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A GIS-BASED APPROACH TO ANALYZING WARNING SIREN NETWORKS: AN ANALYSIS OF RILEY AND WABAUNSEE COUNTIES, KANSAS

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1. INTRODUCTION

Tornadoes are deadly storms that can cause a great deal of destruction in the communities they strike. Although warning systems have been improved upon in recent years, tornadoes still pose a serious threat to property, and more seriously, human life. The location of emergency warning sirens is an important factor in reducing vulnerability and providing people the necessary lead-time to take shelter when a tornado is approaching. Hammer and Schmidlin (2002) noted that 37 percent of the people in the last 21km of the path of the 3 May 1999 Oklahoma City tornado received their warning from emergency sirens. The geographical area covered by a siren network is of great interest to the natural hazard community, as proper placement can maximize the area covered and greatly reduce the chance of being injured or killed by a tornado (Brown *et al.* 2002; Grazulis *et al.* 1998; Hammer and Schmidlin 2002). This paper will examine some of the geographical and population-driven considerations through an analysis of the siren networks of two counties, Riley and Wabaunsee, in northeastern Kansas.

2. OBJECTIVES

This paper has two objectives. The first is to analyze the siren coverage of Riley County and report on the percentage of physical area covered, as well as the percentage of population covered in cities and densely populated areas, and finally, to suggest possible alterations and/or additions to the existing siren network in order to fill gaps in coverage (Chaney 1992; Current and O'Kelly 1992; O'Kelly and Murray 2004). The second objective is to analyze the population centers of Wabaunsee County and suggest locations for the five sirens donated by Pottawatomie County, in order to attain the highest percentage of population covered (Current and O'Kelly 1992; Murray and O'Kelly 2002).

3. STUDY AREA

Census Bureau definitions of urban areas, urban places, and rural area will be used. An urban area is defined as a, "built up area with a population of 50,000 or more," an urban place is defined as, "any incorporated place or census designated place (CDP) with at least 2,500 inhabitants," and an area classified as rural is defined as, "any incorporated place or CDP with fewer than 2,500 inhabitants that is located outside of a UA [Urban Area]" (US Census Bureau 1994).

Riley County, situated in Northeast Kansas (Figure 1), has a warning siren network covering a large percentage of the densely populated areas in the county. There are several urban places and one urban area in Riley County, but the majority of the county is rural, and sparsely populated.

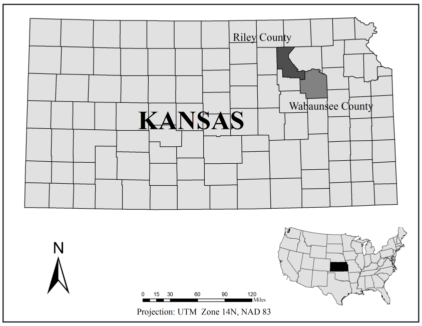
3.1 BRIEF HISTORY OF TORNADOES IN THE STUDY AREA

From 1950 to 2003, there were a total of 46 tornadoes in the study area. The most tornadoes, 25, occurred in Riley County, while 21 tornadoes hit Wabaunsee County. The most frequent type of tornado, in terms of F-Scale, was F0, with 28 (38.4%) of these events occurring

There were no deaths and 67 injuries sustained by residents in the study area from 1950 to 2003. Of the 67 injuries, 50 occurred as a result of the 6 June 1966 tornado in Riley County, which was rated as an F3. The longest path, at 108.4 miles, was recorded on 7 March 1974 in Wabaunsee County. This path is the sixth longest in Kansas tornado history, yet it claimed no lives, and caused no injuries (NOAA 2005).

Although this brief review may give the impression that tornadoes do not pose a serious threat to life and property in Kansas, the low injury and mortality figures presented here may be attributed to the idea that Kansans are generally well informed on how to cope with and react to severe weather. However low the figures may appear, they do not imply warning sirens are unnecessary. The improvement of warning siren networks will continue to provide ample warning time to persons in the paths of tornadoes.

