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The Geothermal Exploration, Geoheritage and Potential Geoturism around Thermal Springs on Puruándiro, Michoacán, México.

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ABSTRACT

In Mexico there are multiple regions with thermal springs that have hosted civilizations since pre-Hispanic times and to these days. The thermal springs have become places of high cultural importance and most of the times have been used for balneology or as baths of local people. Unfortunately, there is often a lack of knowledge about the possible direct uses of these resources, the importance of their conservation and their historical trajectory as elements of local heritage.

The objective of this work is to visualize the thermal springs of the Puruándiro area as main part of the local geoheritage. This work presents: i) a first classification of geosites with educational, touristic and cultural values, ii) proposal of georoutes where the information of geodiversity and biodiversity is well exposed “in situ” and iii) preliminary didactic and multidisciplinary material for use "in situ" where the importance of geoconservation is highlighted.

1. INTRODUCTION

During the last two decades have been developed initiatives focused on the promotion and assessment of the abiotic environment, particularly geology and geomorphology (Palacio Prieto, 2013). Some of the most representatives and those that have terminology in the academic area are: Global Indicative List of Geological Sites (GILGES, entre 1989 y 1993), Geosites promoted ny por la International Union of Geological Sciences (IUGS) and Asociacion Europea para la Conservacion del Patrimonio Geologico (ProGEO; Gallego, 1998; Wimbledon et al., 2000). Geomorphosites, promovida por la International Association of Geomorphologists (IAG) a traves del Working Group on Geomorphosites, Geoparks, promoted by IUGS and UNESCO (Eder y Patzak, 2004)

One important concept, is the heritage. According to UNESCO definitions (1972), natural heritage are: (i) natural monuments constituted by physical formations and biological or by groups of those formations that have a value universal exceptional from the aesthetic or scientific point of view, (ii) geological and physiographic formations and areas strictly delimited that constitute the habitat of species, animal and vegetable, threatened, that have exceptional universal value from the point aesthetic or scientific view, and (iii) natural places or strictly defined natural areas, that have exceptional universal value from the point of view of science, conservation or natural beauty. The definition is similar to the cultural heritage, in that case the objects have exceptional universal value from the point of view of history, art, science, ethnography, anthropology and aesthetics. The idea behind is to take some values of the “object”. The value even can be the cultural importance for a community.

Another important concept, in fact one of the most used terms in this kind of approach is: geosites. The geosites are equivalent to the sites or points of geological interest in a certain territory (Palacio Prieto, 2013). Geosites, originally, do not distinguish between sites of geological interest and sites of geomorphological interest. Then, Panizza, (2001) incorporated the term geomorphosites, that can be from individual geomorphological objects to a landscape, which can be modified, damaged and even destroyed by human activity. Regarding this new concept, Reynard and Panizza (2007) mentioned that geomorphosites are landforms that have historical, cultural, aesthetic and / or socio-economic value. Obviously, all these new dimensions include the geographical point of view in these sites that are highlighting some aspects of territory. Independently that in some research works, the term geosites considers or not the geographic point of view, the aspect in common in all the research work about geosites is that all these points must to be previously compared and chosen from all the other points forming the territory.

We will explain how is the methodology to choose these points, it is a hard task and the methodologies are diverse. As part of this geographic point of view, in a certain territory can be listed: biodiversity, geodiversity, culture, traditions, history. All these issues can be documented, described and classified according to some specific values. To priorize or jerarquize sites are sometimes in the same line of heritage definitions, (e.g. exceptional scientific, aesthetic, cultural, historic values). Methodologies to do this are still not systematically same, but there are some proposes in order to qualify some indicators to valorate the scientific, touristic and educative value of these sites (e.g. Brilha et al. 2016).

Once done the classification, geosites are named and a strategy of geoconservation or environmental and cultural education can be carried out. The studies where geosites are proposed are strategies of conservation, education, sustainable development and alternatives for a holistic and integral type of tourism, where you can appreciate not only the beauty of a place, but also the natural, geological, historical and cultural heritage. The current trend is to approach the natural environment holistically and geographically; therefore, integrating all values (heritage) in a single indicative to highlight them, give for result what is known as geoheritage in one territory.

