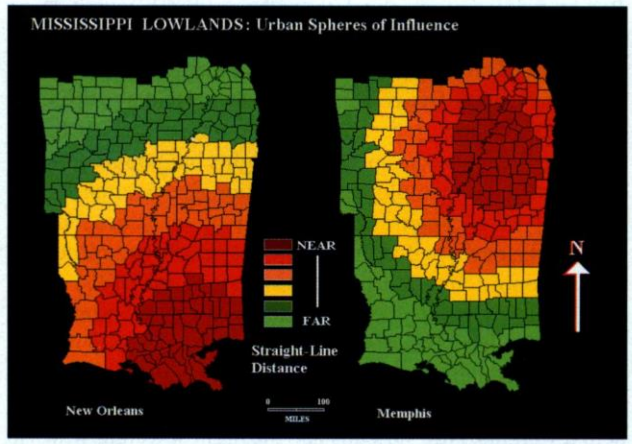

Figure 2 Straight-Line Distance Maps for New Orleans and Memphis

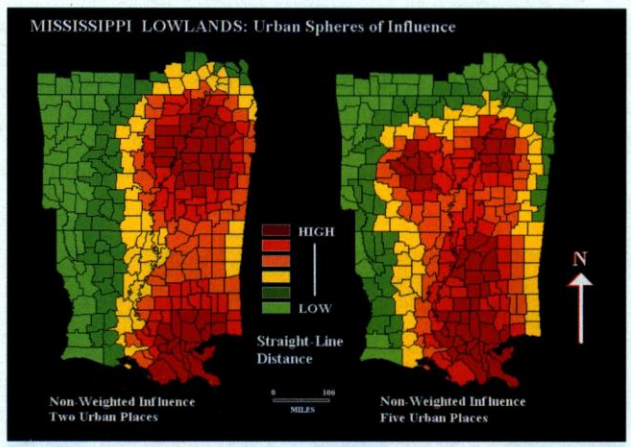

Figure 3 Combined Distance Maps for Two and Five Urban Centers

** MapViewer provides attribute files for each of the fifty states within the United States. These files contain population data (i.e., number of people) for each county within a state. This information was taken from the U.S. Census of Population, 1990, and was used to determine the number of people within the sphere of influence of each MSA.

*** The type of map range used for all the maps throughout the module is the same. It is an equal number range with six classes. In this case the equal number of data units per class is 48 (288 counties/6 classes). Using this approach for displaying the results reduces bias in designing the maps and makes the maps comparable to each other.

Orleans and Memphis the counties immediately around these two urban centers fall within the centers' higher spheres of influence than those counties farther away. This map can introduce class discussion as to why the eastern half of the Mississippi Lowlands falls more under the influence of these two centers than the western half. The map of the five centers introduces further discussion. The spheres of influence for New Orleans and Memphis decrease in size when the other three centers are introduced. In fact, Little Rock's sphere of influence appears to be equal in size to Memphis' sphere of influence even though Memphis has almost twice the number of people. This pattern provides the opportunity to introduce the idea of a weight factor for each center into the model. It also illustrates that Little Rock falls less under the shadow of the two major centers than Jackson and Baton Rouge, a situation which relates to the geographic positioning of the five centers to each other.

The third step in constructing the model is to weight the importance of the five centers and relate this factor to distance. Class discussion generally centers on several different variables being used as possible weights but population size is the one mainly employed. Population size is often a good indicator of a center's gravitational or influence pull. It reflects the concept that the number of people in a place is in direct proportion to the gravitational attraction of the place.

The New Orleans MSA has the largest population of the five centers. Its population size is divided into the populations of the five centers in order to create proportional values that should range between 0.0 and 1.0. These values became the actual weights. New Orleans had the highest weight with 1.0 and Jackson had the lowest weight at .314. Again, using the transformation function in the MapViewer worksheet these weights are multiplied times the straight-line distance calculations previously generated.