FIGURE 1
STUDY AREA: RILEY AND WABAUNSEE COUNTIES, KANSAS

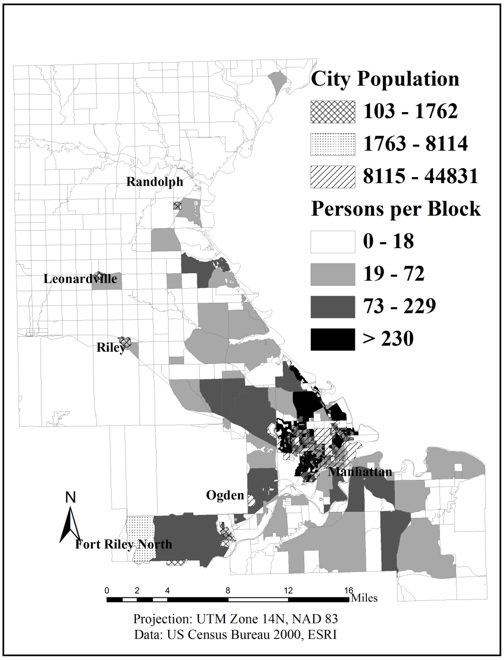


Riley County has a population of 62,843 and covers 609.6 square miles. The city of Manhattan, which is only 15 square miles in area (2.46 percent of the county), has a population of 44,831, or 71.34 percent of the total county population (Figure 2). Given the low density of RIley county, and the high concentration of persons in a few cities, the warning siren network does not have a large spatial extent.

Wabaunsee County is an extremely sparsely populated county, having just 6,885 residents. Only seven towns in the county have more than 200 people and only two have more than 500 (Figure 3). Preliminary analysis has shown that each town is small enough in area as to require only one siren to effectively cover the entire town. It is unlikely that the vast majority of the rural population could be covered by a siren network due to low population density and the high cost of installing warning sirens in sparsely populated areas (O'Kelly and Murray 2004, 566)

While the Pottawatomie County EMA donated five sirens to Wabaunsee County, this analysis will suggest the purchase of three additional sirens to attain maximum coverage of densely populated areas. In the event the Wabaunsee County government is unable to purchase three additional sirens, this analysis will also include suggestions for placing the five existing sirens in such a manner as to cover the maximum number of residents in the five largest towns and surrounding areas. This will be accomplished through a simple analysis using the populations and boundaries of the towns and density of residents in surrounding areas.

FIGURE 2
POPULATION ANALYSIS OF RILEY COUNTY, KANSAS



Given that Wabaunsee County clearly is at a different stage in the development of their warning siren network than Riley County, the methods for completing the analyses will be different for Wabaunsee than for Riley. As such, the METHODS and RESULTS sections will be presented in two parts each, one for Wabaunsee County, and one for Riley County.

4. METHODS

4.1. METHODS FOR WABAUNSEE COUNTY

With a limited budget, Wabaunsee County has been unable to afford the purchase of warning sirens. However, in 2005 the Pottawatomie County EMA donated five sirens to Wabaunsee County after purchasing new equipment for their own warning siren network. Data on the audible range of the donated sirens was obtained from the Pottawatomie County EMA. Each siren has an audible range of 4,800 feet, thus, the total area covered by each siren in 2.6 square miles (range refers to the radius of the circle described by the sirens klaxon) (Boyd 2005) The square mileage covered assumes no interference from buildings or topographical features. Given that each town in Wabaunsee County is very small, has no large buildings, and a relatively flat topography, that there should be minimal interference as a result of the factors mentioned above is a reasonable assumption to make (Current and O'Kelly 1992).