Regarding all the explained framework, in this work we are applying it to some specific territory, Puruándiro city in Michoacán state, México. In Mexico, there are multiple regions with energy sources that have harbored civilizations since the pre-Hispanic era and to this day. The thermal waters have become places of great cultural importance and most of the time they have been used for balneology or as baths for the local population. Unfortunately, there is often a lack of knowledge about the sustainable uses of these resources, the importance of their conservation and their historical trajectory as elements of local geoheritage.

This project presents a proposal to work in the municipality of Puruándiro, Michoacán, the main issues to consider are: i) classification of the geosites in which the educational and touristic value of the geological heritage of the area of rural and interurban hot springs can be seen Puruándiro, ii) proposal of georoutes highlighting information on geodiversity, biodiversity and culture; and iii) various materials with themes of conservation, sustainability and geoheritage. Therefore the main object of the project is to highlight the natural, geological and cultural heritage (geopatrimony) of the municipality through communication campaigns that involve conferences, workshops, physical tours, infographics and other graphic resources distributed and socialized in school institutions and civil organizations of Puruándiro, Michoacán with the purpose of Integrate the population into a dynamic of re-valuing their assets. The visualization of the thermal springs of the Puruándiro area stands out as part of the local natural, geological and cultural heritage.

1.1 General Description of Study Area

Puruándiro is a municipality located north of the state of Michoacán, (Figure 1) between the geographical coordinates 20 ° 16 'north latitude and 101 ° 42' west longitude and 19 ° 57 'N and 101 ° 36' W, with an area of 72,029.16 hectares (CARSED , 2011). In the polygon that forms the municipality, abiotic and biotic components of great ecological, landscape, tourism, etc. interest are established. However, at present the permanent and / or visiting population does not give the appropriate importance to the various elements, neglecting them in a worrying way, to such a degree that habitats and microhabitats that allowed the development of biological communities since the past have disappeared and that the population, without noticing this fact, continued and continues to develop activities that threaten its stability.

