PROPOSAL FOR THE LOCATION OF A WASTE MANAGEMENT CENTER ON A UNIVERSITY CAMPUS: A CASE STUDY

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ABSTRACT

Garbage management and the use of waste are part of sustainable development goals (SDGs) 8, 11, and 12. The recycling process is simple and contributes to improving the environment. Therefore, garbage management in Ecuador is a relevant issue that society must address regardless of the size of the community that generates it. In this case, university campuses need services and infrastructure, including waste management at the scale of a small city, because they require services like these (e.g., accommodation, transportation, cleaning, and waste management). This research seeks to propose the ideal location for a separation, assessment, and recycling center (CSVR), through the implementation of a multi-criteria matrix, with the application of the vertical electrical sounding techniques (SEVs), for the sustainable management of waste. The methodological process includes: (i) identification of probable sites; (ii) application of a multi-criteria matrix for CSVR; (iii) application of geophysical methods (SEVs); and (iv) interpretation of results and selection of suitable areas for the recycling center. Six sites were analyzed, of which three were ideal for the implementation of SEVs where there will be control and management of invasions, as well as non-contamination of water resources. All the selected areas are permeable in their superficial layer and favor leaching; therefore, waterproofing at its base and some design criteria that contemplate technical and environmental monitoring were recommended.
Keywords: garbage, recycling, water resources, vertical electrical surveys, resource recovery.

1 INTRODUCTION

Garbage or rubbish generation is a problem that affects the entire society due to its exponential growth [1]. This growth is mainly conditioned by per capita income, weather conditions, geographic areas, and cultural issues. In general, garbage is classified into two large groups: (i) trash, which includes that part of the garbage that is no longer susceptible to any use; and (ii) waste or residue, that garbage that can become a resource for a new good and service [2].

The pollution generated by a poor garbage disposal, or inefficient waste and residue management, also grows significantly [3]. This situation is aggravated by the difficult access to collection vehicles in marginal areas; additionally, this means increasing the unit price of waste collection and generating the illegal disposal of household waste that can cause significant problems to the environment and water resources, contaminating them with leachate [4]. First-world countries have considered this problem and have acted to minimize it [5]. In the European Union (EU) countries, suitable containers can be observed to separate and assess each waste, which can be used to manage a circular and sustainable economy [6]. The purpose of good waste and residue management is to seek mainly to reduce the amount produced, then it is about minimizing the amount of unclassified garbage eliminated, to finally increase the recycling of materials [7].The entities in charge manage the management of garbage produced by the community, generally local governments [8]. However, its

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doi:10.2495/WMEI220111

resources are limited and are directed to other areas; therefore, collection routes do not increase in depressed and/or marginal areas [9].

The decomposition of garbage generates leachates, which are liquids caused by the presence of organic matter, between 40% and 70% of the garbage [10]. In addition, they can be caused by factors such as the composition of the waste, discharge management, climatic conditions, the physical–chemical characteristics of the landfills, the age of the landfill, and biochemical demands [11]. Often, leachates have extreme pH, high chemical oxygen demand (COD) and biochemical oxygen demand (BOD), high concentration of inorganic salts, and relevant toxicity [12]. It should be remembered that leachate is the primary source of contamination of water resources, mainly underground [13], [14]. Less than 3% of fresh water is available on planet earth; Of this percentage, 30% corresponds to fresh groundwater [15]. One of the ways to determine the presence or not of underground water resources and the composition of the soil is through vertical electrical soundings (SEVs) [16]. SEVs are a practical method with a significant contribution due to their relevance in geological and hydrogeological studies. They can be applied for exploration projects in the depths of the underground layers in predetermined areas. It is necessary to investigate weathered, sedimentary material, rocks, runoff, and soil resistivity [17].

