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Identification of Environmental Units for Geothermal Exploration Areas Using Geographic Information Systems

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ABSTRACT

Geographic information systems GIS have been used to evaluate environmental units EU because they allow the analysis of spatial impact scenarios of development projects. In particular, for geothermal projects, GIS provide the spatial representation of environmental impacts. These provide a tool for landscape ecology research, facilitate the analysis of the effects of anthropogenic activities on environmental processes, and make it possible to model changes on the territory with socio-ecological indicators for a hypothetical geothermal development project. In this work the UA concept builds a reference framework for data retrieval through some common landscape pattern metrics to analyze dispersion versus development scenarios and their effect on the landscape pattern, independently of land use changes due to fragmentation and drills from previous exploration activities. In addition, landscape metrics identified the importance of paying attention to the impacts of degradation caused by anthropogenic activities within the area. The use of these landscape pattern metrics allows the use of different evaluation algorithms according to different contexts or evaluation paradigms of the same reference system, independently of changes in land use over time. This document illustrates the basic concepts on which the construction of scenarios by landscape metrics is based and their application for ecological planning, the evaluation of social and environmental effects, as well as for the management and preservation of ecosystems in the face of possible geothermal power plant developments.

1. INTRODUCTION

Over the last few decades the human population has increased and with it the need to satisfy the use of energy essential for the maintenance and advancement of human well-being, ensuring the functionality of economic activities, governments, hospitals and emergency services, agricultural systems and communication networks (IEA, 2014). One of the most pressing issues today is the energy demand, partly as a consequence of the human and technological development that leads to a lifestyle dependent on electricity. This is why a series of changes in the perspective of energy security have been generated at a global level. These changes seek the inclusion of relevant issues such as climate change, pollution of water bodies, both marine and continental, soil acidification (IPPC, 2001), the emission of greenhouse gases (GHG), air pollution, and the ravages that these alterations have generated in human health, within energy planning (Bini, 1998; INECC, 2016). The purpose of this work is to determine a set of environmental indicators that may be applicable to serve as a reference to know the possible environmental impact in the exploration site of Acoculco Puebla, to identify the threats and potential environmental impacts, based on the current situation and the impact scenarios that may occur in the site. Also, to propose prevention, control, and mitigation actions that are applicable to the socio-environmental system especially in the natural environment sometimes there is no clear identification between the different patches of different kinds. The transition between the different classes is not very clear (Brown, 1994; Arnot, 2004; Walz, 2011; Lausch, 2015; Moro, 2017).

Multi-Criteria Analysis (MCA) techniques began to emerge in the early 1970s and have therefore had several amendments and alternatives in response to the understanding of these methods to address the negative external spillover effects of environmental and economic developments. The above techniques were developed to have more rigorous elements that provide tools for analyzing the complex alternatives of the different environmental and socioeconomic impacts (Barredo Cano, 1996; Gómez Delgado, 2005; Buzai, 2011; Aznar, 2012). Such is the case of Geographic Information Systems (GIS) as a toolbox for the management of geographic data that provides decision-makers with a powerful set of tools for the manipulation and analysis of spatial information. This type of project leads to identifying the environmental, social and economic factors of the place based on the different study approaches of the different disciplines when creating tools that allow adequate development for the new challenges that geothermal needs (Carlsson, 2005).

The integration of analytical techniques designed to address multi-criteria problems in GIS can provide the user with a valuable addition to the functionality to solve a multitude of spatial data problems. Systems based on GIS and MCA have the potential to provide a more rational approach to the input of new methods and integrative concepts in the implementation of conservation policies. Also, to raise awareness of the degradation that anthropogenic activities affect the environment and the consequent loss of biodiversity as well as unbiased decision making.

Geothermal energy is considered an important component in the transformations of sustainable energy systems, due to the energy security that is a global concern in these days of diminishing fossil resources by the growing demand for energy (Owusu, 2016). In this race, geothermal energy has been identified by the international community as an important part of the transformation towards sustainable energy systems. The most obvious advantage is the environmental benefits due to its fuel-free nature with less greenhouse gas emissions; a common feature of virtually all renewable energy technologies (Edenhofer, 2011). Despite sustainability assessments of energy technologies, they often fail to take into account social or cultural impacts and long-term effects on the developmental impacts of energy systems. While economic policies and assessments of the ecological sustainability of energy systems are common, little social research has been conducted on the subject (Carrera and Mack, 2010). It is also important to note that geothermal power plants are highly reliable and typically operate more than 95 percent of the time; some plants operate more than 99 percent. This is in comparison with the 60-70% availability of nuclear and coal-based plants (Kutscher, 2000; Yang, 2012).

