Solid Waste Disposal Site Selection for Capital Region of Andhra Pradesh Using Multi-Criteria Analysis and GIS

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Abstract

Solid waste disposal is becoming a major global problem. Due to increasing human activity, solid waste is creating serious damage to the ecosystem and human health. Damage is caused by illegal dumping of urban waste in unacceptable locations. For this reason, local municipal and central governments are moving forward to construct engineered solid waste landfills in suitable areas. A geographic information system (GIS) is a tool that can be utilized by engineers and city planners to identify the best possible sites for disposal. This study leverages GIS and multi-criteria analysis to develop a suitability model based on previous studies of solid waste disposal site selection. Data was collected, and locations in the capital region of Andhra Pradesh, India were prioritized based on the suitability model developed in this study. The model developed by this study utilized raster layers (land use classification, distance to roads and railways, slope, and constraint layers) categorized to conduct suitability analysis. Suitable locations were then converted to polygons in order to evaluate their size and land use type. Due to the high population of India, available land is limited. This study utilized various techniques to identify sparsely available land suitable for solid waste disposal.

Introduction

Solid waste management (SWM) is a complex and challenging task, as it requires significant skill to work with citizens and the environment in many fields such as engineering, geology, lithology, economics, cartography, and topography. In addition, there are rules and regulations that must be followed, which are set by a governing body (Deswal and Laura, 2014). There are many issues surrounding solid waste disposal in developing countries such as India and Brazil where most of the population lies just below the poverty line (Chabuk, Al-Ansari, Hussain, Knutsson, and Pusch, 2016). Chabuk *et al*. (2016) references the United Nations 2010 report indicating that generated solid waste disposal amounts to 277 million tonnes per year; low and middle-income countries produce approximately 57.1% and 12.2% of waste, respectively, whereas developed nations are producing 30.7% of total waste generated around the globe. Solid waste is predicted to increase to 677 million tonnes by 2025 (Chabuk *et al.*, 2016). At that time, low-income countries are expected to contribute 70.9% of overall solid waste around the world (Chabuk *et al.*, 2016).

There has been a critical increase in solid waste in India throughout the years, from 100 grams per individual per day in residential communities to an average of 500 grams per day per capita in

cities (Nishanth, Prakash, and Vijith, 2010). The majority of the city's solid waste in India is dumped illegally (Nishanth *et al*., 2010). In India, most of the open lands are now being used as waste dumping sites, and most waste is generated from urban communities and manufacturing industries (Subramani, Krishnan, Kathirvel, and Sivakumar, 2014).

In most of India's cities, a portion of Municipal Solid Waste (MSW) remains disposed on streets. Waste that is gathered is moved to a disposal site (Sharholy, Ahmad, Mahmood, and Trivedi, 2008). According to Sharholy *et al*. (2008), the accumulation of MSW is the local municipality's responsibility. The primary system of collecting solid waste in Indian cities is through placing common bins at several points on the side of the roads and periodically disposing the bins at illegal open collection points. Endeavors to organize a door-to-door collection system began in metropolitan cities such as Delhi, Mumbai, Bangalore, Madras, and Hyderabad, with the assistance of non-governmental organizations (Sharholy *et al*., 2008).

There has been a long history of solid waste disposal problems in Vijayawada. Almitra Patel, "a member of the committee for solid waste management appointed by the Supreme Court in 2000," explained that solid waste produced in India contains a large amount of moisture and scrap content, which is unsuitable for incineration (Jain, 2007). According to Subba Rao (2012), there is "no place to dump the garbage in Vijayawada." Dumping solid waste became a big task for city government officials since the waste-to-compost plant was closed (Subba Rao, 2012). "Waste is being dumped at four different sites outside the city far away from habitation," said one of the municipal

authorities (Jain, 2007). But such dumping in India is a contravention of Municipal Solid Waste Rules 2000. When asked, city officials said they do not have any other option (Jain, 2007).