The study of SEVs serves to identify vertical sections in the upper layer of the soil; it generally sends electrical waves that analyze the resistivity variations of the material in the study area [18]. The electrical sounding of the soil is given to various nodes that are scattered within the analysis area, which allows understanding of the behavior of the soil and the type of existing material; all this is due to the device known as a Tellurometer, introducing alternating current using electrodes [19]. The electrical resistivity produced by a Tellurometer in SEVs studies serves to recognize the number of pores present in the different soil layers [20]. Additionally, in selecting a suitable site for the CSVR project, it is necessary to implement a decision matrix. It is a quantitative scheme that helps the team or subject analyze and identify the correct relationships between the set of project information; the evaluation criterion is provided by the analysis of the mode of action and a systematic consistency check [21].

Finally, geographic information systems (GIS) are applied, models with various geo-processing tools in ArcGIS, which generate several tools for geotechnical, environmental, topographic, road, and hydrological studies [22], [23]. The most used tools, according to information sampling, are raster DEM (digital terrain model for numerical data structure, which represents the spatial distribution of a quantitative and continuous variable) and TIN (digital elevation models to represent the morphology of the surface) [24], [25].

The Escuela Superior Politécnica del Litoral (ESPOL) in Ecuador, has a university campus that generates waste and collects it without proper processing [26]. This situation requires that the creation of a CSVR be addressed by running SEVS, applying a decision matrix, and being supported by GIS. In this case, using SEVs for a CSVR helps identify suitable areas far from the aquifers so as not to contaminate them with leachate or non-environmental factors [27]. Worldwide, especially in Latin American and Caribbean countries, the management and use of solid waste have been improving through investments and continuing education on the subject [28]. In neighboring countries, such as Colombia, the design proposal for a comprehensive recycling center, including alternative energy sources, has already been presented [29].

The purpose of this work is to secure the ideal location for a separation, assessment, and recycling center (CSVR), through the implementation of a decision matrix, with the application of the vertical electrical sounding technique (SEVs), which will delimit the hydrogeological zoning and suitable sites that present the best conditions, for the sustainable management of waste and use of residues in the university.

2 LOCATION OF THE STUDY AREA

ESPOL is the number one public university in Ecuador. It is located in the center-north of the city of Guayaquil, located on the Gustavo Galindo Campus, with the topographic zone 17 S on the Universal Transversal Mercator (UTM) scale. It coordinates East: 615230.56 m E, North: 9762623.83 m S (Fig. 1). The Campus has a size of 675.35 ha, where 332.30 ha are from the Prosperina protective forest, and 343.05 ha are the sites that could be intervened. Its topography varies with heights between 35 to 210 m above sea level. From a geological point of view, the Piñón formation (Jurassic) are emissions of volcanic flows with extensions in the oceanic crust, often produced by basaltic lavas "pillow lavas, and various volcanic intercalations" [30], [31]. However, at the local level, according to Sánchez Padilla et al. [32], it establishes that the Cayo Member, represented by volcanic materials, is the one that outcrops in the most significant extension of the study area.

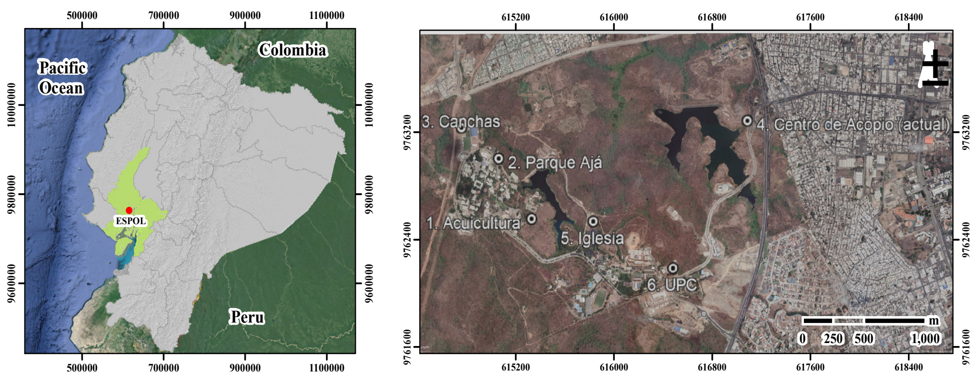

Figure 1: Study area.