Population data was obtained from the 2000 U.S. Census at the block level. In addition to Census data, 2003 Landscan data was used to determine percentages of populations covered by the siren networks. All references to population and/or square mileage are attributed to these two datasets. Digital elevation models (DEM's), which include slope data, were obtained from the United States Geological Survey's (USGS) National Atlas. County and city boundaries were obtained from the Environmental Systems Research Institute's (ESRI) Geographic Names Information Service (GNIS). All GIS analysis was completed using ArcMap v9.0, and data analysis was completed using Microsoft Excel v11.0.

The first step in the analysis was to place a preliminary siren location in each of the eight towns examined in Wabaunsee County. Next, a 4,800-foot buffer was placed around these potential siren locations. Census data at the block group level as well as 2003 Landscan data was then overlaid on the siren buffers to determine percentage of county population each siren covered, total percentage of county population covered, and percentage of the population for the larger cities and high-density areas covered. The spatial extent of the coverage was also examined for each county. Since each siren can effectively cover 100 percent of the towns in Wabaunsee County, a special effort was made to include as much of the outlying population as possible when determining a site for each siren.

4.2. METHODS FOR RILEY COUNTY, KANSAS

Data on the audible range for Riley County was obtained from the county EMA. The audible range for the sirens varies by location, with ranges of one-half mile and one mile, which cover 1.57 and 3.14 miles respectively. The first part of the analysis for these two counties is similar to the analysis of Wabaunsee County. Siren locations were entered into a GIS and an appropriate buffer was placed around each siren location. Again, as with Wabaunsee County, census data at the block group and 2003 Landscan data was used to determine the same population coverage totals and spatial extent as was done in Wabaunsee County.

The second part of the analysis differs from Wabaunsee County in that there are large population centers (Manhattan in Riley) that do not have 100 percent coverage. These cities were examined in terms of the total coverage of the city, and gaps in coverage were identified. The RESULTS section points out these gaps, and suggests new locations for warning sirens in order to better cover the populated areas.

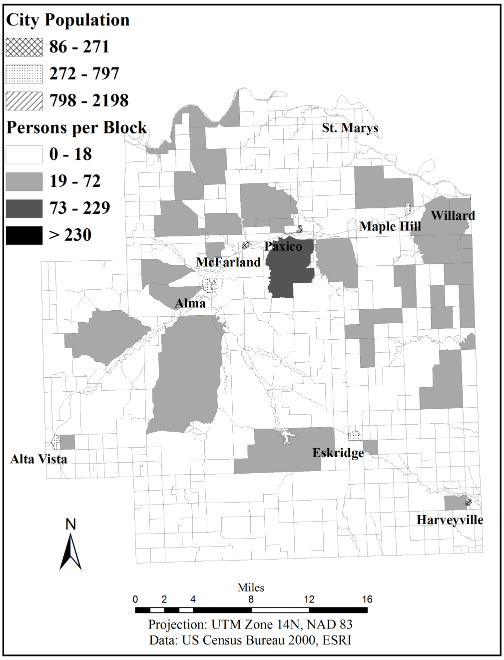
5. RESULTS

5.1. RESULTS FOR WABAUNSEE COUNTY, KANSAS

Results of the data analysis show the maximum population coverage attainable with five sirens is 39.11 percent. This assumes siren placement in the five largest cities. Currently, The Wabaunsee EMA plans on installing one of the five sirens near Lake Wabaunsee, in south central Wabaunsee County. This area consists of approximately 185 residents situated around the lake. Placing a siren in this area, rather than the fifth-most populated town of McFarland, will decrease the percentage of total county population covered to 37.57.

If Wabaunsee County is able to purchase three more sirens, and install them in the sixth, seventh, and eighth largest cities (Harveyville, Paxico, and Lake Wabaunsee respectively), the percentage of county population covered will increase to 49.66. There are no other major population centers or areas of high population density in the county. Additionally, given the topography in central Wabaunsee County, the effective range of the sirens would be limited in rural areas (Figure 3) (Chaney 2003; Current and O'Kelly 1992). As such, raising the percentage of population covered above 49.66 would require installing sirens in sparsely populated rural areas, and thus, be too cost-inefficient to justify.

