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Planning for the Suitable? Land Use Suitability and Social and Ecological Factors for Locating a New Hazardous Facility

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Abstract

A land suitability analysis, one of the oldest forms of decision-making support systems in the field of planning is still referred as an effective decision-helping aid that will enhance the complicate planning decision environment. Also, technological improvements, such as the Geographic Information Systems (GIS) and personal communication devices have accelerated the movements toward more technical solutions. The GIS implemented decision-making support system is a particularly good way to handle the difficult planning situations. Within this regard, this paper utilizes a suitability analysis to determine the most acceptable location for a proposed landfill facility in Hays County in the State of Texas. Using the Delphi panel discussion, Analytic Hierarchical Process (AHP), and map algebra in GIS environment, three most suitable sites for a future landfill facility are identified. This paper also has provided an in-depth overview on the latest decision support systems research and spatial multi-criteria decision sciences. Land suitability analysis is one of many possibilities that GIS could bring to the field of land use planning, and should be studied constantly.

Keywords: *land suitability analysis, Geographic Information System (GIS), Spatial Decision Support Systems (SDSS), Landfill Site, Analytic Hierarchical Process (AHP)*

1. Introduction

From the most frequently referred subject: land use planning, to the most complicated procedure: policy-making and evaluation processes, planners are required to perform diverse duties. In many cases, planners need to present or suggest a decision-making process that will satisfy the general public in a more unbiased way. This is particularly true for locating a facility that may confront many citizens with no intentions to build near their homes. For example, the proposition of creating a waste disposal or a landfill site near residences conjures up resentment among locals as many express the attitudes of NIMBY (not-in-my-backyard) and LULU (locally unwanted land use) (Schively, 2007; Shen and Yu, 1997). In order for the stakeholders to gain a better sense of understanding and to build consensus toward an acceptable outcome, planners are strongly required to present a methodology that reflects the stakeholders' interests in a balanced way.

In this extent, a land suitability analysis, one of the oldest forms of decision-making support systems in the field of planning (Collins and Rushman, 2001; Malczewski, 2004) is still referred as an effective decision-helping aid that will enhance the complicate planning decision environment. In order to justify the demands and evenly distribute people's interest, planners actively utilize a suitability analysis that will provide a more reliable solution. Technological improvements, such as the Geographic Information Systems (GIS) and personal communication devices have accelerated the movements toward more technical solutions (Chen and Khan, 2010; Sharifi *et al*., 2009). The GIS implemented decision-making support system is a particularly good way to handle the difficult planning situations (Bojórquez-Tapia and Ezcurra, 2001). Improvements in geographic data availability allow planners to have more diverse input and thus, obtain more complicated, but much more organized outcomes (Bobade *et al*., 2010; Sancar, 2010). Within this regard, this paper utilizes a suitability analysis to determine the most acceptable location for a proposed landfill facility in Hays County in the State of Texas.

2. Background and Margins for More Improvements

Decision Support Systems (DSS) in general refer to all types of

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decision helping systems and academic areas, such as statistics, economics, and operations research have long utilized DSS. Recently, with the advancement of personal computers, other disciplines, such as information science, psychology, and urban planning also implement different types of DSS to acquire optimal solutions (Druzdzel and Flynn, 2002; Ascough *et al*., 2002; Malczewski, 2006). There is no single DSS application. Nor is the DSS field homogenous (Arnott and Pervan, 2005). Each DSS type identifies different philosophy, system structure, and execution environment. Marginal controversy still remains and user's understanding on DSS slightly varies to some degree. However, the general consensus on DSS is: 1) communication-driven; 2) data-driven; 3) document-driven; 4) knowledge-driven; 5) model-driven; and 6) web-based systems (Power, 2007; Druzdzel and Flynn, 2002; Eom, 2001).