2. THE SITE

The municipality of Chignahuapan is located in the State of Puebla. Its geographic coordinates are: parallels 19º 39' 42" and 19º 58' 48" north latitude and meridians 97º 57' 18" and 98º 18' 06" west longitude, and it is located in the border area between the Mexican Volcanic Belt and the Sierra Madre Oriental. This zone, constituted by tertiary and quaternary volcanic rocks, includes two areas of interest hydrothermally altered by sulphated acid fluids. The areas are: The Azufres-El Potrero Colorado and La Alcaparroza and are associated with NW-SE structures. Although in the region the structural network is very complex including almost all the orientations, it is characterized for being the only geothermal field in Mexico that presents very peculiar thermal manifestations, since it lacks evident thermal manifestations (Rocha-López et al., 2006). It borders to the north with the municipalities of Juan Galindo, Chiconcuautla, Tlapacoya, San Felipe Tepatlán and Hermenegildo Galeana, to the south with the state of Tlaxcala and the municipality of Libres, to the east with the municipalities of Ocotepec, Zautla, Xochiapulco, Huitzilan de Serdán, Hueytlalpan and Olintla, and to the west with the state of Hidalgo. The mountain range crosses the north of the municipality, formed by the hills Tlachaloya, Canoas and others. The complex that rises to the southwest of Chignahuapan, conformed by the hills Amanalco and Huixtepec. The extensive table that rises to the center of the municipality that, although it does not represent a totally flat surface, is more than 7 km long and 3 km wide. There is a great number of isolated hills, dispersed by all the territory, like the Apapasco, the Paila, Half Moon, the Tecajete, and many more. It has an area of 591.92 square kilometers, which places it in thi[rd] place with respect to the other municipalities of the state (INAFED, 1999; SMRN, 2007; INEGI, 2010).

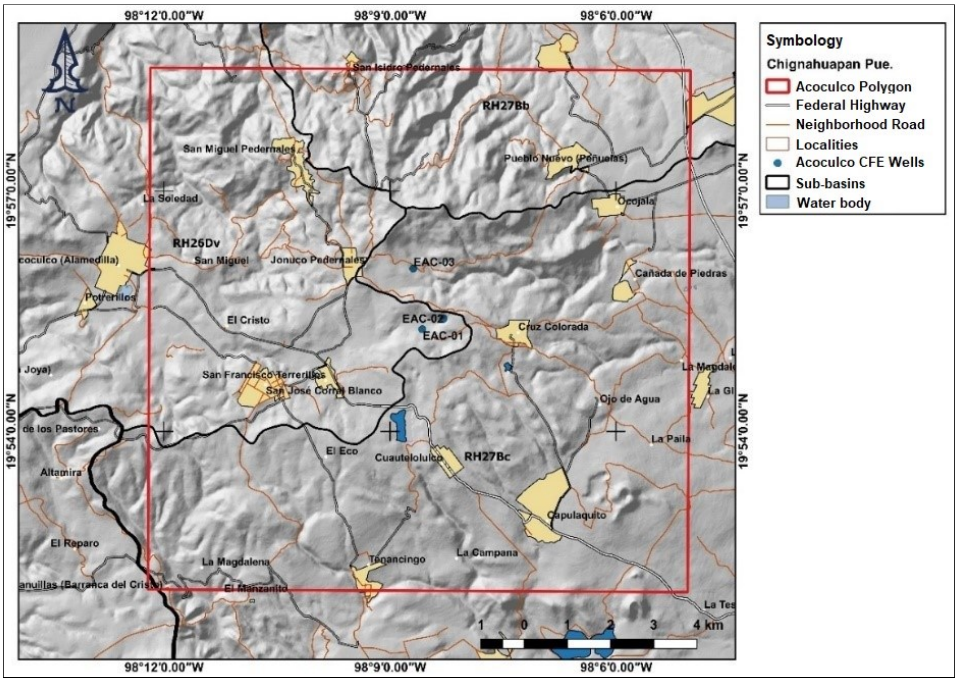

Figure 1. Base map of the CFE Acoculco exploration polygon.

