Environmental Geographic Information System for Solid Waste Management in Municipalities of Mexico

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Abstract. In Mexico, solid waste handling is under jurisdiction of municipalities. However, with approximately 2400 municipalities, most of them rural, authorities struggle with the environmental and public health problems that poor waste handling generates. This project consists of an environmental geographic information system (GIS) that helps solve the issue of misinformation that many municipalities are going through, whose basic data about waste generation and other important aspects remain unknown. The system assists with the identification and estimation of parameters that are needed to plan or to dimension any waste handling facility (sanitary landfills, recycling plants, etc.). By introducing some basic and technical data about the municipality, the system performs an estimation of solid waste generation and composition as well as landfill type and size (according to Mexican norm NOM-083-SEMARNAT-2003) recommended for any particular municipality. The system is divided in two part: the calculator that gathers all the information about a given municipality (name, year, geographical location, population, etc.) and performs the technical calculations (projection of population, waste collection, financing institutions, etc.); and the GIS that performs spatial analyses using GIS to find potential locations for landfill sites within a selected municipality. Although the spatial analysis part is only available for a selected study zone (due to budget restrictions) the developed methodology can be applied to any other region. The calculator section of the system is completely finished, it is now possible to calculate waste generation, type and size of landfill for any Mexican municipality. The information used by the system comes from official sources such as INEGI, SEDESOL as well as specialized literature. The system will be available via internet in a web page and through a mobile application for smart phones, so that any municipal authority (or people interested) can have access to it. The results presented by the system are not to be taken as unique or official information but as orientative. The ultimate aim of this project is to trigger proper solid waste management projects in Mexican municipalities by enabling access to information for decision makers.

Keywords: GIS, solid waste, sanitary landfills, Mexican municipalities, mobile applications.

1. Introduction

Solid waste generation and its handling represent a huge problem for Mexican municipalities. According to the Mexican Secretary for the Environment and Natural Resources (SEMARNAT), there are only 82 authorized sanitary landfills in the Mexican Republic [4]. This is obviously insufficient to control the substantial quantity of waste collected. In Mexico, urban solid waste handling is under jurisdiction of municipalities and with approximately 2400 municipalities, most of them rural, municipal authorities struggle a lot with the problems that poor waste handling generates. Several studies [1, 4] have already identified the causes for the inefficient waste management in Mexico. Some of these are:

- Poor application of the concepts involved in proper waste management (specified within the Mexican Law for Waste Management – LGPGIR)
- In most cases, municipal authorities have poor knowledge of technical waste handling issues, which leads them to make decisions that might not be the best for their municipalities. Therefore, a lot of money and resources are also “wasted” in poor sized infrastructure or in very expensive technologies
that, in many cases, cause further problems such as: idle recycling plants due to high operation costs, sanitary landfills that get full to soon due to bad planning and operation, etc.

- Since urban waste handling is a responsibility of municipalities (among major others issues like water supply, tax collection, security, etc.) most of them have neither enough economic resources to operate it nor enough skilled workers to cope with waste matters, partly because these issues have been traditionally viewed as “non technical” issues.
- In Mexico, several institutions grant financial aid for projects related to waste management. However, these economic supports are not well spread, so the municipalities are not aware they can get access to funds by presenting a cost-benefit analysis of their project to improve waste handling.
- Mexico needs a scheme where public and private participation are encouraged to improve waste management at different levels and within the whole country.

Taking that in mind the idea of an “Environmental Geographic Information System for Solid Waste Management in Municipalities of Mexico” was developed. The system is aimed at municipal authorities or environmental professionals that are or might be working in waste handling projects or any other people interested in knowing data about waste generation in any Mexican municipality.

2. Method

The system consist of two parts: one that makes all the basic questions to the user to answer and from that information it performs the calculation of technical data, and the second part that is the GIS itself which finds out suitable sites for landfills (by means of spatial analysis) and displays the result from both the calculator and the spatial analysis part.


Waste generation per-capita and total waste generation and collection are among the basic data needed when optimizing waste collection and dimensioning waste management infrastructure. However, this information is often unknown or miscalculated by most of the Mexican municipalities when building infrastructure [1]. So, one of the issues to be solved by the proposed system is the lack of information about waste generation. By introducing some data about the municipality, the system gives an estimation of the generation/composition of solid waste for any selected municipality, giving also information about types of disposition sites that are recommended for that particular town, taking into account population size, sub-products expected by geographical region [5], possible financing sources, etc. Figure 1 shows some data entry and the basis on how this part of the system operates.