Of those different types, Spatial Decision Support Systems (SDSS) share the qualities of being model-driven and knowledge-driven (Power, 2007; Eom, 2001; Malczewski, 2006; Ascough *et al*., 2002) because overall process to produce the final decision is closer to that of a model, rather than communication or a document. SDSS are intended to resolve issues under spatial domain. The characteristics of an SDSS allow facilitating a research process that is iterative, integrative and participative (Nyerges and Jankowski, 2012; Malczewski, 2006; Power, 2007). As the nature of SDSS stands on spatial planning aids, its application implies a certain type of spatial interactions. Consequently, GIS have been one of the key interface tools of SDSS allowing a more interactive decision-making environment (Spatial Decision Support Consortium, 2008). Urban decisions have particularly enjoyed the expanded applications of SDSS. There have been a large number of studies utilizing an SDSS in development decisions and many of them tried to improve and revise the practical aspect of SDSS (Crossland and Perkins, 1995; Kim *et al.*, 2014; Ascough *et al*., 2002; Malczewski, 2006).

One of widely utilized forms in SDSS is a combination of GIS and Multi-Criteria Decision Analysis (MCDA). The common purpose of MCDA is to evaluate and select an optimal solution based on multiple criteria defined by users (Graymore and Richards, 2009; Brucker and Verbeke, 2011; Kiker *et al.*, 2005). Optimization methods, such as the Analytic Hierarchy Process (AHP), Delphi panel discussion, and Multi-Attribute Utility/ Value Theories (MAUT/MAVT) are the synthesis of MCDA to prioritize information and evaluate alternatives (Yoe, 2002; Kiker *et al.*, 2005; Belton and Stewart, 2002). There are two dominant features in spatial MCDA. One is the GIS component and the other is MCDA analysis, all of which are the foundations of SDSS (Greene *et al.*, 2011; Ascough *et al*., 2002). The main challenge in the latest SDSS research is not in the development of more sophisticated MCDA methods. More important is in the support of structure and design of the system. Improving the process that is supportive to generate new alternatives and is also capable of evaluating the goodness of outputs makes a major contribution to advanced spatial-MCDA.

There are two main reasons for a rapid increase in GIS-MCDA research, and the first is a wide recognition of decision analysis as an essential element in GIS science (Graymore and Richards, 2009). The second reason is its lower cost and greater ease of use in operation systems (Malczewski, 2006). The major advantage of incorporating MCDA into GIS is in its value judgments capability - users' preferences with respect to evaluation criteria and/or alternatives (Graymore and Richards, 2009; Malczewski, 2006; Kim *et al.*, 2014). In order for the model to produce reliable products, it is often required to have experts' advice at the beginning, and the Delphi panel discussion is a fine form that will enhance the process of expert interaction during the entire SDSS process. GIS-MCDA provides a framework to identify problems, organize the elements, understand the relationships in input components, and stimulate communication among users (Ramsey, 2009; Malczewski, 1999). In other words, GIS-based MCDA have a possibility to incorporate user and expert participation into its overall decision-making environment. Theoretically, this perspective is sustained as the MCDA side of GIS-MCDA provides a structure of merging participants' inputs into the decision-making process, and the GIS side enables a graphical interface illustrating visual results of participation.

In this extent, what are the obstacles for GIS-MCDA to become a more reliable decision-making aid? A distinctive notion about the limitations in MCDA component can be found in a number of articles (Kim and Neuman, 2013; Shen *et al*., 2012; Nyerges and Jankowski, 2012; Coutinho-Rodrigues and Antunes, 2011; Naidoo and Ricketts, 2006). Using logically consistent, mathematically valid methods of assigning and combining weights is absolutely critical to make the GIS-based MCDA reliable. If great care is not taken in establishing a system accurately reflecting community goals and expert judgment, then the results of any model can become unstable. In such cases, Delphi panel discussion and AHP provide a good substitute for more reliable variable selection and distribution.

Another limitation is in outcome validation. The common purpose of GIS-MCDA is to gauge and to choose spatial alternatives based on multiple criteria. Its versatility in outcome generation and low costs in development and maintenance raised the use of GIS-based MCDA in various research works (Gorsevski *et al*., 2012; Coutinho-Rodrigues and Antunes, 2011; Rybarczyk and Wu, 2010; Chen and Khan, 2010). Based on current uses, however, the SDSS environment provides a narrow window for its result interpretation. The GIS side of SDSS provides an easy access to outcome production with graphical interface. The challenge is that more comprehensive ways to validate alternatives are in demand (Brucker and Verbeke, 2011; Malczewski, 2006; Janssen, 2001).