3. METHODOLOGY

To delimitate the study area of the Acoculco (Figure 1), it was chosen an area of direct influence by geothermal activity from the exploration area of CFE (Secretary of Energy SENER trade number DG/014/2015). Within this area, the cartographic information provided by INEGI, CONABIO on scale 1:250,000 were taken taking into account together with the methodology proposed by Gómez-Morín (1995). Which consists of the use of variables such as orography, topography, land use, vegetation, geology, hydrology and sub-basins (Figure 2). The information is analyzed, in which it is observed that four sub-basins converge within the polygon. It is observed that the polygon is within sub-basins RH26 Du, RH26Dv, RH27Bb and RH27Bc as mentioned in the section on the physical environment. Being an important factor to consider for delimitation, observing the need to work on a digital elevation model for delimitation by means of contour lines to determine the area of influence within the polygon (Figures 3 and 4).

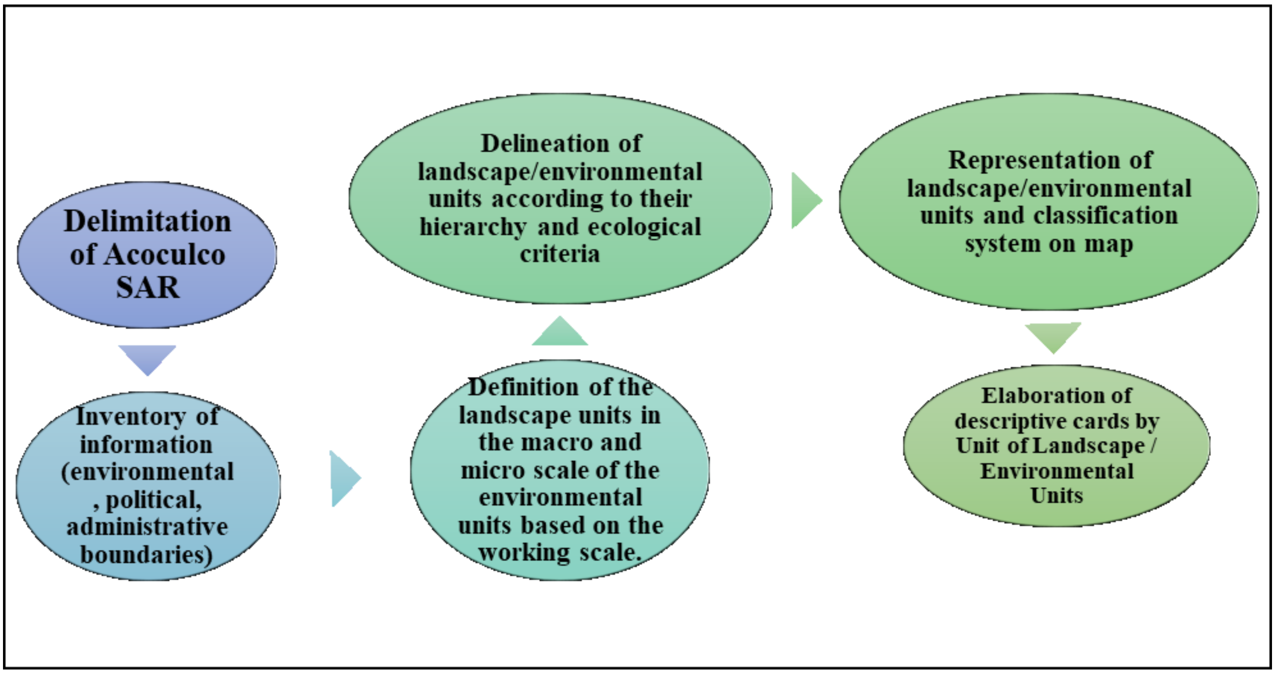

Figure 2. Methodology for the delimitation of the Regional Environmental System (SAR) at the site of study (Modified from Gómez-Morin, 1995).