3 MATERIALS AND METHODS

The implemented methodology is based on the scheme of Fig. 2, therefore there are the following phases related to the project. In Phase I of identification and information collection, the base data for the geophysical analysis within the Gustavo Galindo campus was obtained. This information includes the search for orthophotos, isohyet planes, hydrological data, soil and rock types, seismicity, and groundwater collection points. These data were obtained from the National Institute of Meteorology and Hydrology (INAMHI); the Ministry of Agriculture, Livestock, Aquaculture and Fisheries (MAGAP). In addition, the Google Earth application was used to obtain updated satellite images of the area. The information and data provided were analyzed with which a morphological map, infiltration analysis and landslide susceptibility map of the site were made.

The realization of the morphological map begins with the map of slopes in percentage. It is essential because it reflects the degree of inclination in analyzing its relief. According to the Agustín Codazzi Geographical Institute, within the Land Classification for its capacity to use, it is considered that 12% of the slope gradient is a critical point for mechanization. From this value, the susceptibility to soil erosion increases.

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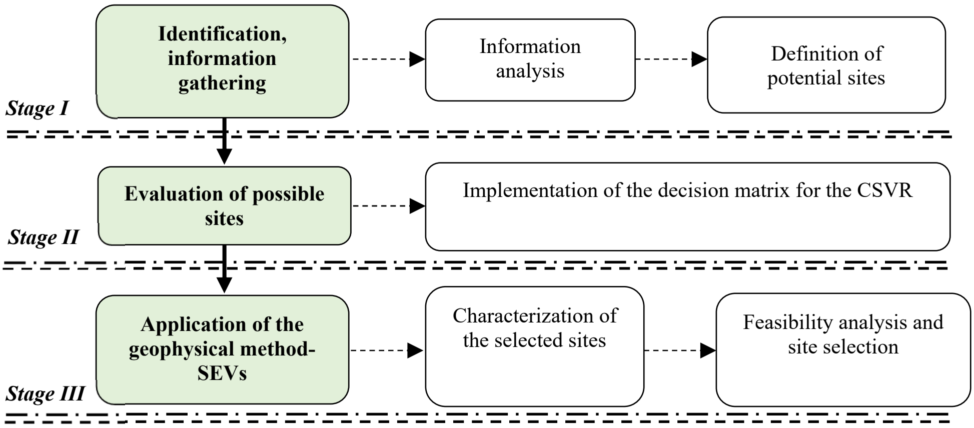


Figure 2: General scheme of implemented methodology.

The orthophotos, the water network, and the DEM were used in the infiltration analysis. The possible zones were created with a 50 m buffer, considering the MAGAP regulations, which suggest this distance for safety to carry out a study in case of any contamination.

In the case of mass susceptibility, also known as landslides, the Mora–Vahrson methodology is used, which is applicable in development zones because it requires few morphodynamic variables, and its application is relatively simple. The most significant factors are included from the point of view of slope instability, which is based on parameters that can be determined in an agile way.

With the results of these three criteria, it was possible to define six probable sites for evaluation in stage II.

In Phase II of evaluating possible sites, the method used uses a decision matrix (MCP), which seeks to facilitate the analysis of problems in a situation that is of great uncertainty or has inaccuracies of the specific terrain when it has a very high degree of complexity. Optimization through MCP must have calculations that involve critical criteria and evaluations that drive the final decisions on the optimal alternatives.

One of the fundamental parts of the segmentation process is determining the influence factors for quantifying results. The first step in creating a good MCP is to have a structure with analysis factors such as population, geotechnical, topographical, water bodies, and route alternatives. Considering the six locations (see Fig. 1), the MCP considers the following:

1. It must be far from runoff and infiltration areas to avoid contamination by leachate.
2. The CSVR must be distanced from the polytechnic campus's central "populated" area.
3. It cannot be considered located within a possible landslide hazard site.
4. The topography should be smooth with no slope.
5. The location must consider the route of the collection truck.