FIGURE 3
POPULATION ANALYSIS OF WABAUNSEE COUNTY, KANSAS

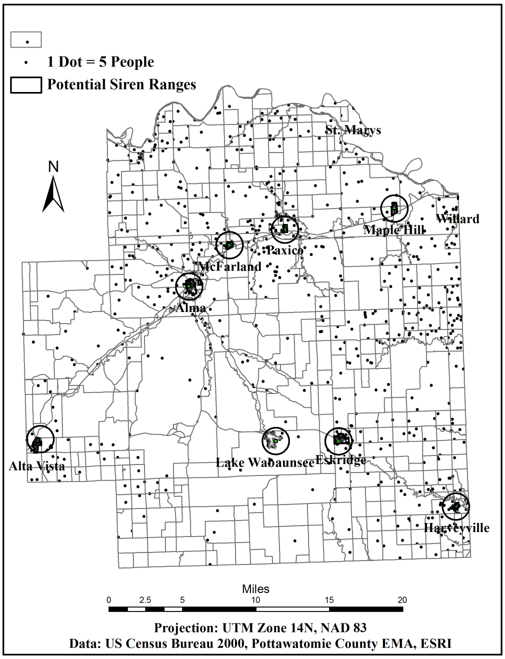


The spatial extent of siren coverage for Wabaunsee County is extremely small. There are 797 square miles in the county, and with a coverage area of 2.59 square miles per siren, the five sirens will cover 12.59 square miles, or 1.58 percent. If three additional sirens are purchased and installed in the sixth through eighth largest towns the square mileage covered would only increase to 2.6 percent. However, the increase from either 37.57 or 39.11 (depending on where the fifth siren is installed) to 49.66 percent of the population covered should provide sufficient justification for the purchase.

Figure 4 illustrates the locations of the eight largest towns, as well as the potential locations for each siren, and the 4,800-foot buffer around them. The point at the center of the buffer represents the location of the siren. With the exception of Alta Vista, the potential siren location was placed near the geographic center of the town. This may pose some problems, as there may be buildings, residential areas, commercial area, schools, or other impediments to the siren installation. Additionally, there must be a power source close to proposed location to prevent having to install one specifically for the siren, which will raise the total cost of the installation (Boyd 2005).

Another consideration to location selection is the aural safety of the residents near the siren. O'Kelly and Murray (O'Kelly and Murray 2004, 579) suggest there is a zone extending 100 feet from the siren in all directions where the noise would exceed, "safe levels (116Db)." This being the case, the actual locations of the sirens may need to be outside of the city limits. Such an adjustment, given the small physical size of the towns, would not affect the percentage of people in the town covered as long as the sirens are placed about 100 feet outside the city limits. However, moving the siren locations will alter the total percentage of the county population covered, albeit only slightly, since the new location would exclude outlying residents contained in this analysis but include new ones.

