A Semantic Environmental GIS for Solid Waste Management

Miguel Felix Mata Rivera, Roberto Zagal Flores
Computing Mobile Laboratory
UPIITA- IPN, ESCOM- IPN
Mexico City
{mmatar@ipn.mx,@zagalmmx@gmail.com}

Diana Castro Frontana, Consuelo Garcia Mendoza
Soil Laboratory, Systems Department
ENCB-IPN, ESCOM-IPN
Mexico City
{dgcastro@ipn.mx,varinia400@hotmail.com}

Abstract— **Nowadays, solid waste handling is a critic problem. Governments and specialists of different disciplines wrestle with environmental problems that poor waste handling generate. For example, in México city the sanitary landfills have been overstepped in their capacity. Then, they are inadequate for the collection and processing of municipal solid waste. We propose as a solution a multi-criteria approach based on semantics, in order to get the adequate place to built any waste handling facility. In this research, a methodology implemented in an environmental GIS system (EGIS) is shown. EGIS identifies and estimates several parameters required for planning or to dimension a waste handling facility (sanitary landfills). The approach proposed involves a multi-criteria solution that includes: environment considerations, administrative parameters, spatial analysis, constraints and Mexican regulations. All of them are combined and processed based on Mexican normative rules. In order to get a management of municipal solid waste (MSW) and a geo-environmental recommendation to locate sanitary landfills in places that comply with official regulations. The results are potential locations for a sanitary landfill site. In addition, information of possible financing sources is given to carry out waste handling projects accordingly. Methodology can be applied to other countries with similar problems regarding to sanitary landfills. Results obtained are better when semantics and multicriteria are combined that when they are used isolated.**

Keywords-Solid Waste Management; Environmental GIS; Spatial Semantics

I. INTRODUCTION

Today, the handling of Solid waste generation is a critic problem for Mexican municipalities. The Mexican Secretary for the Environment and Natural Resources (SEMARNAT by its acronym in Spanish) [3] have reported that there are only 82 authorized sanitary landfills for 2400 municipalities in the Mexican Republic. This is obviously insufficient to control the substantial quantity of waste collected. In Mexico, urban solid waste handling is under jurisdiction of municipalities. Solid Waste are those originated in the domestic and commercial activity of cities and towns. The waste produced by urban dwellers include garbage, old furniture and appliances. Packaging and waste from commercial activity, remains the care of the gardens, cleaning the streets.

Mexico is confronted with major problems in the management of solid waste. Owing to rapid industrialization and population growth in urban centers. There are programs at the municipal level for Prevention and Management of Municipal Solid Waste (MSW). They require several stages from analysis and diagnosis, assessment to strategy approval and publication of results. In order to qualify the feasibility to construct a new sanitary landfill that complies with Mexican regulations and norms.

Another problem is that the availability of information and tools for proper management of solid waste is missing. (Regulations, available technologies, cost analyses, viability studies). Among other issues are completely unknown by people involved. Therefore, the public or private sectors rejects projects of this nature by consequence. Several studies have already identified the causes for the inefficient waste handling en Mexico [4]. Main of them are: Poor application of the concepts involved in proper waste management; null knowledge of technical waste handling issues: idle recycling plants owing to high operation costs, sanitary landfills that get full very fast owing bad planning and operation, etc. In Mexico, several institutions grant financial aid for projects related to waste management. Nevertheless, it is required to present a cost-benefit analysis of their project to improve waste handling (municipalities have no people to generate it).

Therefore, it is necessary to develop systems that support each of the aspects. They can provide preventive measures and planning to the future. We proposed the development of an Environmental Geographic Information System (GIS). On it, each municipality manages information on waste handling projects. It is addressed to municipal authorities or environmental professionals. They might be working in waste handling projects. System is available for any other people interested in knowing data regarding waste generation. This information can be processed for any Mexican municipality.

II. RELATED WORK

An environmental system is a unit whose elements interact together as they continually affect each other. They operate toward a common goal: take care of the environment around us. Landfill Management is a problem that has been treated from long time. A multicriteria approach has been used in [1], where a system manages recollection, transportation, recovery and disposal activities. But the issues of a landfill construction are not treated. In addition, not semantics processing is used. In [9], a multi-criteria decision analysis for supporting the waste was formulated by integrating interval-parameter, mixed-integer, and chance-constrained programming methods. But is addressed to find a balance between cost and diversion rate of waste management. While in [10] research is focused on the optimum selection of the treatment and disposal facilities, their capacity planning and waste allocation under uncertainty associated with the long-term planning for solid waste management. The difference with our work is the planning; we take into account long, short and medium term.