From these five factors, the MCP index is obtained, which allows the possible locations to be identified quantitatively (eqns (1) and (2)).

$$\text{MCP} = (\text{Coef. P.})\text{Population} + (\text{Coef. H.})\text{Hazard} + (\text{Coef. R.})\text{Runoff} + (1)(\text{Coef. T.})\text{Topography} + (\text{Coef. R.})\text{Route}. \tag{1}$$

*The coefficients are different for each factor:

$$* \text{Coef. of each Factor} = \frac{\sum \text{Factor analyzed}}{\sum \text{All Factors analyzed}}. \quad (2)$$

The Pugh matrix was implemented to obtain the coefficients, which quantitatively relate each of the studied parameters. The weight of the criteria is given by the technical point of view modelled in GIS, plus the information obtained throughout the research, for example, the conditions mentioned in Table 1 [33].

Phase III, which deals with the application of the geophysical method by SEVs in the selected sites; is done by supplying current to the ground through "electrodes", aligning them symmetrically concerning the center of electrical charge, placing four parallel electrodes, in such a way that the diameter can be increased to at least 100 m; they are placed throughout the study area and are called "current electrodes" (AB), and those that measure the potential difference are called "internal electrodes" (MN).

The application of the method in the field is based on the Schlumberger array to acquire the resistivity of the soil (eqn (3)), which orders the various electrodes in a specific way known as an electrode device. The theoretical foundation is based on the stationary electric field and on detecting the surface effects produced by the passage of electric current to obtain information on its properties.

$$\rho = 2 * \pi * R * (n + 1) * na \quad (3)$$

where ρ: average resistivity at depth (A); R: tellurometer reading in Ohms; N: electrode number; na: distance between electrodes in meters.

With the help of the ABEM Terrameter SAS 1000 equipment, a current is injected in short periods ranging from 0.5 to 0.4 second duration from the external electrodes, and information is collected through the internal electrodes, with a Schlumberger configuration with a range horizontal (AB/2) of 31.6 m, for which the equipment was placed with the established configuration and measurements.

It is necessary to carry out a previous field visit in the selected places to carry out the SEVs. The access of the equipment, excess vegetation, or the material found in the area, be it soil, or rock, can be determined, and avoid concrete. Once compliance with the conditions for the application of the electrical method is verified, a code can be assigned to each of these sites, and the fieldwork is prepared.

The interpretation is performed using the IPI2win software, which approximates the resistivity curve with an error of less than 5%, which increases the confidence level in the results obtained. It must be considered that these are approximations of the lithologies and their depths in the subsoil, a product of the subjectivity of the data since there are no fixed ranges of resistivities. These data tend to vary depending on fractures or water saturation parameters.

The feasibility phase, which usually includes the economic viability analysis, was not carried out because the three selected sites have the same characteristics at the ground and subsoil levels. Therefore, there will be the same expense and preparation in all three before placing the structure.

4 RESULTS

In Phase I, it was possible to identify and analyze the available information with which Figs 3–5 and Table 1 were prepared. In Fig. 3, the four implantation zones found are observed, which delimit the morphological map, such as alluvial colluvium, low hills, medium hills, and populated or non-applicable areas for the implementation of the CSVR. Fig. 4 is the map of the seven delimited areas for the measurement of infiltration. Fig. 5 shows the landslide zone map.

Table 1: Valorization of site selection.

Selected site	1. Aquaculture		2. "Ajá" Park		3. Courts		4. Current collection center		5. Church		6. UPC	
Factor	Sum. influence | Coefficient of each factor											
Population	5	0.14	8	0.21	8	0.22	7	0.19	8	0.21	6	0.17
Hazard (landslides)	8	0.23	8	0.21	9	0.24	7	0.19	7	0.18	7	0.19
Runoff	11	0.31	8	0.21	8	0.22	7	0.19	8	0.21	10	0.28
Topography	6	0.17	8	0.21	7	0.19	5	0.14	7	0.18	8	0.22
Route	5	0.14	7	0.18	5	0.14	11	0.30	8	0.21	5	0.14
Summary	35	1.00	39	1.00	37	1.00	37	1.00	38	1.00	36	1.00
MCP	7.743		7.82		7.649		7.919		7.632		7.611	

Table 2: Results of the SEVs implemented.