In this extent, this paper focuses on improving the current use of SDSS by merging Delphi panel discussion to input selection and factor weighting process. Also, zonal statistics is implemented to understand the output in a more interpretable manner. Allowing experts opinion to the factor selection and weighting process will improve the reliability of the final output, and the zonal statistics will show the final results in a more comprehensible way in accordance with its geographical interface.

3. Integration of GIS and AHP for Land Use Suitability Analysis

As illustrated in Fig. 1, a land use suitability analysis using GIS involves four distinct steps. First, the analysts need to define what factors are required when determining the potential sites for the required facility. Among various approaches, the Delphi Panel Discussion is a widely accepted method (Tudes and Yigiter, 2010), and it is also a reliable approach to ease the limitation identified previously in chapter 2. After establishing the factors, articulating the relationship between the factors is necessary. This relationship is usually represented by numerical values and thus, can be calculated in several ways. Third, the analysts must implement the findings into the GIS modeling, especially a raster-based modeling is often employed. Finally, the suitability scores for each parcel within the study area are compared, and the study utilized the zonal statistics to illustrate the final results. Also, the classification process was pre-examined based on people's surveyed preferences from literature reviews. The relationship between factors was calculated with the Analytic Hierarchical Process (AHP). Because it is another important aspect in the overall decision-making process, this study used the AHP in a more conventional way, even though ArcGIS has an extension for the AHP (Tudes and Yigiter, 2010; Fu *et al.,* 2009). Subsequently, all of these communication and numerical results were used in the raster modeling process. Specifically, the "raster calculator" in the "spatial analyst" extension was the function used when implementing the analysis procedures.

