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Geothermal Direct Use to Overcome Frosts in Peruvian High Altitude Areas

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ABSTRACT

Frost is a climate phenomenon which consists in the decrease of temperature to values under 0 °C. It occurs every year between April and September in the Andean regions of Peru, especially in areas over 3000 m.a.s.l., causing health problems to the population, damages to their houses, loss of great extensions of crops and cattle and, in some cases, the decease of vulnerable people and animals. Many of the measures taken by the Peruvian government up to 2013 to face the problem were reactive, providing people blankets and vaccination to prepare them for the impacts of low temperatures. However, since 2014 plans included interventions aimed at reducing the vulnerability of the population and their livelihoods, such as the implementation of interventions to provide thermal comfort inside houses. Unfortunately, these measures have not been successful due to high costs and insufficient increase in temperatures of the technologies, high dispersion of the population, great difficulty to access affected areas, among others.

The present study uses geographical information systems to overlap zones with the greatest impact of frosts, with low to medium geothermal areas and places that have social services like the "Tambos" in charge of the Ministry of Development and Social Inclusion, which have physical facilities and services, fully equipped with technology and human resources for the provision of services. The assessment identifies potential zones for the direct use of geothermal energy in the provision of heat to Tambos, sheds for animals and greenhouses to preserve crops in areas affected by frosts. The software QGIS Version 3.4.8. was used to integrate the information gathered from official institutions like the Mining and Metallurgical Geological Institute (INGEMMET), the National Center for the Estimation, Prevention and Reduction of Disaster Risk (CENEPRED) and the National Geo-Referenced System Sayhuite from the Presidency of the Council of Ministers of Peru. Twenty zones that matched all the requirements mentioned above, were selected for further calculations like the distance from the geothermal source to the Tambo, the slope of the territory and chemical properties of the geothermal resource, in order to find the areas that could be technically feasible for the implementation of geothermal direct use projects.

1.INTRODUCTION

Every year, in the Peruvian highlands located at more than 3000 m.a.s.l., it occurs a phenomenon called frosts or "heladas", where air temperatures drop down to values under 0°C between April and September, reaching the lowest temperatures in June and July (SENAMHI, 2019). Nationwide, from 1873 districts, 1367 are exposed to the occurrence of frosts (CENEPRED, 2017), being the most frequent and intense in the regions of Puno, Arequipa, Tacna, Moquegua, Cusco, Ayacucho, Huancavelica, Pasco, Junin and Apurimac (SENAMHI, 2019). The most critical temperatures have been recorded in the province of Macusani in Puno with -28.2 °C, Yauri in Cusco with -25 °C and Imata in Arequipa with -23 °C for the period 1964-2009 (SENAMHI, 2010).

Frosts constitute the phenomenon that has occurred with greater frequency and higher consequences in Peru according to the National Institute of Civil Defense (INDECI). Just in 2016, there were registered 1205 events of low temperatures along the country, which affected 1,278,907 people, with 6,565 victims and 9 deceases (INDECI, 2017). Frosts are associated with an increase in Acute Respiratory Infections (ARI's) like influenza or syncytial virus infection, acute diarrhea, eye diseases produced by snow-driven reflected sunlight, and skin disorders (GORE Arequipa, 2007). By the end of 2018, there were registered 2'513,552 cases of ARI's different from pneumonia, 27,622 cases of pneumonia and 291 deceases in children under 5 years old, being Arequipa and Cusco the regions with the highest number of cases, which can be associated to the frost phenomenon (MINSA, 2018). Especially during the low temperature season in 2018, there were registered 17,512 cases of pneumonia in children under 5 years old from which 187 turned into fatal deceases, whereas for adults older than 60 years old, there were registered 13,362 cases of pneumonia and 629 deceases (CDC Perú, 2018).

On the other hand, frosts constitutes also an infrastructure problem. In 2016 they damaged 7,625 houses and totally destroy 45 of them (INDECI, 2016), mainly due to the low quality of their construction materials. In rural areas, walls are usually constructed using adobe, tapial or quincha; roofs are made of plates of calamine or straw and floors are directly the area's ground. These characteristics make houses vulnerable to the effect of the thermal gradient during frost seasons and allow the entrance of coolness and heat losses from the house. Moreover, frosts make people lose their animals and crops, which are the main sustenance of their economy. In 2017 during the frost season, there were affected 19,185.76 has of crops and 2562.37 were lost in their entirety, whereas 189,751 animals where affected and 28,155 died (COEN, 2017).