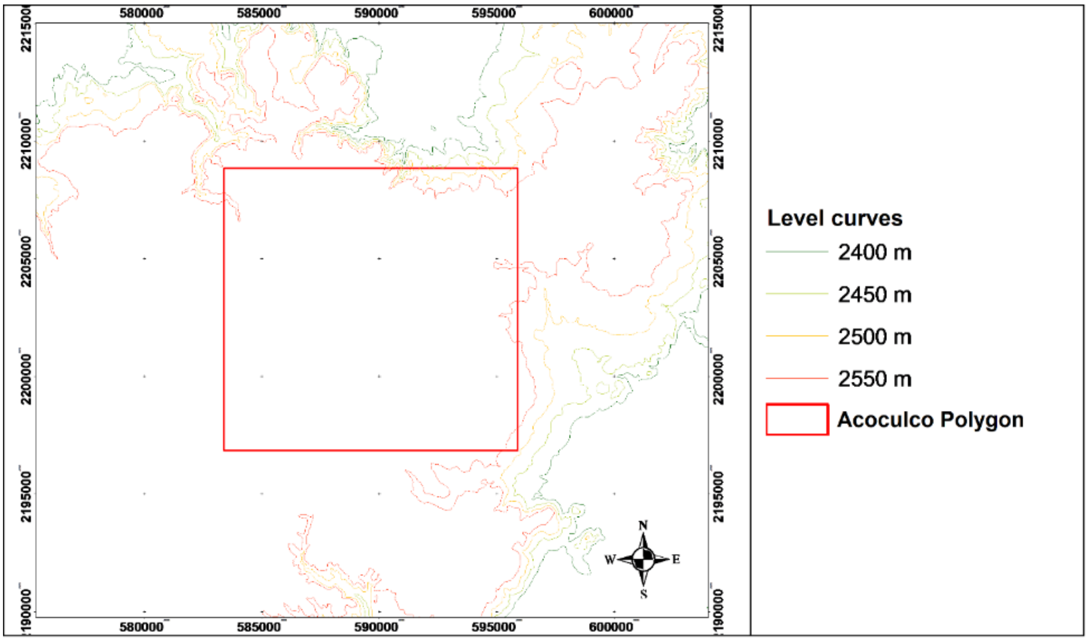

Figure 3. Level curves to delimit the area of influence of the exploration zone with geothermal influence.

Once the information layers of the digital elevation model (DEM) are loaded at 15 m resolution (INEGI, 2017a), the processing is carried out to obtain the orography of the site with respect to the mountainous system as in the section on the natural physical environment. All this, taking the reference limits of the CFE exploration polygon of Acoculco (Figure 4), with this information and by adding the layer of the sub-basins to be able to define the landscape units.

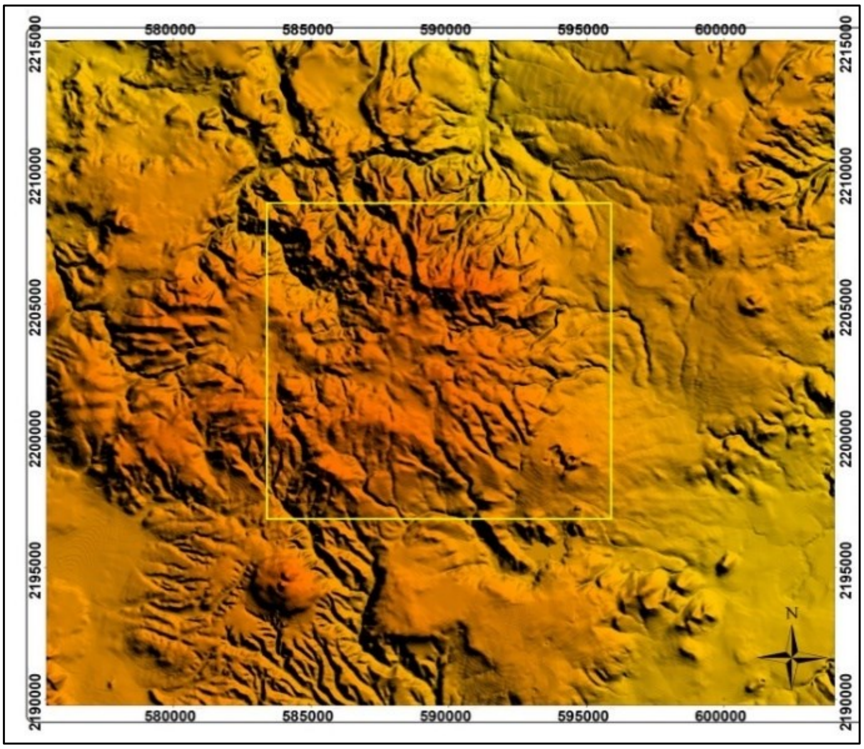

Figure 4. The o**rography of Acoculco spatial analysis determine**s **the boundary of the area of influence to obtain landscape units.**