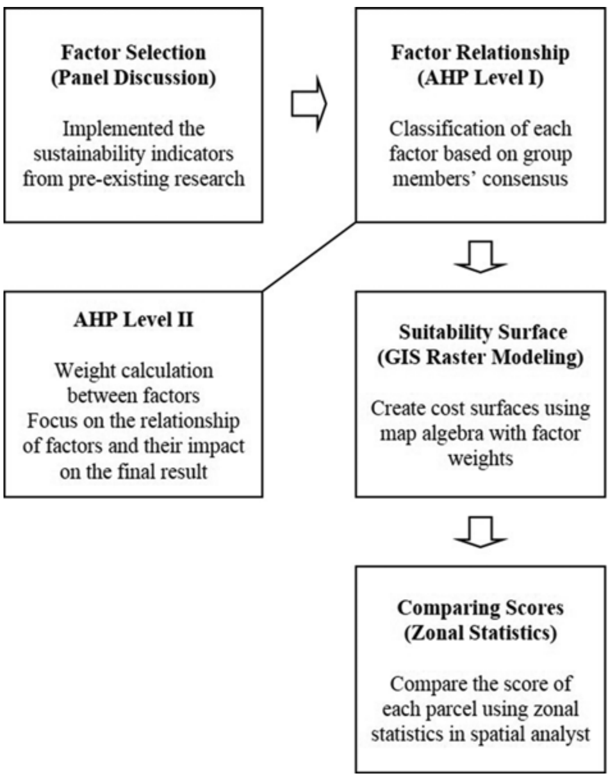


Fig. 1. Analytical Procedure

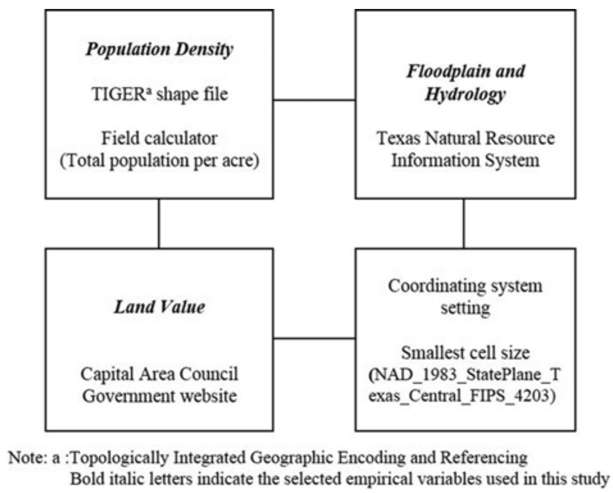
4. Research Design and Method

4.1 Study Boundary and Data Management

This study restricts the model to Hays County in Texas for several grounds. First, Hays County has established a relatively good GIS database that is open to the public. Second, the authors were privy to the fact that a public hearing for a future landfill site in Hays County was underway at the time. Even though this study was not a part of the legal planning process, this case provides a valuable opportunity to utilize a scientific and academic approach to potentially solve a real-world problem. As described in Fig. 2, in terms of data management, a number of variables were used. First factor, population density was implemented in a combined format of the U.S. 2010 Census in a block group level and Topologically Integrated Geographic Encoding and Referencing (TIGER) shapefile. After that, the density was calculated using a "field calculator" (total population per acre). Second, floodplain and hydrology were selected as other input factors, as they represent key environmental measures. Shapefiles were downloaded from the Texas Natural Resources Information System. Finally, land value data were available at the Capital Area Council of Government website. As the final step, an appropriate coordinate system was selected. Because determining a coordinate system relates to the cell size and the base unit, the unit was initially set to meters and the cell size to 30M × 30M. The main reason for using a 30 × 30 grid is that even though this study did not use Digital Elevation Models (DEMs) of Hays County, the smallest cell size available in the Hays County DEM was 30M × 30M. Therefore, this study followed the convention of using the smallest cell size available.

4.2 Factor Selection, Classification and Relationship

As described in Fig. 1, factors for a suitability analysis vary across the study purpose, requiring different methodologies in



Note: a :Topologically Integrated Geographic Encoding and Referencing
Bold italic letters indicate the selected empirical variables used in this study

Fig. 2. Analytical Data Connection and Management

selection. The Delphi Panel Discussion is a widely accepted method to determine the necessary factors (Loo, 2002; Masser and Foley, 1987). It requires a great deal of input from key decision makers and planners and thus, generally demands significant time and cost. In other words, it is virtually impossible to conduct a Delphi discussion solely for a small project. This study specifically relates to sustainability indices, which can be found in previous research works. The Texas Urban Triangle research team organized a panel consisting of 25 different experts from various backgrounds. The initial results of their research were 42 different indices that are defined as sustainability indicators (Kim *et al.*, 2011). Of those 42, four variables that are most relevant to a landfill site: 1) population density; 2) land value; 3) floodplain; and 4) hydrology were implemented in this research.

The panel discussion result revealed that density must be elaborated within the study since the majority of people do not want a landfill near their properties. Land value is one of the major concerns as it directly relates to the community asset as well as individual interests on the property values (Green and Haines, 2011). Hydrology and floodplain are measures of any impacts on the natural environments. Hydrology is associated with water quality and floodplain relates to the potential natural disasters (Woosnam and Kim, 2013). Population density and land value are ratio and interval variables, whereas floodplain and hydrology are closer to a present or not-present type with a different hierarchy and thus, ordinal items. Once the necessary factors were set, the next step was classifying them into an order. By setting up the standard for each factor with a desired hierarchy, the "reclassify" feature in the "spatial analysis" extension of ArcGIS could be used. The general rule of thumb is that the lower the score, the better the suitability, and all the scores are put into 1-5 scale with 5 being the least suitable. Table 1 illustrates how each factor was classified based on their implications to the overall suitability.

Table 1. Factor Classification and Score

Population Density	
0~0.2	1
0.21~0.40	2
0.41~1.50	3
1.51~5.00	4
5.00~50.87	5
Land Value	
0~50,000	1
50,000~150,000	2
150,000~300,000	3
300,000~800,000	4
800,000~247,818,720	5
Hydrology	
Water Body	1
Stream/intermittent stream	3
Major river	4
Dam	5
Floodplain	
X	1
X500	2
AE	4
A	
AH	5