Other works have treated Solid Waste, but at recollection level like in [4] the work is focused on location of the containers. As well as, the amount estimation of the deposited therein, and routes generation for recollection in municipality of Prat de Llobregat. A similar approach to our work is presented in [2], where Multi-Criteria Decision Making ontology with an inference engine is used. Opposed to our work the paper referenced is focused on distributed autonomous devices. Otherwise, logistic regression model have been used as a methodology in [5] as a part of studies related with MSW. Neverthless, semantics processing was not used. In our research, spatial semantics is used to analyze data. In a similar way that a person who interprets qualitative variables. This approach has been used in works like [6]. Other related approach where semantics processing is used, can be found in [7, 8]. A survey in [11] reviewed the models of MSW generation and to propose beneficial design options concerning regional sampling and other factors, the final result is a relevance tree for methodology used in the works reviewed.

III. METHODOLOGY

The methodology used in this work is described in four steps as follows:

1) *Define axioms and establish rules using Mexican legislation, specilist criteria and the mexican norm (NOM-083 by ist acronym in spanish)*

2) *Design and built ontology based on constraints from NOM-083 and define spatial semantics relations.*

3) *Define geographic operations (spatial analysis) to answer generated queries in semantic module*

4) *Design and implement Web services and mobile app.*

The methodology is applied into a system composed of four modules: 1) Semantic 2) Geographical, 3) Web, 4) Environment, 5) Mobile. General functionality is described as follows and posteriorly in detail:

Environment module: It is a Management Solid Waste (MSW) calculator. It receives data from user and processes them with data from official data sources, taking into account the requirements, constraints and statistical data. Such as: what is minimum distance required to built a MSW from an airport, from a natural protected area, moreover the module indicates if these distances can be relaxed if other studies are made. As well as topographic and geologic aspects, among others. The module works using a semiautomatic process.

Semantic module: Determine the set of geographical operations and queries to find the adequate zones for sanitary landfill construction to any municipality. The data input are processed, filtered and analyzed in conjunction with a set of rules from Mexican norm (NOM-083-SEMARNAT-2003) and environmental constraints. The result is a set of attributive parameters such a as: what type of landfill sanitary should be built (in accordance with population size), the candidate geographic area, and constraints-descriptions of geographic objects within of area selected. Data are re-sent formatted as a geographic query to geographic module.

Geographic module: Here, the goal is to make the spatial analysis required to answer the geographic queries received by the semantics module. For example, flooding areas at 10 km to each possible landfill sanitary location. Output is a map with the potential zones to become a landfill sanitary.

Web and Mobile module: Displays area suitable for construction of a landfill. On maps interface. In addition, detailed reports with suggestions for financing the construction of an landfill sanitary. The mobile version offers the same functionality. It uses a set of Web services to communicate with the modules. Each module is able to respond itself, however it is necessary, the interaction of all modules, receiving the correct inputs and generating outputs when is necessary. Figure 1 shows the general operation of system.

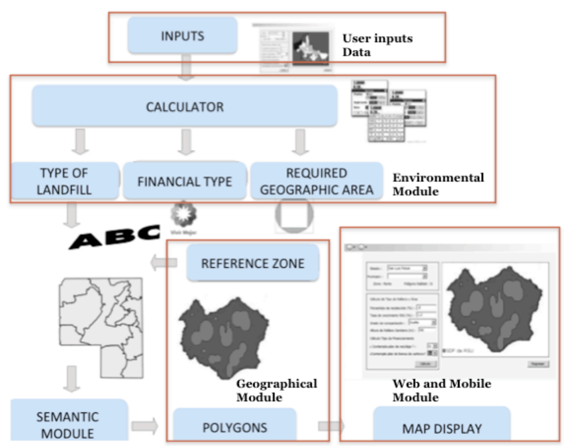

Figure 1. Working diagram (inputs and outputs of system)