Once the different layers of information have been obtained, the three layers are combined, observing the need for more information to determine the area of influence. Therefore, it is determined to add a new layer to limit the area of study, choosing to use the geological layer (Figure 5). With this new layer, the surface of interest is trimmed and the spatial analysis of the site is carried out, with the support of the geological layer and the sub-basins already added to the layers, and the necessary trimming of the areas that are not of interest is determined. Obtaining, as a result, a polygon called Regional Environmental System (SAR), which allowed us to overlap the layers of land use and vegetation obtaining the landscape units described in Table 1. Then, in the microscale or scale of the exploration polygon determine the environmental units of the exploration area.

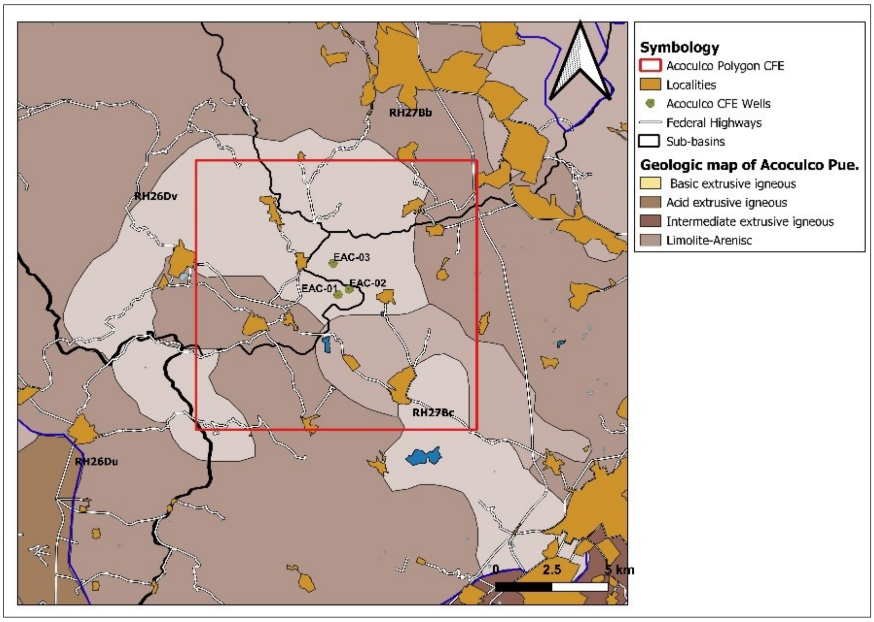

Figure 5. Geology of the study area.

Table 1. Classification of landscape units and land use on the Macroscale for SAR.

Sub-basins	*Natural landscape*	*Landscape Transformed*	*Total landscape units by sub-basin*	*Percentage in Area Km ²*
RH26Du	7	3	10	18.52%
RH26Dv	11	6	17	31.48%
RH27Bb	7	3	10	18.52%
RH27Bc	11	6	17	31.48%
General total	36	18	54	100.00%

Within the SAR polygon in the Basin/Sub-Basin RH26 (Dv and Du) and RH27 (Bb and Bc), there are 54 landscape units of which 7.5% or 18 surface units is a natural condition situation that is to be considered for the current site condition (Table 1). Finding a 92.5% transformed soil of all the polygon surface or 36 surface units is a transformed condition. For the delimitation of the micro-scale contained in the area within the exploration polygon, the environmental features of the SAR are taken into account, such as sub-basins, geology and the use of soil and vegetation, all of which are found within the exploration polygon as shown in Table 2.

Table 2. Classification System of Environmental Units Exploration Polygon.

System: Sub-basin	*Environmental Unit: Land use and vegetation*	*Area : km2*	*Surface in exploration zone: Percentage*
RH26Dv	Pine forest	17.528	11.68
RH26Du	Secondary shrub vegetation of pine/pine forest -oak (Mixed)	46.904	31.26
RH27Bb	Annual Seasonal Agriculture	76.284	50.85
	Induced Grassland	1.353	0.902
RH27Bc	Annual and permanent agriculture/Permanent agriculture	7.931	5.28

Within the classification of the environmental units of the project site for the determination of the micro-scale of the exploration area, it is observed that mixed forests such as pine forests occupy 42.45% which is significantly higher than that obtained for the SAR, due to the environmental conditions present in the study area. On the other hand, this presents the activities of rain-fed agriculture occupying 57% of the total area of the exploration polygon.