Population density was assessed using the total population and number of area block groups. The areas were calculated with the "calculate geometry" feature, and one new field, density, was added to the attributable. Land values were sorted by improvements on the land. Hydrology and floodplain were categorized into their types. This study was concerned more with the types of hydrology or floodplain in terms of a landfill site. A population density of 5.00 indicates that there are five people in one acre of land. The categorization was done in a quantile base. Land value was also done with a quantile classification and the highest appraised parcel in Hays County was valued as US$247,818,710. Each classification for hydrology differs in its type and is scored accordingly. Finally, an "X" in the floodplain indicates a minimal disaster area, and "X500" indicates a 500-year floodplain. "A" and "AE" indicate a 1% annual chance of flooding without scrutinized depth, and "AH" implies a 1% annual flooding chance with an average depth ranging from 1 to 3 feet. In general "X" and "X500" are considered low-risk areas, whereas "AE," "A," and "AH" are thought of as high-risk areas. Fig. 3 represents the classification results in a map format. The darker the color, the lesser desirable for a landfill site.

4.3 Factor Weight and AHP

Among the previously mentioned research steps, establishing the relationships between the factors is the most critical part of the research process. The way in which a researcher handles this step can make a significant difference in the final result. In the same way as the factor selection, there are several different ways to articulate the relationships. Some of them are based on statistical methods, such as confirmatory factor analysis, and others are based on a relatively straightforward judgment with a few mathematical procedures. The most popular example of the latter would be the AHP, which this study have implemented.

AHP is a widely utilized method in the decision-making process, and ArcGIS even supports for an AHP extension. Once the decision, based on the participant consensus, is made for the initial input then the standardized factor weights can be calculated with a simple calculation. The initial input is setting up the relative importance between the factors. For example, if the study values population density two-times higher than the hydrology because the impact and required cost of moving people is higher than building a bridge, then the initial input (ratio) between population density and hydrology becomes 2:1. Similar procedures adapt to other factors. Once the basic numbers are set then the general procedures in the AHP are followed. Table 2 illustrates the final results of factor weights using AHP. The consistency ratio indicates that the calculated weight has a 2% error in its scale consistency and has a less than 5% significance level. In other words, this study can use this