Recent literature concentrated on ideal solid waste disposal site selection relies on multi-criteria decision analysis (MCDA) and geographic information systems (GIS) (Sumathi, Natesan, and Sarkar, 2008). It is apparent that many considerations must be integrated into landfill site selection and GIS is appropriate for this sort of preparatory review because of its capacity to oversee substantial volumes of spatial information from a selection of sources. GIS proficiently stores, recovers, examines, and displays data as indicated by client-determined criteria (Siddiqui, Everett, and Vieux, 1996; Şener, Süzen, and Doyuran, 2005).

It is possible solid waste disposal site selection can be implemented by considering different types of spatial and non-spatial components (Ohri and Singh, 2013). According to Ohri and Singh (2013), previous studies (Shukla *et al.,* 2012, Moeinaddini *et al.,* 2010; Sener *et al.,* 2010; Guiqina *et al.,* 2009; Ohri and Singh, 2009; Gemitzi *et al.,* 2007; Mahini and Gholamalifard, 2006; Javaheri *et al.,* 2006; Melo *et al.,* 2006; Kontos *et al.,* 2005; Natesan and Suresh, 2002; Lin and Kao, 1998; Charnpratheep *et al.,* 1997) utilized the blend of GIS and MCDA in solid waste disposal site selection processes.

Study Area Introduction

The study area consisted of a polygon with an area of 3837 km^2 formed by the following points of location: 16°41′43″N 80°17′53″E, 16°11′15″N 80°17′30″E, 16°11′46″N 80°57′00″E, and 16°41′24″N

81°56′56″E. The study area included Vijayawada, Guntur, Tenali, Amaravati and some parts of Nandigama, Gudivada, and Eluru Municipalities within the jurisdiction of the Capital Region Development Authority of Andhra Pradesh (APCRDA). The human population of this area is approximately 3 million (Andhra Pradesh Capital Region Development Authority, n.d.), including those living in key cities such as Guntur and Vijayawada.

The economy of both Krishna and Guntur districts is mostly (65.065%) agriculture, which is the main source of income for the population (Andhra Pradesh State Portal, 2014). The study area ranges in altitude from 0 to 60 meters above sea level, and annual rainfall in this region is 800 mm to 1200 mm. Maximum temperatures during summer are over 40°C, making this region one of the hottest places in the South Indian region (Andhra Pradesh Capital Region Development Authority, n.d.).

Methods

In order to reach the research goals, this entire study was carried out in a systematic manner (Figure 1).

Figure 1. Flow chart illustrating procedural processes included in this study.

Technology

Technology used for conducting this study was computer based. To fulfill study goals, Esri's ArcGIS 10.4.1 was used along with the Spatial Analyst extension. The Internet also played a key role throughout the research to gather selected topics on problem solving and general information for data acquisition.

Data Acquisition and Manipulation

Data collected for this study was mostly found by searching the Internet. Primary datasets for this research were shapefiles, which were obtained from the online open source website Mapzen. Four shapefiles (roads, railways, electricity poles and waterbodies) were obtained as polygon, polyline, and point features, all represented in the geographic coordinate system, WGS84 (Figure 2).
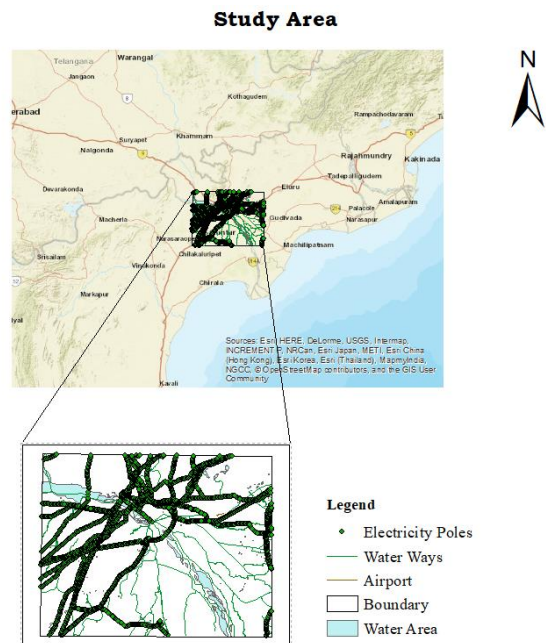

Figure 2. Location of study area in southern India showing the study area boundary and shapefiles.