Looking at this reality, in 2011 it was published the Law 29664, Law that creates the National Risk of Disasters Management System (SINAGERD) integrated by the Presidency of the Council of Ministers (governing body), the National Risk of Disasters Management Council, the National Centre for the Estimation, Prevention and Reduction of the Risk of Disasters (CENEPRED), the National Institute of Civil Defense (INDECI), regional governments and local governments, the National Centre for Strategic Planning (CEPLAN), public entities, Armed Forces, the National Police of Peru, private entities and civil society. This regulation also states the requirement of the National Plan of the Risk of Disasters Management (PLANAGERD 2014-2021), on which the elaboration of specific plans according to the type of disaster are based (Perea Flores, 2018).

In that regard, since 2012 the Presidency of the Council of Ministers as the governing body of SINAGERD, has been conducting the Multisectorial plan against frost and "friajes". Up to 2013, the plan and the measures taken consisted mainly on interventions for the preparation of possible affected people to the impacts of low temperatures. However, since 2014 the yearly plans included interventions aimed at reducing the vulnerability of the population and their livelihoods, such as the implementation of interventions to give thermal comfort to houses and Tambos by the Ministry of Housing, Construction and Sanitation (MVCS); kitchens improvements and rural electrification projects by the Ministry of Energy and Mines (MINEM); periodic improvement of roads by the Ministry of Transport and Communications (MTC); installation of Automatic Meteorological Stations - EMAS by the National Meteorology and Hydrology Service (SENAMHI); environmental thermal conditioning in single-teacher schools and pedagogical kits by the Ministry of Education (MINEDU); health procedures by the Ministry of Health (MINSA), among others (PCM, 2018).

However, the measures for the provision of heat and comfort inside houses, health centers, education institutions and sheds for animals have not been successful due to high costs and insufficient increase in temperatures of the technologies, high dispersion of the population, great difficulty to access affected areas and so forth. For those reasons, it is important to find affordable solutions that can use in situ resources in a sustainable manner. One good option could be using geothermal fluids from medium to low temperature areas for providing heat to houses or to specific places with great influence in vulnerable areas like the Tambos of the PAIS National Program that belongs to the Ministry of Development and Social Inclusion (MIDIS). Tambos gather physical facilities (multipurpose room, bedrooms, kitchen, topic, office) and services (water, electricity, internet), fully equipped with technology and human resources for the provision of services of the sectors and entities of the 3 levels of the government and for non-governmental entities (MIDIS, 2017). The main advantage of this is that most of the geothermal potential of Peru is located in areas greater than 3000 m.a.s.l., being concentrated in the southern volcanic axes, which compounds the regions of Arequipa, Moquegua, Tacna and Cusco (JICA, West JEC and MINEM, 2012) that have the greatest affection by the frosts phenomena. Geothermal energy is present in most of the Andean Mountain Ranges of Peru in high altitude areas where temperatures decrease abruptly. Like this, it could be provided a reliable heat source to the most vulnerable population in Peru, not only satisfying the energy demands of their houses, but having the opportunity to provide heat to crops and cattle, which are their main economic support.

The aim of this study was to identify the areas where geothermal direct use can be applied in the provision of heat to the Tambos, considering their location, proximity to the geothermal resource, and the main populations affected by the frost phenomenon. It also seeks for the best methodologies to apply the geothermal direct use, taking into account the reality of the rural communities in terms of grade of dispersion, infrastructure, economy and culture.

2.METHODOLOGY

The elaboration of the study involved an initial processing of the locations of low temperature geothermal manifestations of Peruvian geothermal areas provided by the Geological, Mining and Metallurgical Institute (INGEMMET) through its interface GEOcatmin; the information of the areas with risks of frosts provided by National Center for the Estimation, Prevention and Reduction of Disaster Risk (CENEPRED) through its interface SIGRID and information of the location of Tambos provided by the National Geo-Referenced System Sayhuite from the Presidency of the Council of Ministers of Peru. The overlapping of all the geographical information was done using the QGIS 3.4.8 Geographic Information System (GIS) software.

Once all this information was correctly georeferenced in QGIS 3.4.8, there were identified those areas were adverse climate conditions, presence of Tambos and presence of medium to low temperature geothermal fluid converge, in order to analyze the technical feasibility of the implementation of geothermal direct use projects. The technical analysis was focused in analyzing if the flow and chemical conditions of the geothermal fluids identified were good for the direct use application, as well as the distances and altitude differences between the geothermal areas and the "Tambos". The following figure shows the diagram of the methodology used.