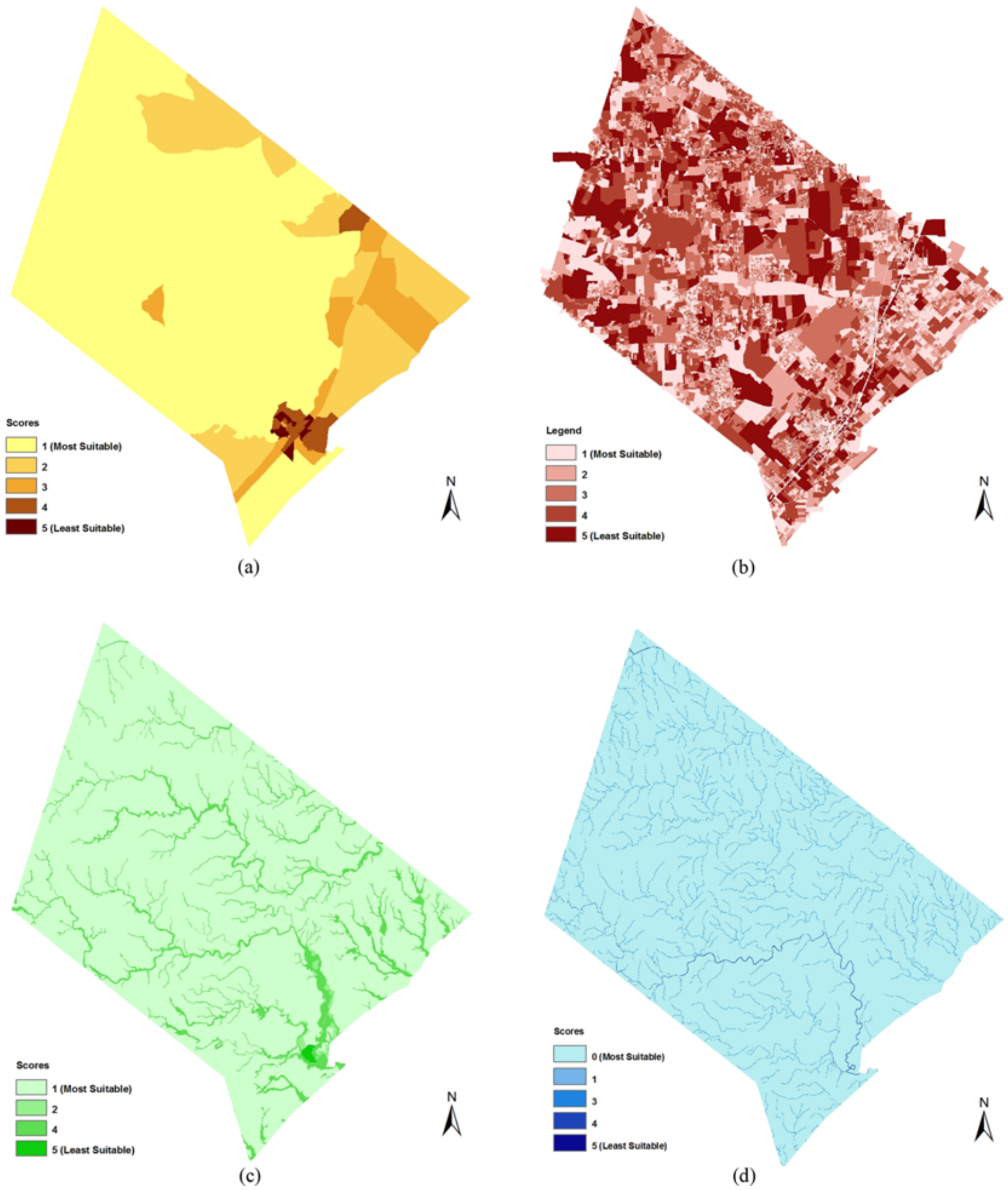


Fig. 3. Factor Raster with Suitability Scores: (a) Population Density Suitability Scores, (b) Land Value Suitability Scores, (c) Floodplain Suitability Scores, (d) Hydrology Suitability Scores

weight as a reliable construct. Eigen vectors are the coefficients (factor weights).

5. Findings

Based on the previous steps, a suitability surface indicating scores for a possible landfill site was created. Since all the maps (factor maps) are in a raster format, meaning that they are composed of 30M × 30M cells, the final suitability map would also be in a raster format with the same cell size. Once this cell-based raster map is created, suitability scores are calculated based on parcel boundaries. As the cell becomes more suitable, meaning that a cell has a lower number in terms of suitability score; the color of a cell becomes bluer. On the other hand, as the cell becomes less suitable, a cell with a higher score, the color becomes redder. As seen in Fig. 4, cells around the city of San Marcos, which is the major city within Hays County in the state of Texas, are predominantly blue in its color, and on the opposite side of the county, the cells are mostly in red. Since this study gave population density and land value relatively greater factor weights, this result is an expected outcome.

With the map created in the previous step, suitability scores at the parcel level were then obtained. The parcel shapefile is overlaid onto the suitability map and "zonal statistics" in the

Table 2. Factor Weight using AHP

	Pop. Density	Land Value	Hydrology	Floodplain	Sum	Percent
Pop. Density	1.00	2.00	3.50	5.00	11.50	45.0%
Land Value	0.50	1.00	3.00	4.00	8.50	33.2%
Hydrology	0.29	0.33	1.00	2.00	3.62	14.2%
Floodplain	0.20	0.25	0.50	1.00	1.95	7.6%
Sum	1.99	3.58	8.00	12.00	25.57	100.0%
Initial input values with relative relationships						
	Pop. Density	Land Value	Hydrology	Floodplain	Eigen Vectors	
Pop. Density	0.50	0.56	0.44	0.42	0.48	48.0%
Land Value	0.25	0.28	0.38	0.33	0.31	31.0%
Hydrology	0.14	0.09	0.13	0.17	0.13	13.0%
Floodplain	0.10	0.07	0.06	0.08	0.08	8.0%
Sum	1.00	1.00	1.00	1.00	1.00	100.0%
Calculated Eigen vectors for each factor						

$\lambda max = 4.07$ / Consistency Index (CI) = 0.02 / Consistency Ratio (CR) = 0.02- > 2% <5%)