Figure 1 shows the flow process, and what operations belong to each module, letters ABC is the type of landfill. The system processed information from official sources such as Mexican Geography Institute (INEGI). These sources are used to estimate total waste generation, size of a landfill and population growth. In other cases, where official information was not available, data from specialized literature is integrated to the system. For example, the method for designing the size of a landfill for any municipality was taken from publications by the Health Pan-American Organization [5]. Environment module receives the following input parameters: population size, subproducts suitable of being recycled, possible financing sources, etc. Output is a set of parameters: type of landfill sanitary, sort of financing and required geographic area. These parameters are interpreted by the semantic module (applying axioms) and sent as a geographic query to geographic module. For example, if output is: landfill sanitary of type three. The constraints applied to this sanitary type are retrieved from semantics relations of this concept. It can be the required area, the estimated growth population, estimated percentage of recollection per day. These constraints are formatted as a string array and sent to geographic module to be transformed into a geographical query (in this case, find areas of 20 km in municipality, because this area is required by landfill type 3). Then, geographical module determines which spatial analysis are required to perform in order to satisfy this query. The result is a map showing potential areas to landfill sanitary. The map display is performed via the web and mobile module which is rendered for appropiate visualization on each device. The general architecture,with some technical details describes the functionality; see Figure 2. In Section IV, the semantic processing is described in detail.

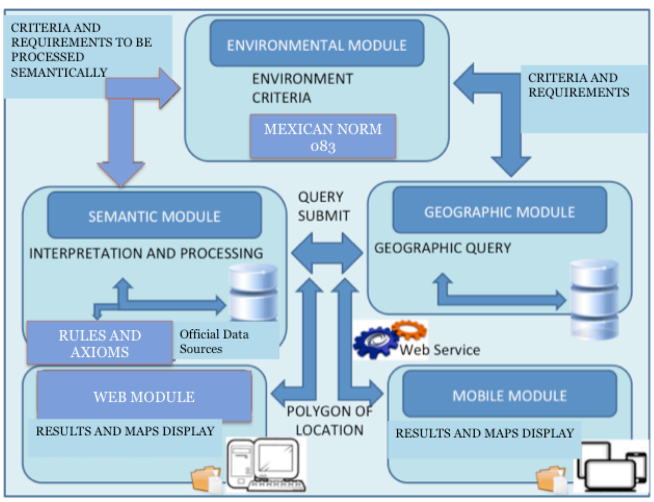

Figure 2. General architecture of system.

Figure 2 shows the data sources and scheme of communications. Data sources are divided into semantic and gepgraphic module, it is due to heterogeneity, data are inserted by XML format. In the case of web module, the communication with semantic module is direct by sending the candidate geographic area (polygon of location). The mobile module is made by using a Web services. The complete process is described in Section IV.

IV. SEMANTIC AND GEOENVIRONMENTAL PROCESSING

Semantic processing involves applying several axioms to get the appropriate place to build a landfill sanitary. Computing the growth population projection, estimation of solid waste generation, among other geographic and environment factors. There are constraints that can be applied to these factors. Some rules and axioms are defined in order to define which of them should be applied. Also, the spatial analysis should be performed. Moreover, in what cases some value factors can be relaxed. In addition, to find financial sources to built a landfill sanitary in municipalities with a small budget. The ontology contains 4 classes and 17 entities. The rules are grouped as follows:

a) Geographic areas conditioned for a sanitary landfill contruction. It means that these areas can be availability if some additional studies and formalities are made; b) Geographic areas not allowed. For example, wells at a certain distance, proximity of lakes, etc., c) Minimum and recommended values of distances between geographic objects and possible areas of landfill construction.

Figure 3 shows the ontology with its classes, too, constraints, relations and concepts that allows to make the semantics processing for data inputs.

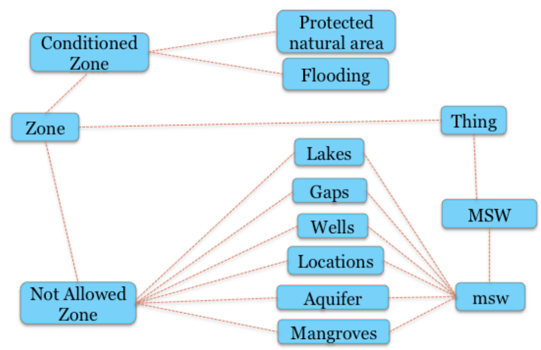

Figure 3. Graph of ontology.

In Figure 3 appears grouped by hypernymy, meronimy semantic relations and the concepts that are classified as not allowed zones. In the same way are grouped to conditioned zones. The following are some examples of axioms used in semantics processing:

Axiom A: If municipality has airport, then minimum distance to airport location is 20 km from landfill location. Flexibility: Aviary study. If an aviary study is presented, the minimum distance is reduced to 13 Km.

Axiom B: If landfill location is close to flooding then a long term of flooding (50 years).