The study area was drawn in Google Earth and saved as a .kml file. The

ArcGIS Conversion toolbox was used to convert the KML to Layer. All newly obtained and created shapefiles were important components for analysis within the study.

The other data components were a digital elevation model (DEM) and Landsat 8 images, which were obtained from India's Bhuvan (ISRO) and the U.S. Geological Survey (USGS) Earth Explorer. To use this data, they were georeferenced and clipped using georeferencing and geoprocessing tools in ArcGIS.

Projection

All data analyzed in this study was projected from the WGS84 geographic coordinate system to the WGS 1984 UTM ZONE 44N projected coordinate system with the following properties:

Projection: Transverse Mercator
False Easting: 500000.0
False Northing: 0.0
Central Meridian: 81.0
Scale Factor: 0.9996
Latitude of Origin: 0.00000000
Linear Unit: Meter (1.000000)
Geographic Coordinate System:
GCS_WGS_1984
Angular Unit: Degree (0.0174532925199433)
Prime Meridian: Greenwich (0.0)
Datum: D_WGS_1984

This projection was chosen specifically for this project, because it preserves the shape of the features such as boundaries, waterbodies, water ways, roads, railways, and electricity poles so they look the same on the map as they do on the earth of the regional geographic area being studied.

Suitability Model Selection

The methods of this study are based on previous studies related to site suitability analysis for solid waste disposal site selection. Malczewski (2006) explained in order to identify a solution, the suitability analysis can be divided into small components, analyzing each component individually, and assigning suitability scores in a systematic manner for the best result (as cited in Sahani, Prasad, and Raghavaswamy, 2014). Sahani *et al.* (2014) used the formula by Luis Carlos Berrocal (2012); this research used the same formula to identify suitability scoring methodologies:

$$S = \Sigma W_i X_i \text{ x } \prod C_j$$

where:

S – is the composite suitability score
X_i – factor scores (cells)
W_i – weights assigned to each other
C_j – constraints (or Boolean Factors)
Σ – sum of weighted Factors
$\prod$ – product of constraints (1– Suitable, 0 – Unsuitable)

Constraints Model

Buffer Distances

According to QGIS (n.d.), "The area that is within the specified distance [of a feature] is called the buffer zone." The objective of the buffer zone or buffer distance is to keep natural or man-made features away from one another. "In a GIS application, buffer distances are always represented as vector polygons" (QGIS, n.d.). The obtained shapefiles (vector) were in geographic coordinates and were converted to a projected coordinate system. Before applying buffer distances, all the shapefiles were clipped to the study area boundary using the ArcGIS Clip tool. In this study, buffer distances were chosen to protect the features and also classify zones as unsuitable for a solid waste

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disposal site. All the buffers were created up to the study area boundary by setting the extent in the ArcGIS geoprocessing environment settings. The buffer distances (Table 1) were taken from past studies on solid waste disposal site selection. The electricity poles buffer distance was obtained from Chabuk *et al*. (2016). Distance to an airport was obtained from Yazdani, Monavari, Omrani, Shariat, and Hosseini (2015). The suitable buffer distance for buildings was provided by Berisa and Birhanu (2016). All the buffer distances were calculated in meters.

Table 1. Buffer distances for the constraints.