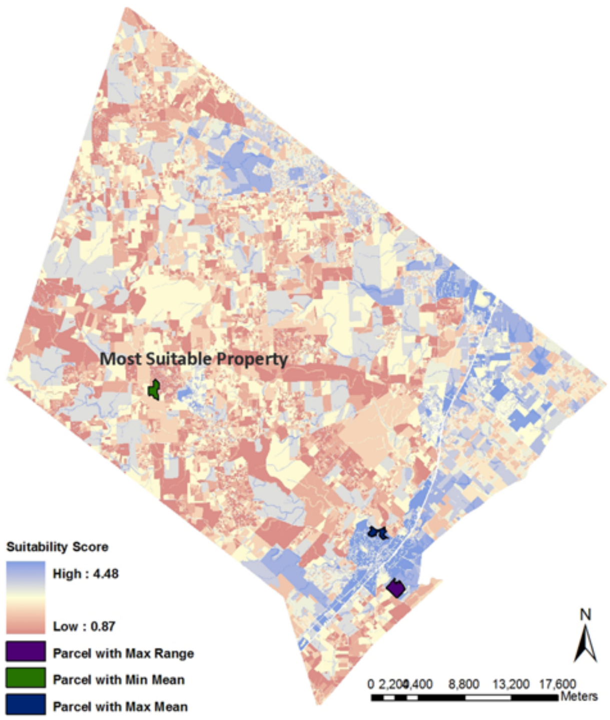


Fig. 4. Most Suitable Parcel

"spatial analysis" extension of ArcGIS was used. Since there are many parcels, a guideline that would possibly eliminate parcels with less relevance was needed. According to the Texas Commission on Environmental Quality (Waste Permits Division, 2007), the average size of a landfill in 1986 was 50 acres, whereas the average size in 2006 was 200 acres. Following this pattern, the study decided to eliminate parcels less than 200 acres of its size. By using the "select by attribute," parcels with more than 200 acres in size were identified. Because suitability information based on each parcel was needed, "zonal statistics" with the property ID was performed. By doing so, the overall descriptive statistics of each parcel were obtained. The summarized output for the entire result of the "zonal statistics" is presented in Table 3. Mean values indicate the average suitability score of the cells within the parcel, and the minimum value is the smallest score. Range is the difference between the minimum and maximum score within the parcel. As can be seen, the property No. 30665 has the minimum mean value and all the cells in that parcel have the same suitability score of 0.87. Property No. 15195 has the maximum mean score value, and property No. 16379 has the highest cell value within the parcel.

Table 3. Summary of Suitability Score

Property ID	Count	Acres	Mean	Minimum	Maximum
30665	1311	291.55	0.87	0.87	0.87
15195	1125	250.19	3.40	2.11	4.18
16379	1822	405.19	3.15	3.07	4.31

6. Conclusions

Urban and regional planning involves the integration of many different disciplines. When land use decisions are contentious, planners are required to present a methodology that reflect stakeholders' interests, ultimately seeking to present an outcome that is acceptable for those involved. In order to justify the demand and properly address interests, planners actively utilize suitability analysis. A land suitability analysis was performed to find a possible landfill site in the study area. Simple map algebra was used in conjunction with ArcGIS and geographic data sets. After that, suitability scores were compared using zonal statistics.

This could be regarded as a powerful tool for the planners to justify the rationale and provide analytical results to the general public. However, there are several possible pitfalls. The first limitation comes from the factor selection. The Delphi panel is still regarded as a dependable solution to a large number of professionals. However, the results might tend to fluctuate based on individual opinions. Second and most importantly, the way researchers deal with the factor weight would significantly affect the final outcome. AHP provides the mathematical process, but the initial input still relies heavily on the researchers' judgment. Therefore, there should be strong theoretical justifications prior to setting up the initial weights on the inputs. Finally, there is a chance that data availability might drive the entire research process.

Despite these limitations, land use suitability analysis using GIS and AHP still seems a reasonable way to reflect various aspects of the built environment. Progress in data availability would allow related professionals to conduct more sophisticated research. If this research is done in a more detailed manner, meaning that use of explanatory or confirmatory factor analysis, implementation of more factors, and utilization of experts' opinions, the final result could render a more solid and persuasive solution. Land suitability analysis is one of many possibilities that GIS could bring to the field of land use planning, and should be studied constantly.

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