Figure 4 displays the results of adding a weight into the construction of the model. The differences between Figure 4 and Figure 3 relative to New Orleans and Memphis are minor. With the weight for New Orleans being 1.0 and the weight for Memphis being high (.807), it is not surprising

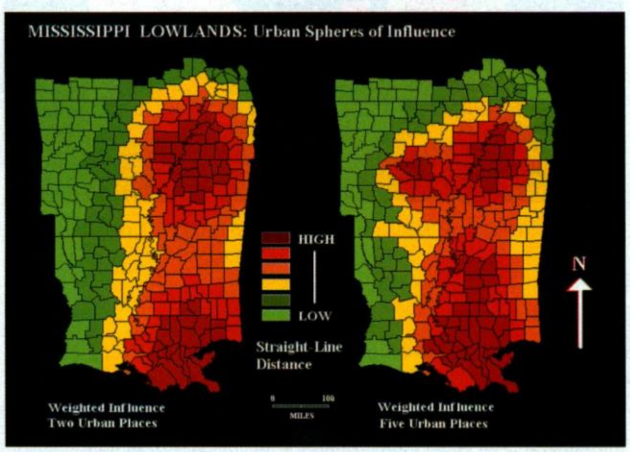

Figure 4 Maps Showing Population of Urban Centers as Weighted Factor Combined with Distance

that very little difference between the non-weighted and weighted maps for the two centers exists. Some major differences occur when the model became slightly more complex with five centers. On Figure 3, Little Rock and Memphis appear to have about the same size spheres of influence but on Figure 4, Memphis has a much larger sphere of influence. Its population is almost twice the size as the population for Memphis. This change can also be detected between Jackson and New Orleans.

Geometric Distance Model

A major problem with the model is the straight-line distance component. Students are quick to note the problem especially in dealing with an area which is divided half by the large land transportation barrier, known as the Mississippi River. Only fourteen bridges cross the river throughout the region's 575 mile length and three of these bridges are located in New Orleans and two in Memphis. The average distance between bridges is nearly 50 miles, making the connectivity between places within the region more complex than indicated by straight-line distance. To handle this problem the road distance or geometric distance between places has to be calculated. To measure the actual road distance between the center of each county to each of the five MSAs is beyond the scope of this project.

At this point students in the GIS course are instructed to gather actual mileage measurements between 25 and 40 places within the region. This process can be quickly done through the use of a road atlas, which often has recorded the mileage between several places. At the same time the students must determine the straight-line distance between the same places by using latitude and longitude, the same measuring system employed in calculating distance between the counties and the five centers. This information is entered into a worksheet. This entire procedure is done beforehand for the urban geography students.

The next step in producing this model requires introducing students to regression analysis. Trying to explain regression analysis in the urban geography course is best done graphically and without introducing the statistical/ mathematical steps. Students generally grasp conceptually what is happening. In the GIS course students are introduced to the statistical steps since they are involved in working with the software package, Grapher, to determine a best-fit situation. The previously developed worksheet forms the input for Grapher. In the regression analysis the straight-line distance becomes the independent variable and the geometric distance the dependent variable. The data are plotted and several regressions are generally produced before finding the best-fit situation. Knowing the nature of the data in the worksheet the instructor in the urban geography course is able to limit the number of regressions to generally two, enough to illustrate the process.

Figure 5 is an example of a regression analysis. The blue dots identify the actual data points on the graph. These points are plotted first to determine if a particular pattern exists. Next several regressions are run with the regression lines being displayed. In this example a logarithmic regression and a 3rd order polynomial regression were generated based on the distribution of the dots.

To make it easy for the students to understand this process the coefficient of determination (R2) was used as the measure of best fit. The students are told that this measure runs between 0 and 1 with 1 being the best correlation. In the above example the coefficients of determination for the logarithmic regression and the 3rd order polynomial regression are .922116 and .914199, respectively, making the logarithmic regression a slightly better fit to the data.

Returning to MapViewer's worksheet, the logarithmic regression results are entered into the transformation function with the actual straight-line distances between the counties and the five centers being the independent (X) variable. This step produces the expected geometric distances between the 288 counties and the five centers. In this case the logarithmic regression results are

$$\text{Log}(Y) = 1.14224*\text{Log}(X)+4.11774$$

from the formula:

$$\text{Log}(Y) = B*\text{Log}(X)+A$$

The base 10 logarithmic function was used in these calculations. The expected geometric distance values are in logarithmic form and must be converted back to mileage values through the use of the antilog function. The antilog of a number is the result obtained when one raises10 to logarithmic number or 10Log(Y). This operation can be easily handled through MapViewer's worksheet's transformation function.