Input Feature	Buffer Distance	Feature Geometry
Airport	3000 m	Polyline
Water ways	1000 m	Polyline
Water areas	1000 m	Polygon
Electricity poles	30 m	Point
Buildings	300 m	Point

The next step was to create rasters by converting feature buffers for the buildings, waterways, water areas, and electricity poles. Each resulting raster was then converted to 0 (constrained area) and 1 (unconstrained area) values for the constraints model. The Is Null tool was used for water areas, water ways, electricity poles, and building rasters because whatever was not part of the buffer distance in the raster was recorded as NoData (Null). According to Esri (n.d.a) the tool "returns 1 if the input value is NoData and 0 for cells that are not, on a cell-by-cell basis within the Analysis window." The airport buffer involved an intermediate step to ensure data values for the entire study area. The Union tool was used to incorporate the full study area with the airport buffers prior to converting to raster. Then the Con tool (conditional

evaluation tool) was used to convert to simplified Boolean values 0 (unsuitable) and 1 (suitable) based on the condition:

OutCon = Con (AirportUnion, 1, {0}, {-1})

The raster calculator was used to combine water ways, water areas, electricity poles, and airport rasters (Cj) once they were ready to create the constraints portion of the model by multiplying the rasters together. The obtained values are 0 and 1, which indicates that 0 is unsuitable and 1 is suitable.

Suitability Analysis

Slope

Slope suitability was an important factor in considering a solid waste disposal site. A digital elevation model (DEM) was downloaded from Bhuvan Indian Space Research Organization's (ISRO) open data archives portal, which is maintained by the National Remote Sensing Agency (NRSA, n.d.). The DEM was derived from the Cartosat-1 stereo payload launched in May 2005. "The Cartosat-1 satellite provides high-resolution near-instantaneous stereo data with a spatial resolution of 2.5m and 10bit quantization" (NRSA, n.d.). The downloaded, clipped, and projected raster had a high value of 445 and a low value of -105 meters. The slope was generated, reclassified, and ranked according to Shubhasmita *et al*. (2014): 0°-5°(4), 5°-15°(5), 15°-25°(3), 25°-35°(2), and 35°-52°(1) (Figure 3). From the findings, the most suitable slope ranges between 0° and 15°, which was captured accordingly in this classification.

Image Classification

The process of classifying or grouping all the pixels in an image or unprocessed satellite image to allocate land cover features is known as image classification (Al-doski, Mansrol, and Shafri, 2013).
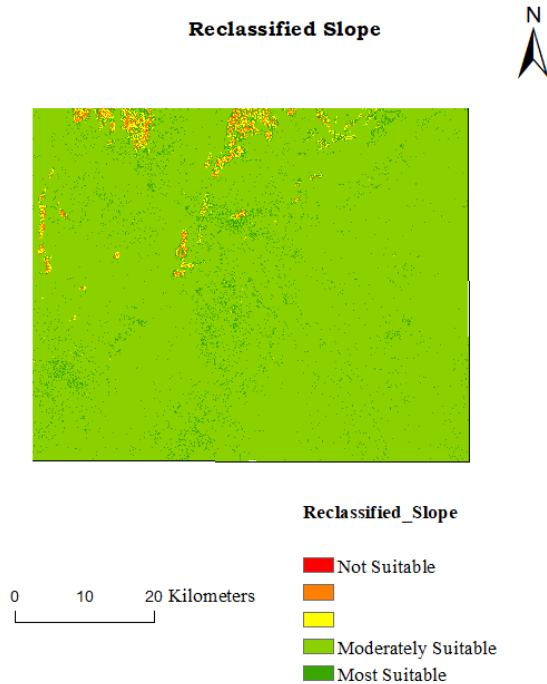

Figure 3. Reclassified slope in the study area (30 x 30 m cell size).