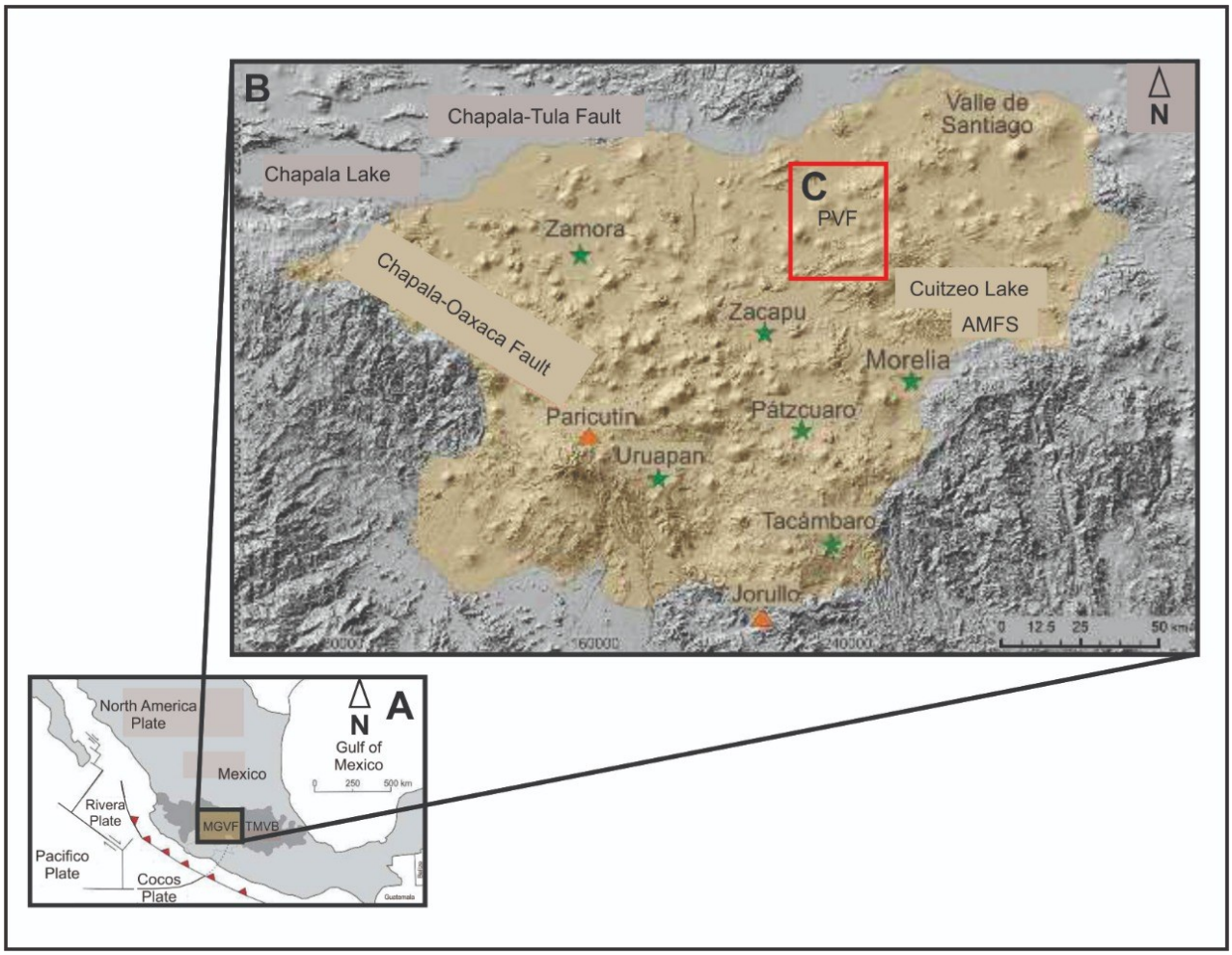

Figure 1: General location. A. Trans Mexican Volcanic Belt (TMVB). B. Michoacan-Guanajuato Volcanic Field (MGVF). C. Puruandiro Volcanic Field (PVF). Acambay-Morelia Fault System (AMFS). (Modified from Gómez Vasconcelos, 2018)

Puruándiro sits on the northern limit of the Trans Mexican Volcanic Belt (CVTM), forming its Geology volcanic rocks from the Miocene (> 5 Million years (Ma) to the beginning of the Quaternary (0-2 Ma), with about 100 volcanic devices (domes, stratovolcanoes, shields and monogenetic cones) and their products, as well as sludge flows, terraces and subsequent lake deposits (Canul, 1986). To the east-southeast of the headwaters, is the Tibia – Jeroche Ecological Park (PEAT-J) and the species of flora and fauna that it hosts, as well as the hot springs, give rise to a unique landscape with a high value Geological, biodiverse and aesthetic. The birds that arrive every year to the lake plain known as "La Laguna", are part of the natural and aesthetic heritage of the municipality (Figures 2,3)

