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WEIGHTED SUITABLE MODEL FOR ZONING HIGH ENTHALPY GEOTHERMAL RESOURCE

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ABSTRACT

The weighted suitable models are used to solve complex problems; their purpose is to find a better location in order to develop a specific activity. Therefore, this type of models can be used to zone the high enthalpy geothermal resources. Nonetheless, it is necessary to synthesize and organize all the data and information, obtained from geo-scientific studies that was generated during the exploration phase (teledetection, geology, geochemistry and geophysics) in thematic layers, before they can be applied to anything, which are then processed with the help of GIS software; with the goal of making a integrated spatial analysis, through the use of algebra of maps, which seeks to select the sectors with the most suitable values for each coverage, defining the sectors with the greatest geothermal potential, and the results are expressed in easier ways to understand. All this makes it easier for the decision-makers, at the time of sitting of deep drilling.

1. INTRODUCTION

Given the global energy crisis due to the scarcity of fossil fuels, the use of geothermal resources is one of several ways to address the energy demand increases every year. Geothermal energy conforms to the global environmental policy as a clean energy and sustainable harvesting, which causes a low environmental impact during development and production stages.

However, to corroborate the existence of geothermal resources at depths commercially exploitable, you must manage an exploration program, which integrates and interprets the results of geo-scientific studies in order to locate the sectors with the greatest geothermal potential.

Everything mentioned above has motivated the present work, which proposes a method that uses advances in technology through the use of geospatial techniques to zone the high enthalpy geothermal resource associated with volcanism. This is obtained by applying a weighted suitable model, which integrates the data and information from the geo-science studies, which are geo-processes through map algebra. Translating the results in an easy way to understand could be really helpful for people to use, people who are not necessarily knowledgeable in the matter. So that, it can facilitate the work to the decisions-makers when selecting areas for drilling, increasing the likelihood of successful wells.

2. GEOSCIENTIFIC STUDIES CARRIED OUT DURING THE EXPLORATION OF HIGH ENTHALPY GEOTHERMAL RESOURCES

Geothermal exploration studies are initiated at the regional level with extensions that may exceed 1000 km^2 (Goldstein, 1988, Wright et al., 1989), its objective is to select one or more sections called "Prospect Areas" Within these areas of interest, geoscience research have become of greater detail, in order to locate evidence from the surface indicating the existence and location of geothermal reservoirs at depths economically exploitable.

The data and information generated by studies (teledetection, geology, geochemistry and geophysics), during exploration, are organized into thematic layers and used as a basis for creating and developing the weighted suitable model, which is processed by GIS software.

2.1 Teledetection

At the beginning of the exploration studies, the use of remote sensing is an invaluable tool, giving biophysical land surface information without any contact with it. Recent advances in this field have opened an opportunity to implement some of the exploration of geothermal energy from space, which provides information for large areas (some of difficult access) in different resolutions: spatial, temporal and spectral.

Satellite images, radar, aerial photographs and digital elevation models, are studied in order to locate points of geological and structural interest, which are then visited to complement and / or evaluate existing information. At the same time, marked lineaments, using morphological criteria (alignments and / or inflections: river beds, watershed, craters and scars of landslides), which can respond to geological structures. As attribute to build the lines layer called "Remote Sensing Lineaments" is used the length of the traces (Table 1, Figure 2).

TABLE 1: Remote sensing Lineaments

	Remote Sensing Lineaments
	Length Location tolerance: X, Y ±

2.2 Geology

During the geothermal exploration, geological works are the first ones carried out in the field. Through these works areas that need to be further investigated are identified and recommended. They are the basis for interpreting the results obtained through subsequent geoscientific studies. The main information that is extracted is: description and distribution of igneous rocks (which may be related to a heat source and / or constitute the reservoir), location and nature of thermal manifestations and the distribution and orientation of faults and fractures. In order to build the polygon layer called "Lithology" (Table 2, Figure 2), attributes such as the lithology and age (absolute or relative) are used.

TABLE 2: Lithology

	Lithology
	Lithology Age Scale Location tolerance: X, Y ±

2.3 Geochemistry

Geochemical studies are mainly developed in areas of thermal alteration, characterizing the rocks chemical and thermically (secondary minerals) and fluids emanating from hydrothermal manifestations (fumaroles and hot springs) in order to make classifications (origin, temperature, chemical composition and relation to lineaments). The main data use as attributes to make the point layer called "thermal manifestations" (Table 3, Figure 2) are: temperature, pH and chemical characterization of fluids. The interpretation of these data provides information on the extent of the reservoir, direction of motion and fluid characteristics that made it.

2.4 Geophysics

The application of geophysical studies is an indirect way of obtaining data of physical parameters in deep geological formations. The electrical conductivity is obtained by geo-electrical methods (magneto-telluric and electrical): the density using gravimetry, and magnetic susceptibility by mean of magnetometry. This information is used to identify geophysical lineaments utilized to produce the layer "Lineaments in Depth" (Figure 2).