The imagery was downloaded from the United States Geographical Survey (USGS) Earth Explorer using the WGS84 geographic coordinate system with a 30 m resolution. The downloaded image was georeferenced. The georeferenced image was clipped and then used for land classification by creating a signature file using the ArcGIS Classification toolbar. The classification was done while also referencing the land use appearance on Google Maps. The classified image was projected to WGS 1984 UTM ZONE 44N. The satellite image was classified into 6 classes: 1) land, 2) water, 3) river sand, 4) vegetation, 5) hill forest, and 6) urban. The classification is shown in Figure 4.
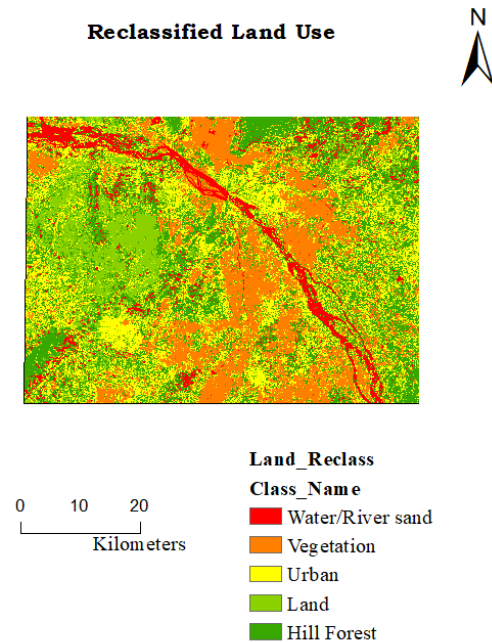

Figure 4. Land use classification in the study area (30 x 30 m cell size).

Euclidean Distance

The Andhra Pradesh Capital Region Development Authority (APCRDA) has mainly two modes of transportation between cities: 1) roads, and 2) the railways network. In the study area, roads and railway lines pass through the main cities, so for the solid waste disposal site selection, it was decided to calculate Euclidean distance for roads and railway lines.

In this study, Euclidean distances were calculated and reclassified based on Nishanth *et al*. (2010) and Alanbari, Al-Ansari, Jasim, and Knutsson, (2014). The Euclidean distance classifications for roads were given by Nishanth *et al*. (2010) and suitable distance to railways (greater than 500 m) was given by Alanbari *et al*. (2014). For both railways and roads, distances from 0 to 2000 m were considered too close to roads and railroads, distances between 2000 m to 3000 m were considered moderately suitable, and distances 3000 m to 5000 m

were considered most suitable for solid waste disposal site selection. Distances are shown in Figure 5.

Reclassified Euclidean Distance

0   10   20 Kilometers

Reclassified Euclidean Distance
- Not Suitable
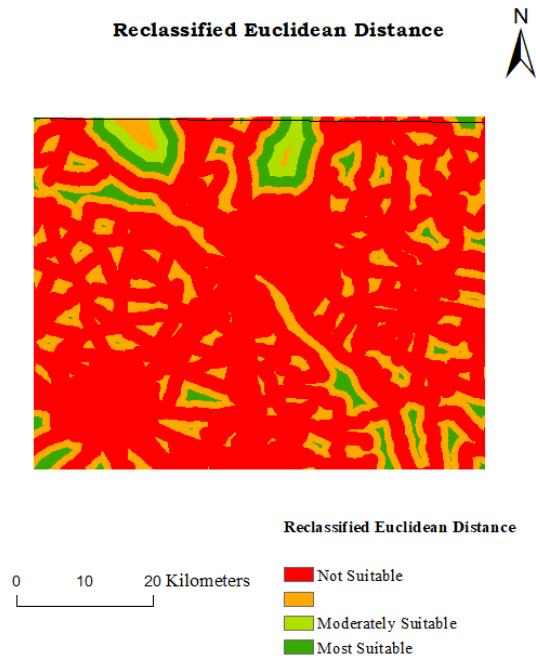- Moderately Suitable
- Most Suitable

Figure 5. Reclassified Euclidean distance for roads and railways in the study area (30 x 30 m cell size).