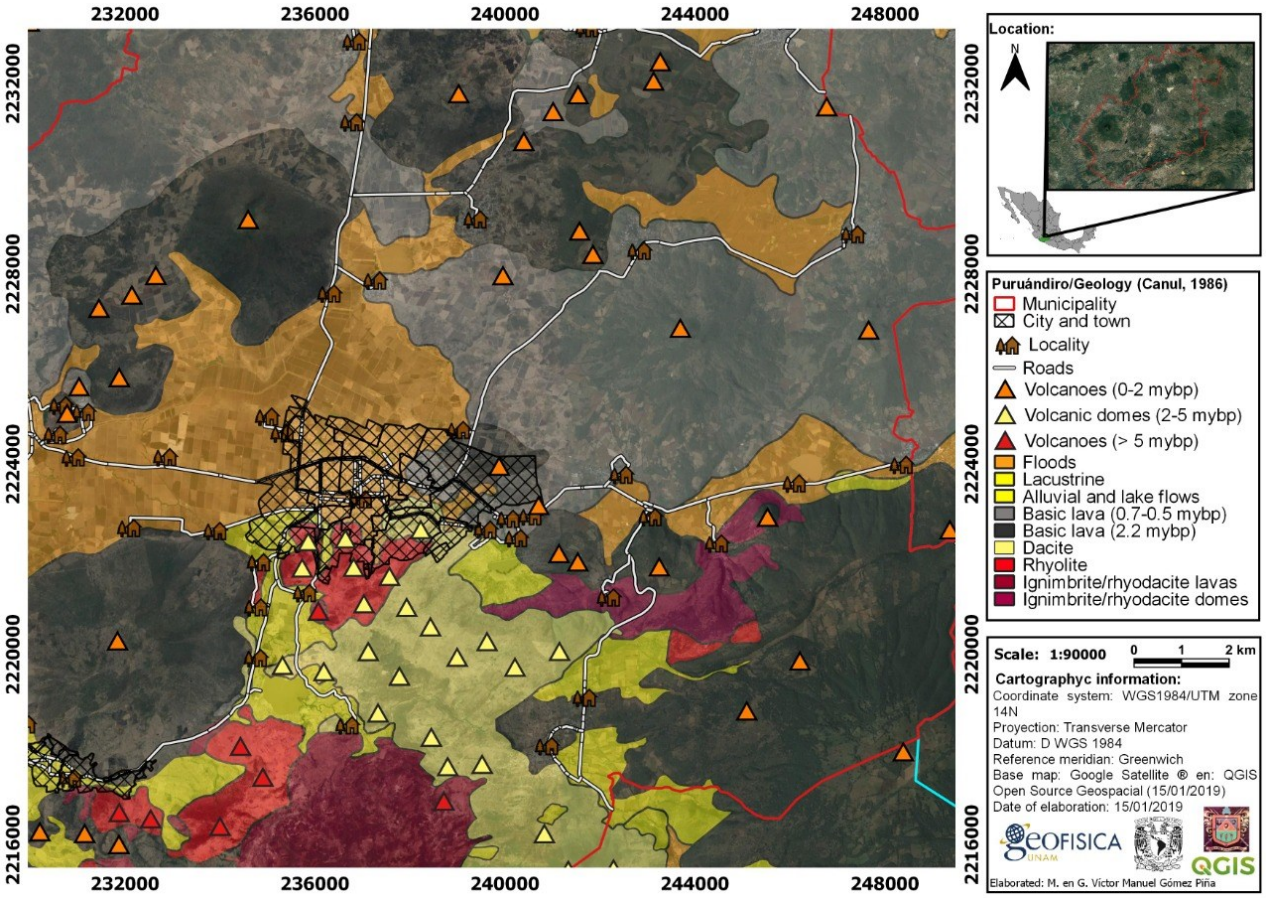

Figure 2: Main geological settings of study area. The map also is part of the thematic cartography done as part of the project (in Spanish) and it was distributed in schools and public spaces.

2. METHODOLOGY

2.1 Geothermal Exploration

Geothermal exploration includes geochemistry of fluids and geological survey. Main methodologies are described below.

Water samples for geochemical analysis were collected in 250 ml Nalgene® bottles. The samples collected for determination of cations were acidified after collection through the addition of Suprapure® HNO3 to attain a pH less than 2. The pH (± 0.1 units), electrical conductivity (± 0.1 mS/cm), and temperature (± 0.1°C) were measured on site using a portable instrument Thermo Scientific ORION® A329 model that was calibrated in the field prior to sampling. Untreated water samples were collected for anion and stable isotope analyses (δ^2H and $\delta^{18}O$). Additional samples were collected for the analysis for aqueous SiO_2 by the molybdate spectrophotometric method using a Hach DR-2800 instrument (Hach, 1997).

Bubbling gas samples were collected from thermal springs using 40 ml vials capped with a pierceable butyl rubber septum to determine the isotopic composition of the CO_2 flux.

CO_2 flux survey was performed following the accumulation chamber method using a West Systems instrument and water surface measurements were carried out using a floating chamber. The instrument was equipped with three detectors for CO_2, CH_4 and H_2S flux measurements: (1) LICOR LI-800, a non-dispersive infrared CO_2 sensor with a detection range from 0.1 to 20,000 ppm/s with accuracy <3% and reproducibility lower than 10% in the range of 0.2 to 10,000 g m^{-2} d^{-1}; (2) CH_4-WS infrared with flux detection range from 0.02 to 1,444 g m^{-2} d^{-1}, 5% accuracy, 2% of repeatability, 22 ppm resolution and ± 25% precision in the range of 0.1 - 5 moles m^{-2} d^{-1} and ± 10% in the range 5 – 150 moles m^{-2} d^{-1}; and (3) WEST H2S-BH chemical detector with flux detection range from 0.0002 to 0.6 moles m^{-2} d^{-1}, accuracy 3%. Total areas of each zone were computed using both GPS coordinates and Wingslib® software. Flux Revision software of the West system, Wingslib®, Surfer® and Origin® software were used for data post-processing. The graphical statistical analysis method (GSA) and sequential Gaussian simulation (sGs) were performed to compute the total CO_2 flux and to show the total degassing area (Chiodini et al., 1998; Cardellini et al., 2003)

2.2 Geoheritage Dissemination

The main messages to be communicated in the path to visibilize the geoheritage and the natural resources that represent the thermal springs were: basic aspects of geology, ecology, history, community mapping, conservation and sustainability with a view to the public appropriation in Puruándiro of science, technology and culture.