4. RESULTS

It was performed seeking uniformity of the elements determined in the exploration area, through the combination of environmental indicators such as physiographic homogeneity, vegetation, land use or landscape, especially in the natural environment. As mentioned in the literature, sometimes there is no clear identification between the different patches of different types of vegetation. The transition between the classes is not very clear, whereby zoning the environmental unit and determining the degree of alteration of the plant community, to understand the dynamics of fragmentation through changes in land use and activity within the environmental units as seen in Figure 6.

Several studies have modeled and analyzed the deforestation process considering socioeconomic and environmental variables so that for this study, patterns are observed that may be repeated in other localities of the region studied. So, it is important to know the environmental, social and economic patterns that stimulate deforestation and its possible anthropogenic threats incompatible with the maintenance of environmental quality. In order to identify biologically significant areas, they begin with a large-scale inventory of landscape patterns, vegetation and habitat structure to determine the models of the natural vocation of the soil at different spatial scales, for the generation of future scenarios of land use. It is observed the authorization for the change of land use of forest lands to agricultural use of temporary because this activity has a significant relationship with the degree of marginalization of the different localities located within the polygon determined by the CFE as a zone of exploration. The geoelectoral sections contain useful information for the socioeconomic part of the site, allowing us to determine the degree of marginalization presented by the SAR system. By reviewing this part and comparing it with the information obtained in the field, the need is identified to elaborate on a new diagnosis of the different communities in terms of basic housing services and equipment for the different localities (Table 3).