FIGURE 4
POTENTIAL WARNING SIRENLOCATIONS FOR WABAUNSEE COUNTY, KANSAS



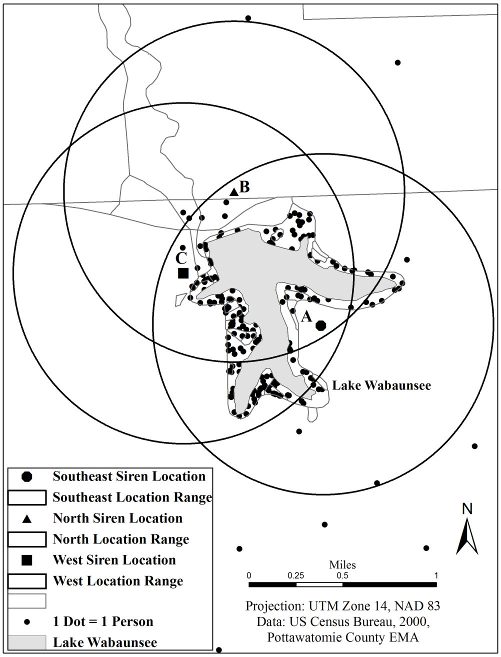
In the case of Lake Wabaunsee, the siren should be placed at Point A (Figure 5) if possible. If the siren is placed at the north end of the lake (Figure 5, Point B) it will put the residents at the south end out of range, and further reduce the total percentage of county population covered. If placing the siren at the south end of the lake is not possible, the second most optimal location is the small bay on the west side of the lake (Figure 5, Point C). Doing so would leave the fewest possible number of residents (on the eastern-most side of the lake) outside the audible range of the siren. These suggestions are the result of manipulating the buffer in the GIS environment in order to attain maximum coverage.

5.2. RESULTS FOR RILEY COUNTY, KANSAS

The analysis for Riley County centers mainly on the city of Manhattan. Aside from the city of Manhattan, there are only four other major population centers in the county, Randolph, Leonardville, Riley and Ogden, that are very small, comprising only 5.13 percent of the county population combined (Figure 2). Within each population center there is minimal slope change, and as such, it is assumed that slope will not play a part in preventing the siren's signal from reaching all the residents within its range. There are several thousand soldiers and other non-military personnel living on the Fort Riley Military Installation, however, they were not included in this analysis, since the Census Bureau does not consider them permanent residents, and the military maintains a separate siren network for the base. The four smaller population centers mentioned above, however, were included in this analysis.

FIGURE 5

POTENTIAL SIREN LOCATIONS FOR THE LAKE WABAUNSEE SIREN



The cities of Randolph, Leonardville, and Ogden all have one siren providing coverage, and Riley has two. The spatial extent of coverage for each town in 100 percent, and the population of the town covered is the same. In addition to covering every resident of the town, each siren in these towns covers a number of residents living outside the city limits. Added together, these four towns account for 4,106 county residents covered, or 6.41 percent of the county population. The spatial extent of these four sirens, plus the one covering Keats and the one covering the area south of Randolph total 15.7 square miles, or 2.58 percent Riley County.

Southwest of Manhattan lies Ogden, the second largest city in the county with a population of 1,762. One siren with a one-mile range services this city, with two more on the Highway 18 corridor between Ogden and Manhattan (Figure 6). The city of Ogden has 100 percent of its population covered, as well as 386 outlying residents for a total of 2,148 county residents covered by that siren, or 3.42 percent of the county population. The spatial extent of the Ogden siren is 3.14 square miles, or 0.52 percent of the total square mileage of the county.

As stated in the STUDY AREA section, almost three-quarters of the population of Riley County live in the city of Manhattan (Figure 2). As such, providing adequate warning to the 44, 831 residents, as well as the several thousand living just outside the city limits, is an important issue. The warning siren network covering Manhattan and surrounding areas consists of 26 sirens, 21 having an audible range of one mile and the remaining five having a range of one-half mile (Figure 7). The spatial extent of coverage for the city (within the city limits) is 14.06 square miles, or 93.75 percent, and the percentage of city population covered is 99.69 (44,692 out of 44,831 residents). Within range of the Manhattan network are 6,219 residents living outside the city limits, and these residents, along with the residents of the city account for 51,050 county residents covered by a siren, or 81.02 percent of the county population.