Axiom C: If data total waste generation (twg) > 70 ton/day then the municipality can apply for resources from a Mexican infrastructure fund like PRORESOL (acronym in Spanish).

Axiom D: If twg > 100 tonnes/day then a "type A" landfill applies [3,2]. Depending on the geographical zone values of waste composition percentages are applied. Factor of twg is then multiplied by the percentages from this table [3]. The system analyses the input data to define which of them complies with the conditions and requisites requested by financing institutions to get sources of financing. In the case that not match was found the system indicates what studies or analysis are missing in order to get the funds. The

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software Protégé [12] was used to build the ontology in similar form like in [6]. The knowledge model eas implemented in OWL language. Ontology exploration is made using Hermit reasoner [13] with a OWL API. The semantic processing is performed in three steps: load ontology, runs the reasoning Hermit, relations are explored. The ontology returns a string array to be interpreted as a geograhic query by PostgreSQL engine. An example of the output is shown as follows.

ARRAY[

['', 'distance = 2000', 'MinimunDistance = 1000', 'exists = 1','', 'weight = 0.7', 'name = Lakes','"],
['', 'distance = 1600', 'MinimunDistance = 500', 'exists = 0','', 'weight = 0.7', 'name = Pozos','"],
['', 'distance = 0','', 'exists = 0','', 'weight = 0.8', 'name = Wetlands','"],
['', 'distance = 0','', 'exists = 0','', 'weight = 0.6', 'name = Soiltype,"],
['', 'distance = 2000', 'MinimunDistance = 1000', 'exists = 0','', 'weight = 0.7', 'name = Estuaries','"],
['', 'distance = 13000','', 'exists = 1','', 'weight = 0.3', 'name = Airports','"],
['', 'distance = 2000', 'MinimunDistance = 1000', 'exists = 1','', 'weight = 0.7', 'name = Lagoons','"],
['', 'distance = 0','', 'exists = 0','', 'weight = 0.7', 'name = Mangroves','"],

As is shown into array, several parameters appear; the *'weight'* attribute is computed based on the number of conditions complied and constraints flexibility. The scale used is from value 0 to value 1, where value 0 means that this place not qualify as a candidate for landfill construction.

The attribute *'exists'* represents if the municipality has a manage plan and funds to built the sanitary landfill. The value 0 means that no funds are required and value 1 means that is required a financial plan in order to get funds. Each one of these parameters is parsed by geographic module and transformed into a geographic query.

For example, the attributes:

'MinimunDistance = 1000', 'name = Lakes',

are transformed in query:

Q_{G1}=SELECT ST_Buffer_Meters(the_geom, num_meters) FROM MunicipalitiesTable;

The semantic engine consists of a browser, semantic reasoner and query designer. The process is as follows: a polygon (candidate area to a landfill construction) is received from Web module in WKT format (Well-known text) with its location. The reasoner performs an exploration of ontology to find the concepts associated, the output is formatted as a string array. And it is sent as an input parameter to the query designer. It get browser parameters. Parse the strings array and transformed into queries. They are executed in PostgreSQL [14] such as "find locations match conditions". The array syntax is:

*SELECT * FROM getHollows(ARRAY[[name=zzz', distance=#', `minimundistance=#', weight=#', 'exists=#', 'ManagementPlan=#']...] ,"polygon");*

where:

_Name is the name of the layer
distance: normal distance in meters between an element of a layer and MSW
_ Minimum distance: in meters for a feature and MSW.
(constraint added by the expert)
_ weight: is a weight (0 to 1) designated by the expert to identify which place has a greater weight than another.
_ ManagementPlan: exists (1) or not (0) a Management Plan.

The result is a list of objects containing geometry in WKT, the area of the polygon, the weight assigned to the layer, the layer name, the name of the polygon and the existence of the management plan. The function getLayersOntology() returns in a record two layers of possible locations: one with the normal distance and the other with the minimum distances (relaxed).

V. Experiments and Results

The study case for testing the system is with municipalities from San Luis Potosi (SLP) State, from Mexico. The attributes and values belong to these municipalities. A set of attributes is listed with values associated to define the size and type of landfill. Figure 4 shows a map from SLP State. On it is displayed the candidate areas to built a landfill sanitary considering the Mexican regulations and suggestions of specialists.