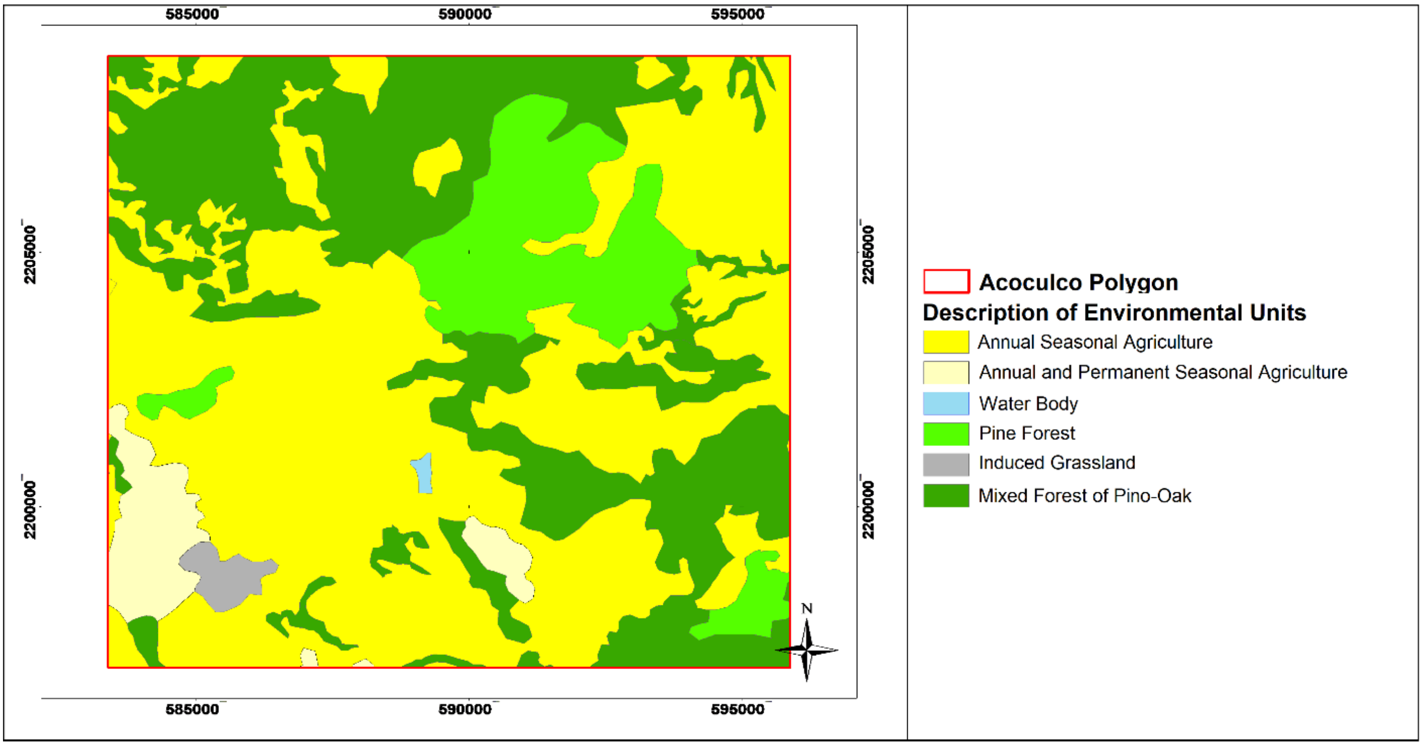

Figure 6. Environmental units CFE Acoculco exploration polygon.

Table 3.- Classification according to their indicators of marginalization, Acoculco Puebla.

INHABITANTS	CLASSIFICATION
0 – 50	Ranching
50 -100	Small town
100 – 500	Medium town
500 – 1500	Large town

The model determined for the municipality of Chignahuapan shows the same deforestation trend as the regional model. Therefore, the new model should consider biophysical and socioeconomic variables based on information such as Table 4 and Figure 7. Therefore, for each scale, the phenomenon or process under study should be defined and used at a spatial level for its design and to determine proposals for public policies or strategies for conservation management and the use of natural resources.

The National Development Program and the Sectorial Program estimated that illegal deforestation, with the purpose of changing land use is responsible for 90% of deforestation in Mexico. This indicates that deforestation is a fundamental action for the transition to sustainability, establishing that the study of its quantification, its geographical location, and the causes that motivate it, will be the basis to stop the advance of the deterioration of forest resources to reverse this trend. In general terms, it can be said that the vegetation in them is altered vegetation with different levels of degradation. There are spaces devoid of woody vegetation under agricultural uses or subsistence cattle ranchers. These lands are regularly abandoned for certain periods, which should be taken into account as indicators of a deforestation process that since its characteristics can lose their productive properties and may be abandoned to erosion processes.