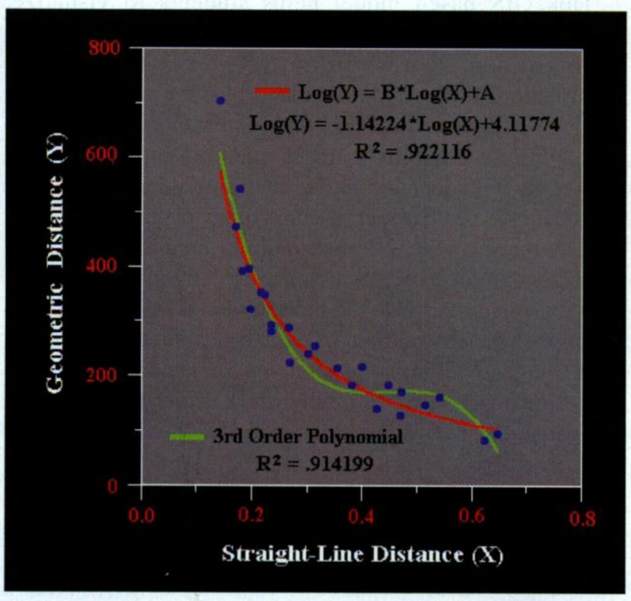

Figure 5 Logarithmic and 3rd Order Polynomial Regression Lines for Straight-Line Distance and Geometric Distance

At this point the students in the GIS course are moving along reasonably well even though they might not understand each step completely. The students in the urban geography course are becoming apprehensive about the introduction of formulas, high-level math, and unfamiliar terminology. The instructor assures them that none of this information will appear on any tests, which helps to reduce their concerns. It also helps to reinforce in their minds that what is simply being done is to find a mathematical statement, which best fits the sample points on the graph. From this statement expected geometric distances can be produced. This project might push some of these students to their existing mathematical limits but it also makes them aware that mathematics can be applied to an interesting problem.

Figure 6 shows both the straight-line distance and geometric distance for the five MSA centers. This figure is based on geometric distances generated from the formula in Figure 5. The geometric distance map illustrates more separation between the urban center's immediate spheres of influence than the straight-line distance map. The separation is quite apparent between Memphis and Little Rock, and Memphis and Jackson. This difference can introduce some class discussion as to what might be occurring. The Memphis and Little Rock separation is especially interesting since the straight-line distance between the two centers is nearly identical to the geometric distance. However, the students must be reminded that the distances are based from the counties to the urban centers. The counties immediately across the river from Memphis are no longer in a straight-line distance from the city. They are farther away due to the geometric arrangement of roads and bridges. An examination of the routes for Interstates 40 and 55 in Arkansas to the patterns on the geometric distance map shows that those counties through which the interstates pass are closer by road to Memphis than those located farther away from the interstates. Logically this pattern relates to what one would expect. This pattern also confirms that the method for calculating the geometric distances has validity even though it is based on a small number of sample distances.