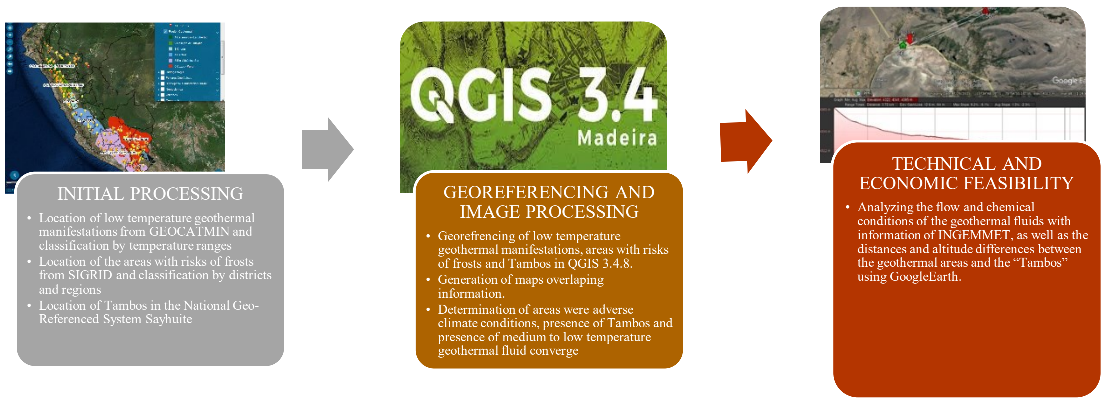

Fig. 1. Methodology diagram (Own elaboration)

3.RESULTS

In the following figures it is shown the location of low to medium geothermal manifestations, zones of high risk of frosts and Tambos (Fig. 2, Fig.3, Fig.4) and the integrated map of all the information (Fig. 5).