Location, and general description	Coordinates and elevation	Resistivity (ω m)	Description by layer
SEV01AC, highly fractured shale outcropping with clay, strike 12°N, located behind UPC (Fig. 6)	616490, 9762175, 85 m	71.6	Sand with gravel thickness of 2.63 m, with a depth of 2.63 m
		380	Consolidated shale (impervious material) with a thickness of 0.854 m, at a depth of 3.48 m
		20.9	Sands with clay, with a thickness of 2.52 m that extends to a depth of 6.01 m
		202	Fractured shale with clay at a depth of 19.8 m, with a thickness of 13.8 m
		1,724	Consolidated rock (fresh shale)
SEV02AC, heading 56°N, located near the ESPOL water intake (Fig. 7)	615823, 9762526, 99 m	79.6	Sand with gravel thickness of 2.32 m, with a depth of 2.32 m
		47.8	Shale fragments with clay with a thickness of 2.63 m, at a depth of 4.95 m
		206	Consolidated shale (impervious material) with a thickness of 15.2 m that extends to a depth of 20.2 m
		9.65	Fine sands with zeolites
SEV03AC, heading 30°N, located by the soccer fields (Fig. 8)	614760, 9763218, 89 m	560	Sand with gravel 0.495 m thick, with a depth of 0.495 m
		12.3	Fine sands with zeolite with a thickness of 0.977 m, at a depth of 1.47 m
		117	Consolidated shales (impervious material) with a thickness of 3.22 m to a depth of 4.7 m
		54.1	Medium grain sands at a depth of 9.49 m, with a thickness of 4.79 m
		109	Consolidated shale with a thickness of 11.4 m, at a depth of 20.9 m
		1,694	Consolidated rock

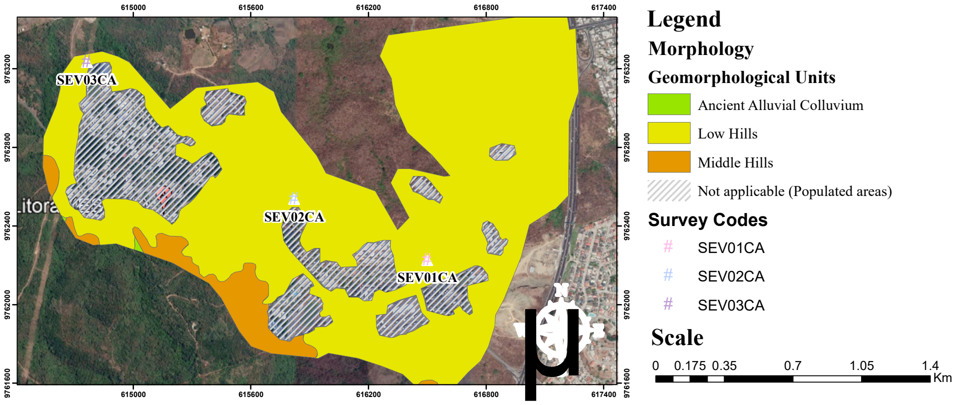


Figure 3: Morphology of the study area.