Weighted Overlay Analysis

According to Esri (n.d.b), solving multi-criteria problems such as site selection and suitability analysis is best accomplished using the Weighted Overlay tool. In this study, Esri's Weighted Overlay tutorial steps were applied to the reclassified Euclidean distance to transportation raster, slope raster, and the land use classification raster datasets to meet the goals of the research. Steps for weighted overlay are as follows.

Reclassified Euclidean distance to transportation values were assigned new values from 1 to 5. One was for least suitable and 5 was for most suitable. This was the suitability range already applied to slope. In the land use reclassification, the least suitable value of 1 was assigned to water/sand, 2 to urban, 3 to hill forest, 4 to vegetation, and 5 (most suitable) was assigned to land.

Second, to match the suitability scale of the reclassified Euclidean distance to transportation and slope rasters, the scale used by the Weighted Overlay tool was changed from the default range of 1 to 9 to 1 to 5, where 5 was considered most suitable, and 1 was least suitable.

Later, the input raster datasets were added to the weighted overlay table. The sum of weights assigned to input rasters should be equal to 100. This study was based on the Esri (n.d.b) examples. Land use was assigned the highest percentage of influence with 65%, followed by 25% slope, and 10% for Euclidean distance to transportation (Figure 6).

Weighted Overlay

0   10   20 Kilometers

Weighted Overlay Value
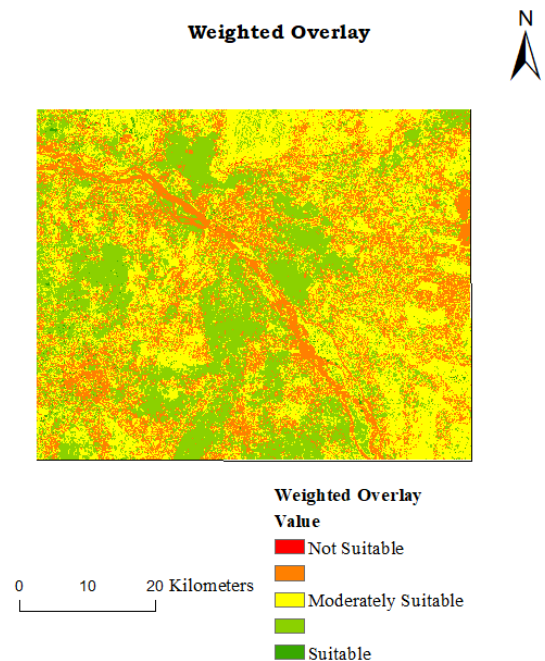- Not Suitable
- Moderately Suitable
- Suitable

Figure 6. Weighted Overlay result in the study area (30 x 30 m cell size).

Final Suitability

In the final suitability analysis, two rasters (weighted overlay result and constraints obtained by the Raster Calculator) were evaluated on a cell-by-cell basis.

According to Esri (n.d.c), the Times tool is considered the best tool to multiply two rasters on a cell-by-cell basis; however, the multiply operator (*) was used in the Raster Calculator as a matter of convenience. In the final suitability raster, shown in Figure 7, green areas were considered suitable for solid waste disposal and red and dark yellow areas were unsuitable for a solid waste disposal site (Figure 7). According to Esri (n.d.b), changing values and weights could produce a different output.
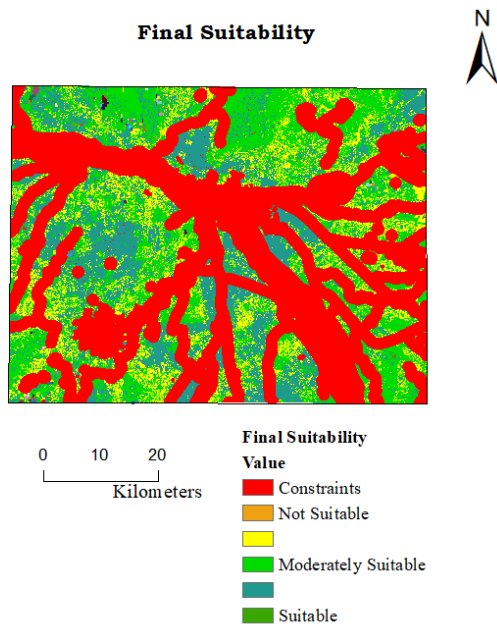

Figure 7. Final suitability result in the study area (30 x 30 m cell size).