→ Knowledge of the Puruándiro environment so that a responsible interaction of the natural, geological, cultural and historical heritage (geoheritage) is allowed.

→ Forms of use of natural resources and territory management.

→ Examples of sustainable community work, where higher education institutions and civil organizations can propose initiatives to apply them in their own territory.

→ Conservation of Geoheritage through the application of environmental education.

→ Sustainable management through specific management actions of Geoheritage, raised and applied with the population, as well as the parameters to evaluate them and quantify results.

→ Responsible tourism in areas that make up the Puruándiro Geoheritage as spas, thermal springs, wetlands, gallery forests, mosques, as well as historical sites composed of temples, mansions, parks, squares, etc.

To communicate this information the project was divided in three stages:

Stage 1: Compilation of general information. Planning and design of strategies to implement diverse activities. Public conferences of local geology and geoheritage in schools and public spaces as libraries, municipality and communitarian house. Implementation of dissemination campaigns in digital media. Classification of geosites with scientific, touristic and educative value according to Brilha et al. 2016. To evaluate cultural value, it was carried out the implementation of surveys to look into the appreciation of geoheritage and the communitarian point of view.

Stage 2: Specialized workshops and talks in educational centers, tours in the area, and explanations of the Puruándiro Geoheritage. Classification of geosites together with community and according to the survey results. Design, printing and delivery of infographics, posters, brochures and other graphic materials in the different institutions and civil associations. Media monitoring of the dissemination campaign and design of georoutes according to the chosen geosites.

Stage 3: Completion of the project leaving the management of georutes to the inhabitants of the municipal head of the proposed strategies, assigning direct managers and functions to be carried out with defined goals.