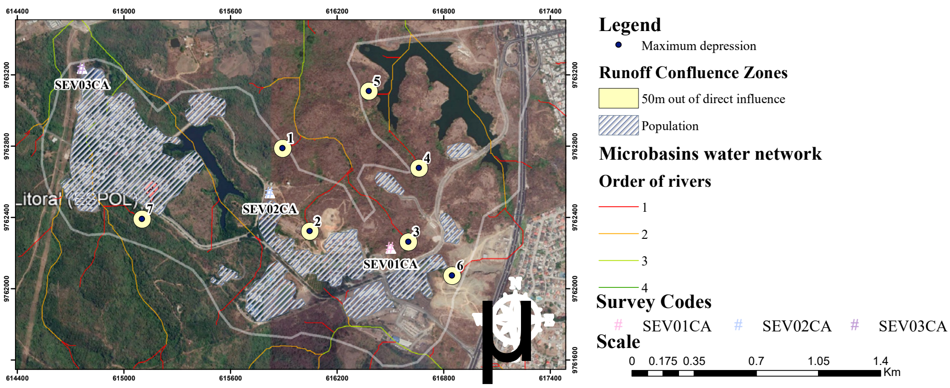
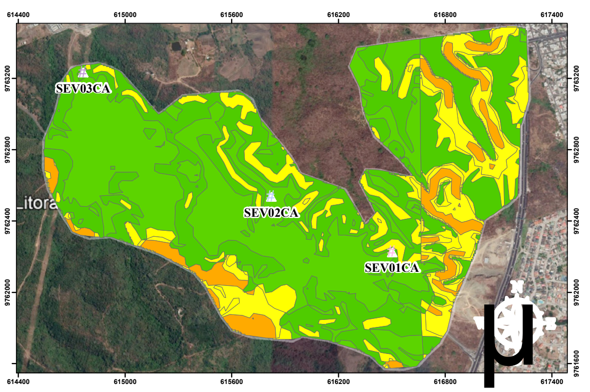


Figure 4: Areas of possible water infiltration.



ZONING			
CLASS	AREA (ha)	AREA (%)	DEGREE OF SUSCEPTIBILITY
2.1 - 2.9	105.01	34.45	*Very low*
2.9 - 3.6	114.82	37.66	*Low*
3.6 - 4	37.43	12.28	*Medium*
4 - 4.3	26.58	8.72	*High*
4.3 - 5.5	21.03	6.89	*Very high*
TOTAL	304.87	100%	

Figure 5: Susceptibility by Mora–Vahrson methodology.

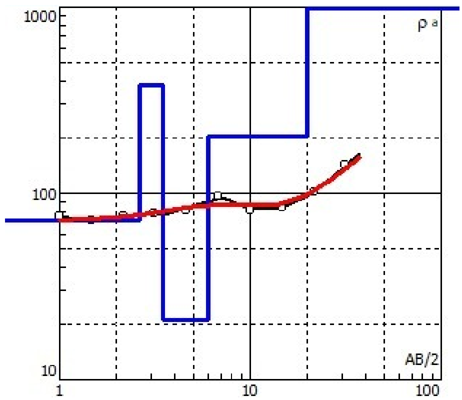


Figure 6: Data processing of point SEV01AC using the IPI2WIN program.

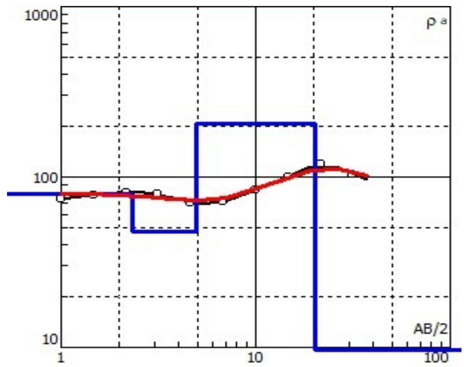


Figure 7: Data processing of point SEV02AC using the IPI2WIN program.

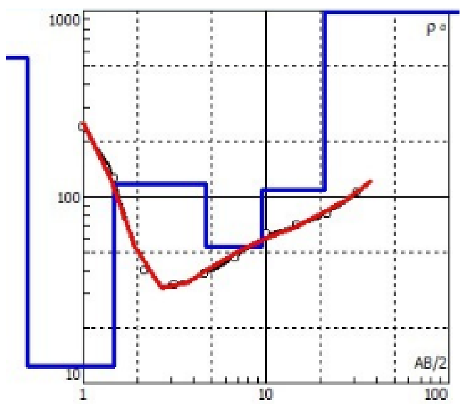


Figure 8: Data processing of point SEV02AC using the IPI2WIN program.

In Phase II, the evaluation of the five factors was carried out with a scale from 1 to 4. The results for each of the six points show in summary Table 1. The three points that obtained the lowest value have selected sites 3, 5 and 6.