Suitable Tracts of Land

Based on the final suitability raster, suitable tracts of land were identified. The Set Null tool was used to isolate the cells with a suitability value of 5 using the expression "Value < 5." The ArcGIS's Raster to Polygon conversion tool was used to convert the resulting raster into a polygon feature class. A long integer type field was added to the attribute table of the resulting feature

class, and the shape area was calculated in square meters using the Calculate Geometry operation. A selection was made by querying from the suitable tracts of land those with an area > 0.02 km^2. In Figure 8, suitable polygons are shown in black and selected (light blue) polygons have an area greater than 0.02 km^2.
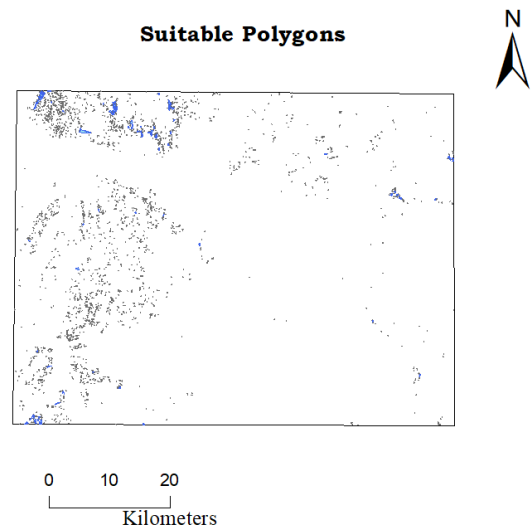

Figure 8. Suitable polygons in the study area. Black areas are suitable areas, while light blue polygons are suitable areas > 0.02 km^2.

All the blue polygons shown in Figure 8 (suitability = 5 and area > 0.02 km^2) were further analyzed using the ArcGIS Tabulate Area tool to determine the contributing area of every land use class. According to Esri (n.d.d), "When the zone and class inputs are both rasters of the same resolution, they will be used directly". The Polygon to Raster tool was used to convert the obtained suitable polygons and project them into WGS 1984 UTM Zone 44N at the same resolution as the land use raster (30 x 30 m). Input features were the projected raster polygons obtained from the query (suitability = 5 and area > 0.02 km^2) and the input raster was the land use classification. The resulting table included fields for each land use class, including hill forest, urban,

land, vegetation, and water/river sand with values indicating the area of that class in each polygon. For example, in the resulting table, polygon number 2808 has a value of 0 for water, vegetation, sand, and urban, 0.011910 km^2 (2.69%) for hill forest, and 0.430608 km^2 (97.3%) for land. During the weighted overlay, the highest rank (5) was assigned to land and lowest rank was assigned to sand and water (1). Out of 76 highly suitable tracts of land with an area > 0.02 km^2, four tracts were ultimately considered the most suitable (80% and above of the polygon area has a land use class of land).

Future Work

A supplementary investigation could be done with other factors such as population density and economy of the region which were not considered in this project. Furthermore, a field investigation may be needed for the selected tracts of land before construction. A study could also be done to bring awareness to younger generations regarding solid waste disposal.

Conclusion

The results of this study could be useful to prospective government officials and current city planners. With the steady increase in population in Andhra Pradesh over the past decade, identifying suitable solid waste disposal sites is important. This process can be simplified when using remote sensing and GIS. This study obtained data from several sources and integrated measurements in ArcMap appropriate to identify where suitable land is located for a new solid waste disposal site. The study found many areas in the capital region that met the criteria described in this project and would create a healthy environment for future generations.

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