TABLE 3: Thermal manifestation

●	Thermal Manifestation
	Temperature ± ºC Chemical characteristics pH ± Scale Location tolerance: X, Y and Z ±

Furthermore, taking into account that high-temperature systems show a electrical resistivity structure which, among other factors, is generated by the distribution of hydrothermal alteration mineralogy (product of fluid-rock reaction) displaying on the external parts, areas of low resistivity, which constitute the caprock, and higher resistivities into the reservoir, allows the use of resistivity values as an attribute to form the polygon layer "Resistivity". In this way the geophysical data is used to identify structures and sectors most likely to have conditions of a commercially exploitable reservoir (Table 4, Figure 2).

TABLE 4: Resistivity

⬠	Resistivity
	Resistivity ≥ Ωm ± Depth ± Scale Location tolerance: X, Y and Z ±

2.5 Thermal gradient

It is another geophysical study. In this one the physical parameters are determined by temperature measurements carried out in shallow drilling. The thermal gradient is the rate of temperature change with depth, the average value of the continental crust is 30 ºC / km (Paniagua, 2000). However, it increases in the vicinity of active volcanoes, along geological faults, or where there are intrusive rocks with minerals containing radioactive elements decay. In order to obtain representative data of the superficial area of the geothermal reservoir, the profiles are selected with depths greater than 150m and stable temperature curves without disruption caused by lateral thermal anomalies (hot or cold). Then, the temperature gradient values are interpolated to model the spatial distribution of isogradient curves, from which, are deduce the distribution of the thermal anomaly and direction of flow. With this information is generates the layer named "Thermal Gradient" (Table 5, Figure 2).

TABLE 5: Thermal Gradient

●	Thermal Gradient
	Thermal Gradient ±ºC/m Scale Location tolerance: X, Y and Z ±

2.6 Geographic information system (GIS Software)

In order to facilitate the visualization of geospatial data and transformed into an important support in making decisions, the GIS software is used. It is a tool that integrates and models data of different nature, in order to answer complex questions, usually inventory or location. However, in order to get answers, it is necessary to combine different layers of data that is overlapped and processed using analytical functions by means of the algebra of maps, which, according to Dana (1990), is a high-level computational language for performing cartographic spatial analysis using raster.

3. WEIGHTED SUITABILITY MODEL

Considering the development of models as the way to make abstractions of the real world, modeling is a technique that has allowed a better understanding, describing and predicting phenomena that take place in nature, facilitating the solution of different problems.

In order to zone the high enthalpy geothermal resource, we propose a model of suitable weighted to create an integrated analysis, which seeks to select the cells with the most suitable values in the different coverage. Therefore, it is necessary to make thematic layers and subsequently reclassify them based on a scale of relative fitness, in this case, consisting of 9 values, where 9 is the best fit. This type of scale facilitates assessment, as it gives itself a division low - medium - high (Figure 1).

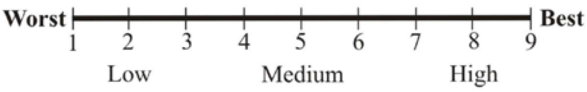

FIGURE 1: Relative value scale, used to reclassify the thematic layers

Each reclassified layer is multiplied by a weight (Fallas, 2002; Noorollahi, 2005, ESRI, 2006). In order to assign this value to the different coverage, it must be consider the influences of each activity or phenomenon that intends to be evaluated (Molina, 2009). The higher the weight value, the more important is the coverage. The total sum of all weights should be 1, thus they can be used as percentages and the output values remain at the same level of input (ESRI, 2006).

Subsequently, the layers are added to obtain the zoning of the geothermal resource. With the purpose to optimize the result, it is necessary to analyze different scenarios, which the relative values and weights assigned are modified.

3.1 Methodology

The first step is to develop a sub-model aimed at defining what has been called "Prospect Area". However, before doing that, it is necessary to join morphotectonic identified evidence through teledetection (aerial photographs, satellite images and radar) in order to get the layer "Remote Sensing lineaments". Then apply a simple suitable model in which the layers: "Lithologic", "Thermal Manifestations" and "Remote Sensing lineaments" are used. These are reclassified singly into true and false (0 and 1). Then he seeks the intercept between the three coverages and the resulting layer is the "Prospect Area" (Figure 2).

In the second stage, another sub-model is developed with the purpose of selecting and categorizing the geological structures related to the geothermal system. The data used is derived from: remote sensors, geophysics, thermal springs and field geology. The interception of the layer “Remote Sensing Lineaments" with the thermal spring, that have temperatures greater than or equal to 50ºC, is done in order to create the layer "Surface Lineaments". Subsequently, we define the "Depth lineaments" by joining the results obtained by the different geophysical methods. After that, a series of consultations at the discretion of the integrator is applied to these two coverages, along with the layer "Field Evidence", formed by faults and fractures mapped on the surface, to create the layer "Structures" (Figure 2).