The system starts by asking a year of start (of the intended project), state and municipality. To avoid error during data entry, the system displays the states and then the municipalities within this state so that, later on, the system can load other data (population, per-capita waste generation, total waste generation, etc.) from databases incorporated to the system. When available, information used by the calculator was obtained from official sources such as the Mexican Geography Institute (INEGI) whose database “Projection of population by municipalities 2000-2050” was incorporated and it is used by the system to obtain the population growth and to estimate the total waste generation and size of a landfill with a life span of twenty years (which is recommended as well by financing institutions so that a municipality be eligible to receive resources for waste infrastructure). In other cases, where official information was not available, data from specialized literature (in waste management) was integrated to the system. For example, the method to design the size of a landfill for any municipality was taken from publications by the Health Pan-American Organisation [2] and this method has been integrated within the system. Finally, the calculator section also includes the requisites that Mexican NOM-083-SEMARNAT-2003 imposes regarding site selection and construction of sanitary landfills.

Once the user has input data, the system carries out the following operations:

- Solid waste generation and estimation of waste composition: the projection of population to the next twenty years comes from the database published by INEGI.
- Total solid waste generation (twg): generation per capita taken from specialized literature) X Inhabitants (input data)
Solid Waste composition: depending on the geographical zone (the system automatically locates a municipality within its corresponding zone: north, south, center, border and metropolitan area) values of waste composition percentages (published by SEDESOL) are applied. Total solid waste generation is then multiplied by the percentages from this table [5].

Sources of financing: the system compares input data with the proceedings that each financing institutions sets and gives back information to the user. Example: If total waste generation > 70 ton/d then the municipality can apply for resources from PRORESOL, etc.

Environmental regulation NOM-083-SEMARNAT-2003: based on the twg, the system identifies which type of landfill is necessary for the municipality. Example: if twg > 100 tonnes/day then a “type A” landfill applies [2, 3]. Other data is also taken from this norm.

Fig. 1: Operational basis of the technical calculator part of the system.

2.2. Geographic Information System

The second part of the system consists of a geodatabase containing all the municipalities in the Mexican Republic. It also includes the base maps (for a selected study zone) and shapefiles that would allow the system to carry out the spatial analysis to find potential places for sanitary landfills within a selected municipality. Table 1 shows some of the restrictions that are to be taken according to NOM-083-SEMARNAT-2003 [2].

Table 1: Distances and restrictions to infrastructure to be preserved when selecting landfill sites

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Distance to</th>
</tr>
</thead>
<tbody>
<tr>
<td>Airports</td>
<td>&gt; 2 Km</td>
</tr>
<tr>
<td>Towns and cities (with more than 2500 inhabitants)</td>
<td>&gt; 0.5Km</td>
</tr>
<tr>
<td>Lakes, rivers, water courses</td>
<td>&gt; 2 Km</td>
</tr>
<tr>
<td>Natural protected areas (ANPs)</td>
<td>out</td>
</tr>
<tr>
<td>Water wells</td>
<td>&gt; 1.6 Km</td>
</tr>
</tbody>
</table>

Not all the restrictions mentioned in NOM-083-SEMARNAT-2003 are suitable to be presented in the GIS. Hence, the restrictions were reduced to those that can be represented in forms of vector or raster data in the GIS. On the other hand, other attributes which are not contemplated in the norm were decided to be added (for example, soil type, land use, existence of roads, etc.) to complement the information given to the user. These attributes might not be that critical for landfill selection, but can be useful in decision making [6].
The system then performs a series of spatial analyses (buffer creation mainly) to find potential suitable sites for landfills. Figure 2 shows how the results of the spatial analyses part look like:

![Potential suitable sites for landfills.](image)

3. Results and Discussion

So far the calculator section of the system is completely finished. That is, it is now possible to calculate waste generation, type and size of landfill for any Mexican municipality. The system is being programmed on both web and mobile platforms to make it available for the most of potential users. Here is list of some of the results obtained for the municipality of Coyotepec, Estado de México (starting at year 2011) under the following scenario:

- Year: 2011
- Extra covering material factor: 25%
- Additional area factor: 30%
- Waste compacting factor: 450 Kg/m³
- Percentage of waste collection in the municipality: 40%
- Landfill height chosen: 4 m
- Recycling facilities?: Yes

Outputs

- Daily estimated waste generation: 44.45 ton/day
- Collected waste (to landfill): 17.78 ton/day
- Type of sanitary landfill: Type C (topographical and geotechnical study before construction is required)
Figure 3 presents a quick view on how the results are shown to the user (one of several screens):

![Figure 3. View from the Environmental GIS for Solid Waste showing results for a particular municipality.](image)

The system is aimed at municipal authorities or environmental professionals that are or might be working in waste handling projects or any other people interested in knowing data about waste generation in any Mexican municipality. The data provided by the system is informative. The results presented are not to be taken as unique or official information but as orientative. The result facilitates the process of structuring waste handling projects at pre-feasibility level and it is intended to trigger better projects within municipalities.

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5. References