In Phase III, which deals with the application of the SEVs geophysical method, these were executed in the three selected points of Phase II (Fig. 3), which now take the names of SEV01AC for point 6, SEV02AC for point 5, and SEV03AC for point 3. Table 2 shows the results. The implemented method achieved a total range of SEVs of 63.2 m, delving into the subsurface approximately one-third of the total range in the horizontal.

5 INTERPRETATION OF RESULTS AND DISCUSSION

The selection of sites where the SEVs were implemented fell on areas whose geological characteristics represent the best conditions to obtain good field data. Under these conditions, the selected places were three (SEV01CA, SEV02CA, and SEV03CA) located on the map (Fig. 1). As seen in Table 1, most of the MCP factors are in the medium to high range (7.611–

7.92). The highest indices are related to the areas where it is difficult to carry out the SEVs and build the CVRS infrastructure, while the lowest values are those that are optimal for carrying out the SEVs and placing the infrastructure. As shown in Kazuva et al. [34], the three places with the best percentage perspective at the time of mapping in GIS were chosen.

The data obtained from GIS and MCP were of great relevance for the reduction of the margin of error when monitoring the possible study sites; these were compared with the article "GIS- and MCD-based suitability assessment for the optimized location of solid waste landfills in Dar es Salaam, Tanzania". The results have a similar form, where various risk factors were also implemented, prioritizing the analytical study for the best approach to the matrix. When analyzing the article "Multicriteria Decision Analysis in Geographic Information Systems for Identifying Ideal Locations for New Substations" and comparing it with our result, it can be explained that the study proposed in both investigations can identify ideal sites, and they are used by the planner to find the best long-term design alternative for work [33].

According to the article "Multi-Criteria Decision Analysis and GIS Approach for Prioritization of Drinking Water Utilities Protection Based on their Vulnerability to Contamination", the values considered are prioritized concerning the weighted criteria based on the objectives expected for the level supply selection. As in this article, the correct sampling of information supported the decisions for the selection of an ideal site [35].

According to the article by Choudhury et al. [36] SEVs are considered for the determination of zones with aquifers directly related to soil and rock, to study the response of the layer and delineate potential zones, as was done in this investigation.

In Ecuador, geosynthetics are widely used in geotechnical engineering, such as slope improvement works, retaining walls, soil improvement systems, sanitary landfills, drainage control and filtration around geotechnical structures [37], [38]. Therefore, in this case it is not about a sanitary landfill but about the construction of the separation, assessment, and recycling center (CVSR).

6 CONCLUSIONS

This research proposed the ideal location for a separation, assessment, and recycling center (CSVR), through the implementation of a decision matrix, with the application of the vertical electrical sounding technique (SEVs). With this technique, the hydrogeological zoning and suitable sites that presented the best conditions were delimited.

From the analysis of the SEVs, it was found that the area is rich in sands, shales, and gravel. Correlating with the geological information of the area, through the interpretation of the field data of the areas where the drillings were carried out, it can be inferred that the contamination of the water resource could not occur. When carrying out the analysis of the three wells, the point SEV01AC is found to be a layer of approximately 3m that extends to a depth of 6.01 m. In the case of clayey material with sand, it is necessary to be careful because, although it is not considered a typical material for an aquifer, due to the presence of sand, it would be a permeable material. Therefore, it would have the possibility of absorbing leachate. Beyond 20 m, a very compact material was found, which decreases the probability of contamination of the water resource.

With all these considerations, it is concluded that the ideal site for the location of the CSVR is the one behind the UPC, at the coordinates (9762175 N, 616490 E) and designated as SEV01AC, which will allow the sustainable management of waste and use of waste at ESPOL.

ACKNOWLEDGEMENTS

We would like to thank Edgar Berrezueta, (Senior Scientist of the Instituto Geológico and Minero de España (IGME)) for his collaboration in the review process of the structure and content of the manuscript, and Ing. Carola Gordillo, Physical Infrastructure Manager of ESPOL – GIF for the support to the executed work.

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