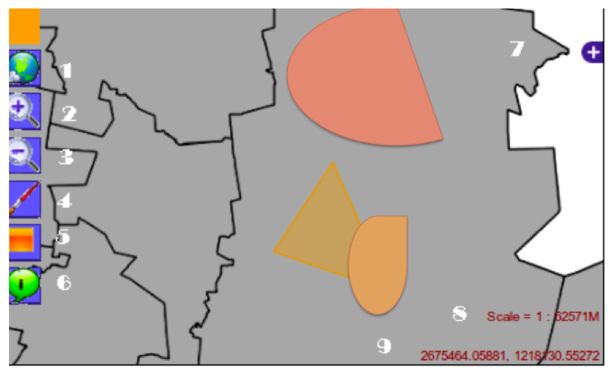

Figure 4. Potencial areas identified to be a landfill sanitary.

Figure 5 shows the areas generated. They represent the potential areas to build a sanitary landfill. Colors indicate the different levels of match. It means that an area match with the requirements from a 70% to 100%.

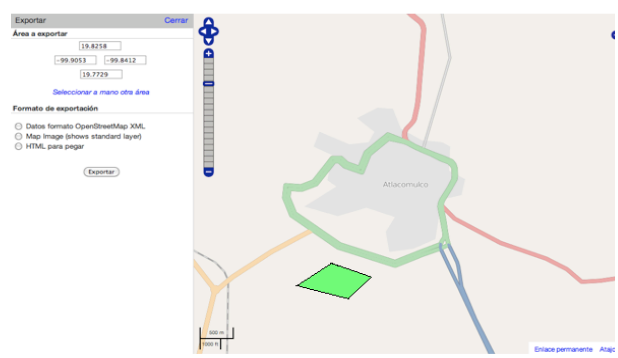

Figure 5. Potential area identified to become a landfill sanitary.

As Figure 5 shown, the descriptive data are obtained associated with the places showed on a map. In this case in green appears a rectangle drawed by user, the idea is to define if this area make with hand tool, is a good candidate to be a sanitary landfill.

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Figure 6 shows the mobile interface of system, the initial screen is a formulary to get the input data: state, municipality, period of term (years of study), etc. Other data are completed automatically by the app.

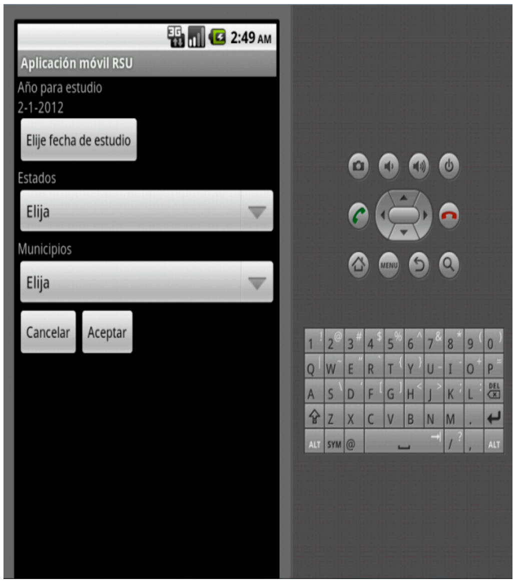

Figure 6. Input data into app in smartphone.

The process is started when data is entered and a connection with geographic module by web service is established. A mapping application mobile shown the result. See Figure 7.

Figure 7. Mobile version of calculator.

The green polygon in Figure 7 shows in this case the candidate area location to build a sanitary landfill in accordance with the user input's data.

VI. Conclusion and Future Work

In this approach, semantics processing is used to solve the cases when a sanitary landfill will be constructed in an area where some constraints are applied. As an example when a sanitary landfill will be near an airport. The Mexican norm establishes a minimum distance of 20km. In this case, the constraint is processed semantically and is obtained that if is performed an aviary study. Then, the distance can be reduced to 13 km. In this scenery without semantics processing will not be possible to get this result.

In addition, is shown how the semantics processing is combined with a multicriteria approach. In order to find a point where constraints can be flexible and comply with the rule. The methodology can be applied to other similar sceneries.

The multicriteria approach is based on weight schemes in order to get relevance for the geographic candidate areas. Based on it, is possible to offer a list of candidates for sanitary landfill construction.

This research is part of a multidisciplinary project. The main contribution is to use a multi-criteria approach combined with semantics. Here is described the overall functionality.

Results are compared with the results obtained without semantics processing. For constraints related with distances. The results are better using semantics processing. Because other areas are found as candidates, while that using only multicriteria approach these areas do not appear as candidates. At this moment, a panel of users is testing the system. They have different levels of expertise (environmental engineers, computer engineers, geographers and students.) The future work considers to include all the constraints for Mexican norm to be processed using the approach mentioned.

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