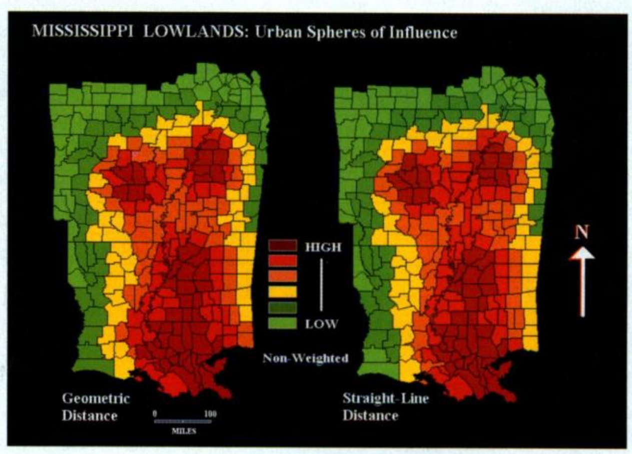

Figure 6 Geometric and Straight-Line Distance Maps for the Five Urban Centers

The two maps in Figure 7 relate both geometric and straight-line distances with the weighted condition of population size of the five centers. The weighted geometric distance map represents the final stage in the construction of the urban sphere of influence model. It is now possible to determine the probability of how many people in each county relate to each of the five centers. Again, this can be accomplished through the MapViewer worksheet. The worksheet has the weighted geometric distance between each county and each center. This information is arranged in five columns in the worksheet with each column relating to a particular center. The five columns are summed and then the sum is divided back into each of the five columns creating proportional values for each county to each urban center. The results of each mathematical step are stored in new columns. The proportional values are multiplied times the population of each county. The sum of all the counties' populations that relate to a particular urban center can now be determined. This information is provided in Table 1. The total population for the region is 11,253,104.

Table 1 provides a good discussion point in the urban geography class. Students can see that although New Orleans has 253,000 more people than Memphis, the number of people within Memphis' sphere of influence is only around 5,000 people less than the number within New Orleans' sphere. The instructor stresses that an urban center occupying the center of a region has an advantage over a city on the edge of the region. In this case the edge city not only has to deal with great distances to places in the northern section of the region but the lack of places to the south due to the Gulf of Mexico. Students can also note that Little Rock with a slightly lower population than Baton Rouge has more people within its sphere of influence. The students are told that Baton Rouge, New Orleans, and Jackson are very close to each other, and therefore, are impacting each other with respect to attracting people. Baton Rouge falls within the shadow of New Orleans that has a greater attraction force with its large population. Little Rock has enough space between itself and Memphis to reduce the shadow effect. Also, Little Rock is the only one of the five centers located on the west side of the Mississippi River giving it an advantage over the other centers pertaining to people on that side of the river.

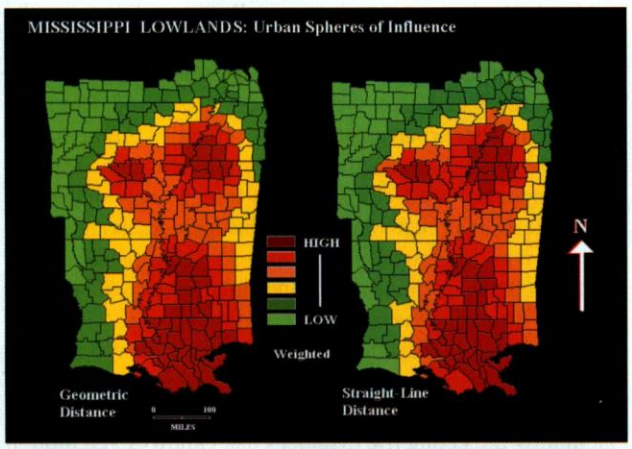

Figure 7 Weighted Distance Maps for the Five Urban Centers

Table 1 Number of People Attracted to Each Urban Center Based on Population Size and Geometric Distance

Urban Center	Population Size	Number of People within Sphere of Influence
New Orleans	1,309,000	3,321,154
Memphis	1,056,000	3,316,011
Little Rock	538,000	1,723,124
Jackson	412,000	1,219,506
Baton Rouge	555,000	1,673,309

The students in the GIS class also enjoy analyzing the results shown in Figure 7 and Table 1. Some of these students repeat the project but introduce the previously identified, smaller MSAs within the region. Other students go through the project again but only elect to make one change such as population size for a particular center. These students are working with the model as a laboratory by holding everything constant but for one thing. A few students introduce a hypothetical sixth center and move its location throughout the region.

Conclusion

This GIS based model helps students to visualize, geographically, urban spheres of influence between metropolitan areas. Working students through the construction of the model in a step-by-step process allows them to comprehend the importance of distance and centrality in shaping a metropolitan area's sphere of influence. They can see how the location of one metropolitan area vis-a-vis the locations of other metropolitan areas plays a significant role in the growth of a metropolitan area. The software packages employed in this lesson are relatively inexpensive, easy to use, and provide the building blocks for developing this model. Finally, although frequently apprehensive about what they are doing, the students in general enjoy the opportunity to learn through direct experimentation in comparison to listening to a lecture in a traditional classroom.