FIGURE 6
SIREN LOCATION ANALYSIS, RILEY COUNTY, KANSAS

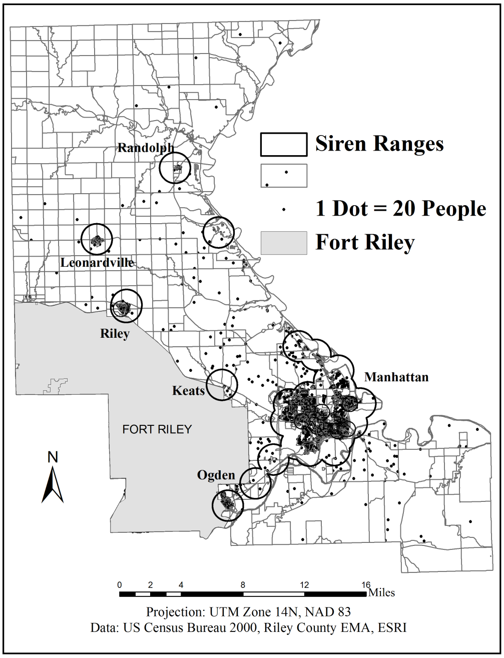
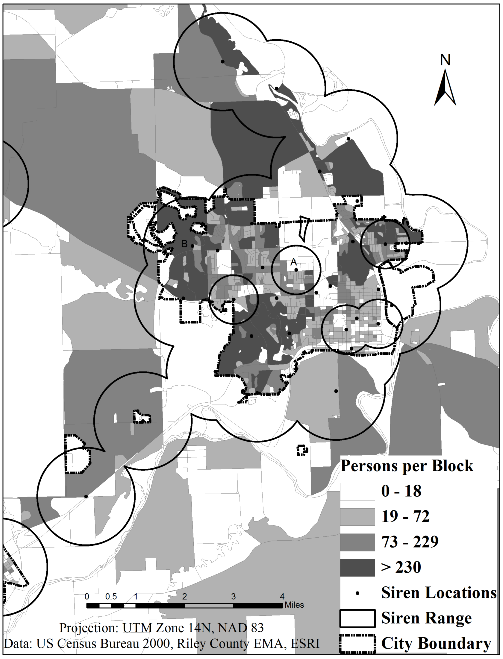


FIGURE 7
SIREN LOCATION ANALYSIS, CITY OF MANHATTAN, RILEY COUNTY,KANSAS



Examining the county as a whole, there are 55,206 out of 62,843 residents covered by a siren, or 87.85 percent. This is very high given that the warning siren network covers only 69.08 square miles, or 11.33 percent of the physical area of the county. These numbers, however, are not surprising when one considers that four of the five population centers (Randolph, Leonardville, Riley and Ogden) have 100 percent coverage (Figure 6), and the largest population center

(Manhattan) has nearly 100 percent coverage (Figure 7). This leaves only residents in sparsely populated areas uncovered, and as mentioned in the Wabaunsee and Pottawatomie analyses, it would be far too cost inefficient to consider covering such areas.

It is clear that Riley County emergency planners have done a superior job of covering the city of Manhattan, the KSU campus, and major recreation areas. Additionally, they have managed to cover over 87 percent ofthe county's residents.

6. CONCLUSION

This paper has examined the existing warning siren networks in Riley County, and the potential siren network in Wabaunsee County. Data from several sources, including the EMA's for each county was obtained through personal contact with these agencies in order to analyze both the spatial extent of coverage as well as the percent of each county's population covered. By using 2000 Census Bureau data, Landscan 2003 data, and the siren location information provided by the EMA's for each county, siren range data was buffered over population data in order to complete the analysis described. In the case of Wabaunsee County, the siren buffers were placed over the eight largest cities in order to attain the maximum percentage of coverage. While five sirens are scheduled to be installed, it is suggested that in order to maximize the percentage of population coverage, three more are purchased and installed as recommended in this analysis.

The implementation and management of an effective warning siren network is an important weapon in the emergency planner's arsenal. Providing ample warning time in the event of an impending natural disaster allows residents to seek appropriate shelter, and provide themselves with protection from the approaching storm. Riley County should take pride in their efforts to provide such a warning system to their residents. Wabaunsee County, while up until now has been without the benefit of a warning siren network, can look forward to increased protection and warning lead-time in the storm seasons to come, as it should provide them with better protection against the threat oftornadoes.

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