In the third stage, coverages are reclassified. It starts with the layer "Structures", generating a buffer area around the lineaments, in order to eliminate these areas of analysis and prevent any drilling located on the fault. Next, the distance ranges are defined, with the respective relative values. Afterwards the thematic layers are reclassified: "Prospect Area", "Thermal Gradient" and "Resistivity". Finally, the weighting is applied properly and the layers are added to obtain the distribution of high enthalpy geothermal resource (Figure 2).

To complement and potentiate the results achieved by the weighted suitable model, it should be incorporated to the analysis other sub-models that consider: the environmental component, topography and models of cost.

The environmental component must include: vegetation, land use, water bodies, and wind direction, among others.

From the topography is extracted the digital elevation model and slope map, which together with the minimum dimensions of the platforms, are used to define the maximum slope on which the land can be adapted to build drilling rigs. These data will define the slope and the spatial resolution of the model as another criterion to locate drill targets.

The cost model is used to locate works and trace routes of communication between them, through the analysis and estimation of cost, expressed in money or time per unit distance.

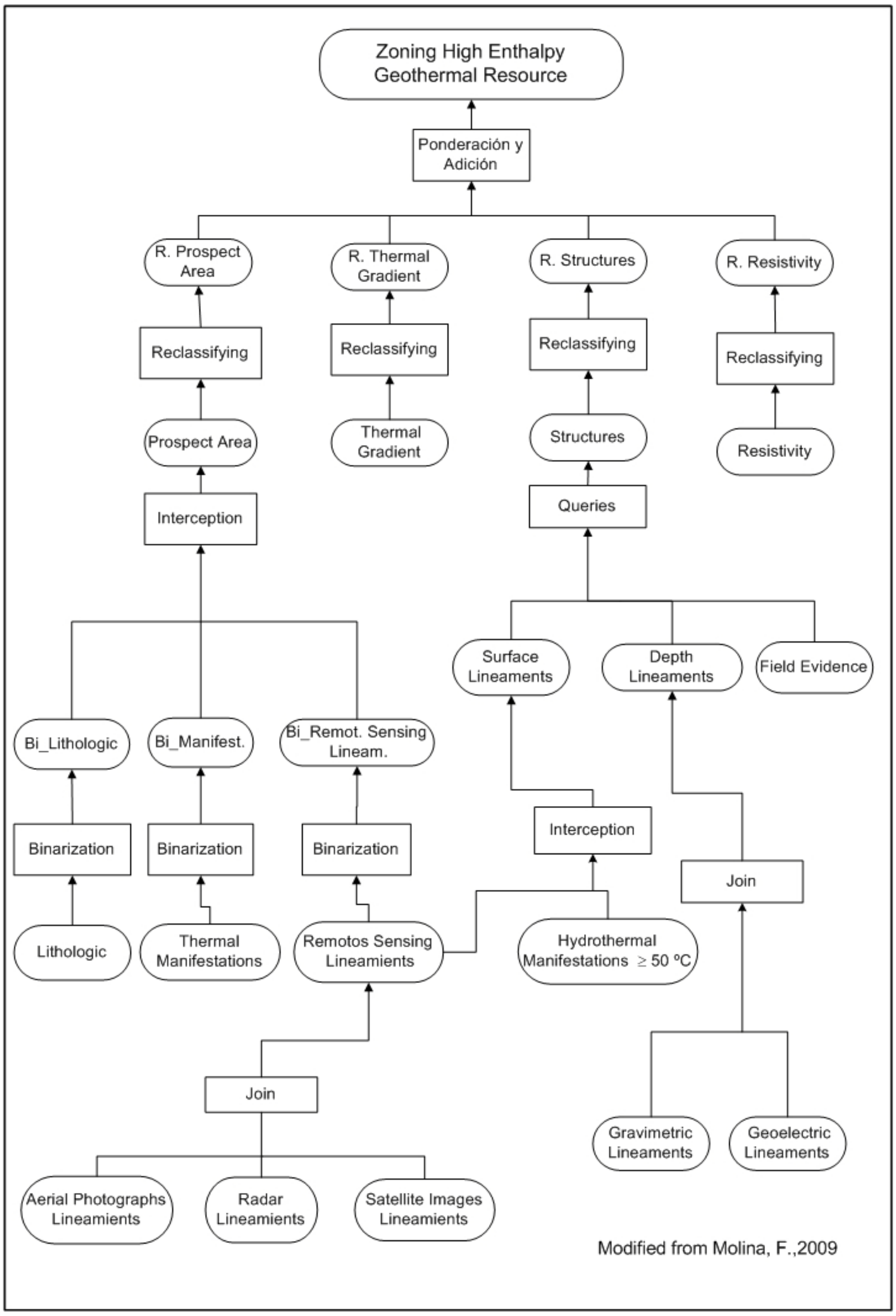

FIGURE 2: Flow diagram weighted suitability model

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