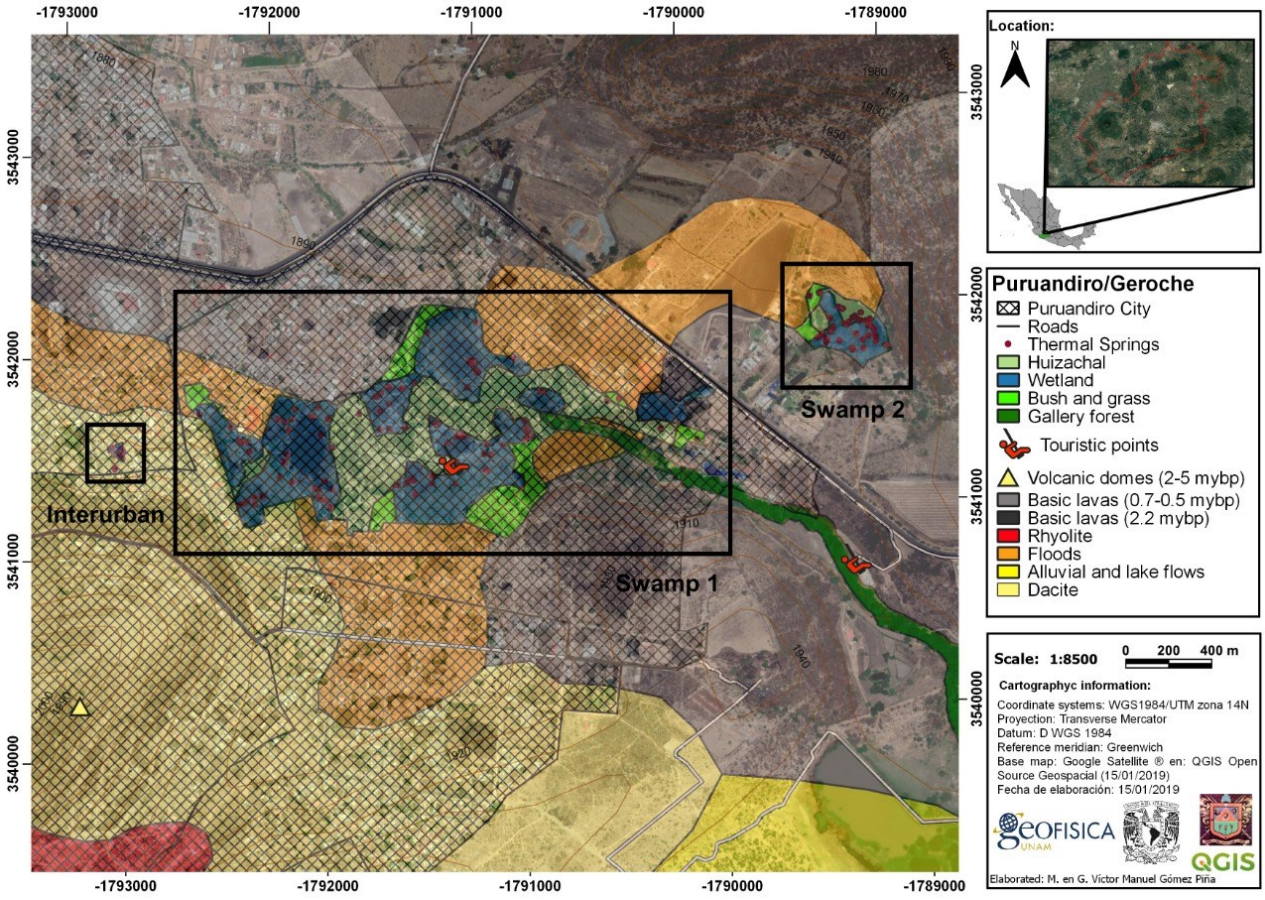

Figure 3: Main biodiversity settings of study area. The map also is part of the thematic cartography done as part of the project (in Spanish) and it was distributed in schools and public spaces. Thermal springs are plotted and divided in three zones (For further explanation see the text).

Figure 4: Example of infographic. This infographic contains information about natural, cultural and historic heritage in Puruándiro. The infographic was distributed in schools and public spaces.

3. RESULTS

3.1 Geothermal Exploration

The study area is about ~ 1.7 km^2. It has at least 28 thermal springs with temperatures in the range of 32 - 78 ° C. The highest temperature was found in the area behind the spa area (swamp 2, Figure 3). The thermal springs that are outside the city are used for outdoor baths and balneology when the temperature allows (swamp 1-2, Figure 3). The springs within the city (interurban) are used for communitarian baths and to recollect water for domestic use. There is a system of shifts between men and women during the different days of the week. All these springs have been used since pre-Hispanic times.

The range of pH of thermal springs is between 7.13 – 7.68, all neutral waters, and the silica concentration is between 66.2 to 98.3 mg/l. To analyze chemical and isotopic composition in laboratory during geothermal exploration were taken 14 water samples, and bubbling gases directly of thermal springs.

As part of the geothermal exploration 108 measurements of CO_2, H_2S and CH_4 fluxes were done on soils and the surroundings of all thermal springs. There was not significant emission of CH_4 and H_2S. CO_2 flux range is between 0 – 1000 g m^{-2} d^{-1}. Highest values of CO_2 flux were measured directly on thermal springs and, in all cases, there is not evidence of anomalous degassing area on soils around thermal springs.

3.2 Geoheritage Dissemination

As part of the obtained results in each stage of the dissemination project are:

Stage 1: During this stage the most important result were the design and implementation of written surveys as well as the survey results. The main result about these surveys was the importance of thermal springs in the area not just for fun and entertainment but as part of culture and symbol of communitarian sharing.

Stage 2: During this stage, the most important results were the infographics series and thematic cartography of geoheritage of Puruándiro. Additionally was obtained a detailed guide for georoutes with of relevant geoheritage information in various locations of the municipality (Figure 2, 3, 4).

Stage 3: As part of this stage was obtained audiovisual material of the entire communication process and technical report to look into the possibility of the direct uses of geothermic in thermal springs of Puruándiro (specifically swamp 1-2, where have been talks to advise and explain the direct use by the local people)

4. FINAL COMMENTS

The basic geothermal exploration allows us to determine the type of lithology and fluid that exists in the Puruándiro area, as well as a recognition of the existing geodiversity.

The analytical medotologies of chemical and isotopic composition of the fluids will give us more information about the origin of the fluids and the thermal source. Analytical methodologies continue.

From the cultural side, it can be said that the recognition of the springs as a historical and cultural symbol of Purándiro caused empathy in the local participants in the project (students from various schools, teachers, government agents, farmers, etc.) with what there was interest and proposals for its geoconservation and a possible sustainable use of the resource.

The methodologies implemented to identify the scientific, educational and tourist values of the sites motivated community participation and the visibility of the Puruándiro geoheritage.

Various activities were proposed that accompany the popular and existing tourist sites, so that tourism and activities can be diversified to make visible the geosites classified in this work.

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