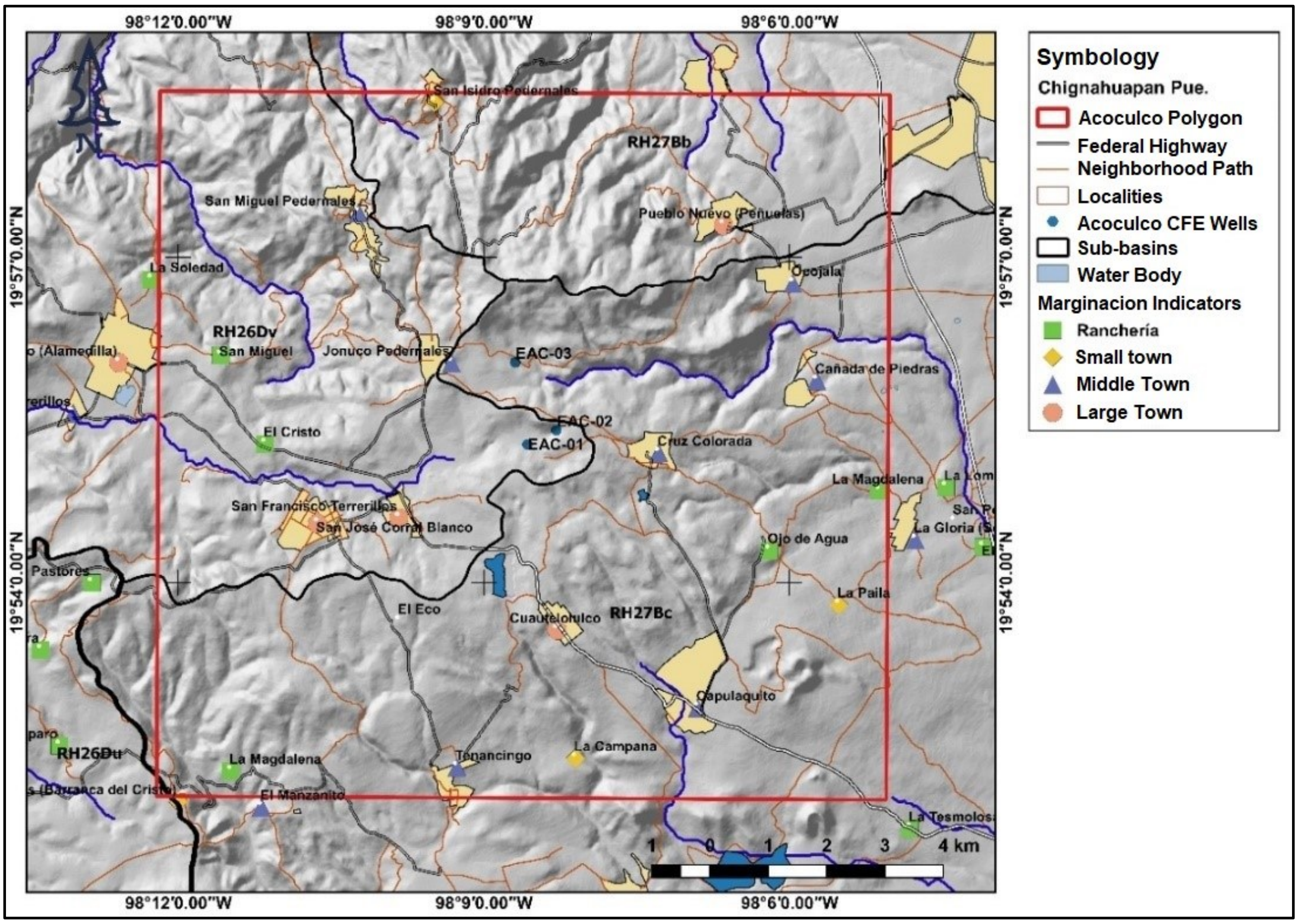

Figure 7- Reclassification of localities within the Acoculco exploration polygon.

5. DISCUSSIONS AND CONCLUSIONS

The diversity of ecosystems in the sector and the processes derived from urban expansion have generated the development of numerous activities of different forms of expression in the territory, giving rise to an extremely heterogeneous space.

Creating the baseline of a geothermal project it is very important to define our regional environmental system (SAR). It is an advanced technique to evaluate the environmental impact of various inputs and products as it is a set of elements that interact and are interdependent so that the interrelationships can modify one or all other components of the system within the region where the project is going to be developed.

Spatial ecological and socioeconomic contrasts determine spatial differences in the expression of environmental problems. Although many derive from activities that require reduced spaces for their operation, there are numerous conflicts that have territorial scope beyond the area in which the activity is carried out.

For the delimitation of the Regional Environmental System (SAR) based on the interactions between the abiotic, biotic, and socioeconomic environments of the region where the project is intended to establish, it is important to consider that human activities are developed in ecosystems as a functional system hierarchically structured at different time scales, macro-scale and micro-scale, to achieve social, environmental and economic indicators and determine the current status of the project area.

Once the macro scale (SAR) has been delimited, we can obtain our landscape units and then define the environmental units within the Acoculco exploration polygon at the microscale. With this, we can make the descriptive cards of each environmental unit in order to define the indicators that will allow us to evaluate the state of the site in order to give a diagnosis for the project. But, in addition to the impacts, there are two potential environmental impacts associated with the development of geothermal areas for energy projects, since they are related to the way in which energy is used in place and the interactions of the ecosystems. These are land subsidence and earthquakes and the sustainability of energy generation (Deichmann and Giardini, 2009; Flóvenz et al., 2015). Based on the socioeconomic indicators and field trips, the results obtained were that the quality of life is very low. This indicates that if a geothermal project is proposed to be implemented, basic services such as health care, quality water for the community, electricity, support programs of the social sector, direct jobs, among other issues that contribute to the communities.

GIS is a tool used to evaluate environmental units (UA) because it allows analyzing and spatially creating impact scenarios of geothermal development projects. The spatial representation of these impacts for environmental and geographic landscape ecology research facilitates the analysis of the effects on environmental processes allowing the modeling of changes in a geothermal development project with the help of indicators.

Environmental economists often make economic assessments of impacts on ecosystem services, yet they are often poorly supplied to assess the degree of physical change. In this document, the AUs were considered to describe the environmental impacts of geothermal energy to determine its suitability for the information required to determine the status of the project area. In order to increase and balance the type of sustainable development, special attention should be paid to adopting environmental preservation measures for ecosystem recovery.

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