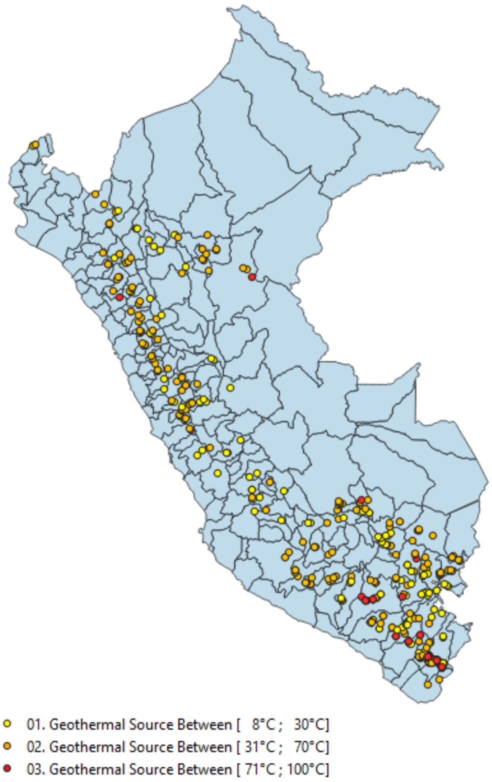

Fig. 2. Low temperature geothermal manifestations **(INGEMMET, 2019)**

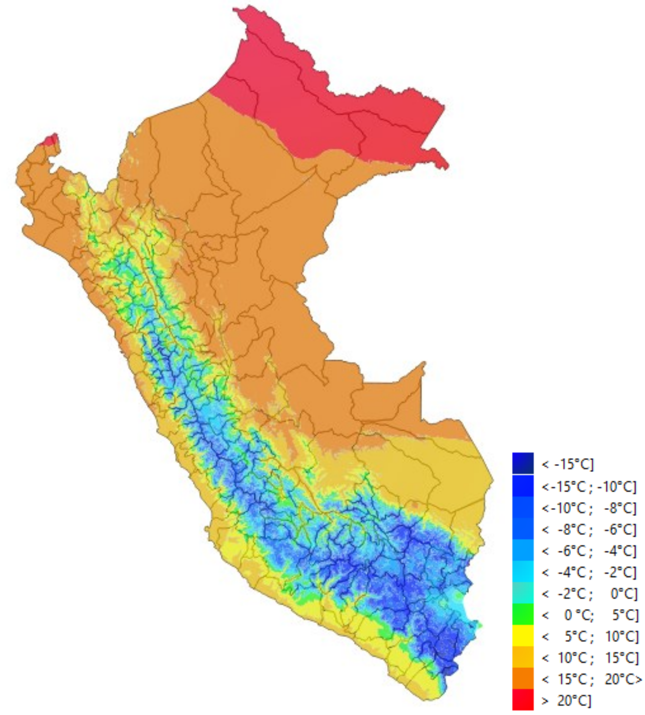

Fig. 3. Zones of high risk of frosts **(CENEPRED, 2019)**

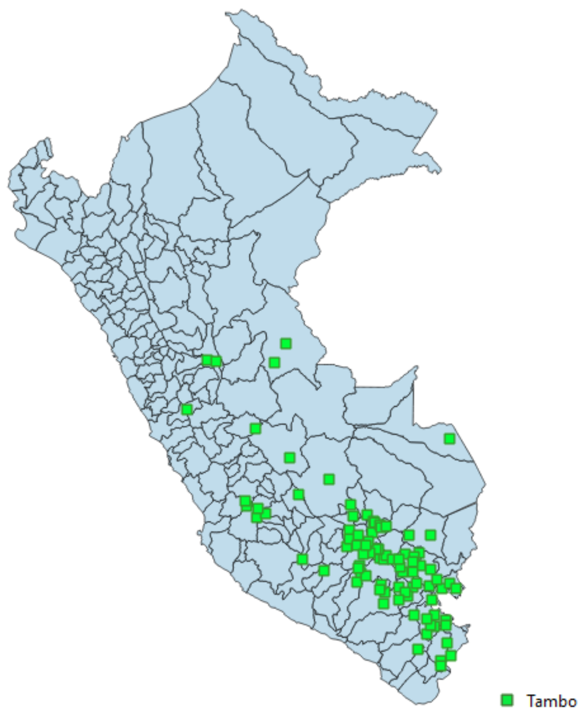

Fig. 4. Location of Tambos (PCM, 2019)

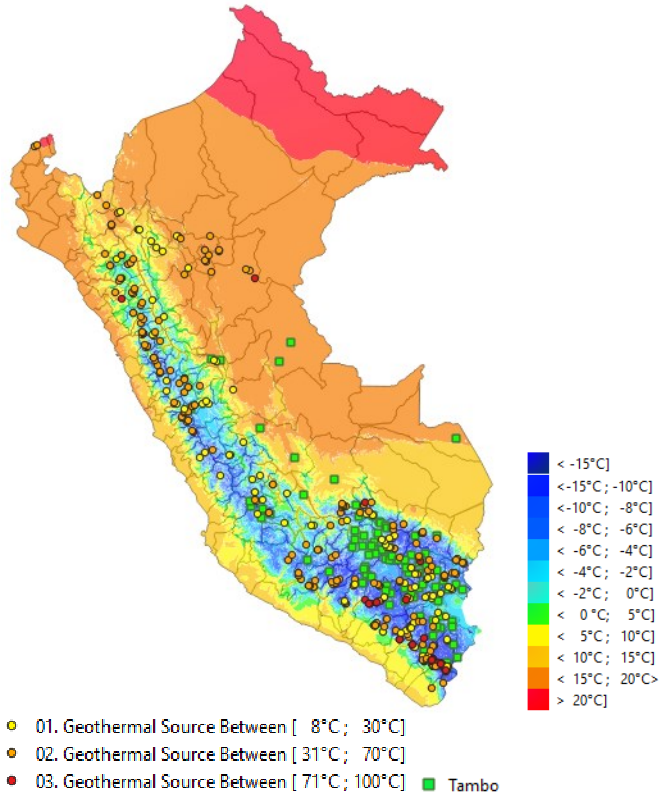

Fig. 5. Integrated information of geothermal manifestations, zones of high risk of frosts and Tambos (INGEMMET, 2019), (CENEPRED, 2019), (PCM, 2019)

From the analysis of the information, there were identified 589 medium to low geothermal manifestations, located mainly in the southern regions of Peru (Arequipa, Moquegua, Cusco and Puno). In terms of frosts risk, in the regions of Ayacucho and Apurímac, temperatures reach values up to -12 ° C; however, in areas located in the upper part of Apurimac, values could be -14 ° C. Meanwhile, in the areas located between the limits of Cusco, Arequipa, Puno and Moquegua, temperatures could go as low as -16 ° C; however, it is in the highlands located between the limits of Tacna, Moquegua and Puno, where the lowest temperatures were identified, being below -16 ° C (CENEPRED, 2018). Finally, regarding the Tambos, the regions with the greatest amount of Tambos habilitated are Puno, with 35 Tambos, and Cusco, with 23 (PCM, 2019).

Taking into account these information, there were selected 20 locations that have geothermal resources from 21 to 81 °C, with critical ambient temperatures (<15°C) during the frost periods and with nearby Tambos. These locations were characterized in terms of flow, temperature and chemical conditions of the geothermal resource, as well as for the distance and slope between the geothermal source and the Tambo. Table 1 summarizes this characterization.

As it can be noticed from Table 1, the geothermal source of Aguas Calientes-Pinaya, is the one with the most favorable conditions for the provision of geothermal heat to the Tambo and associated infrastructure, as it has a good temperature (81°C), considerable flow (3 L/s), favorable chemical conditions of Calcium and Magnesium (having a moderate risk of scaling), and is located at around 4 km from the nearest Tambo with an slope of 3%, which will allow the conduction of the geothermal fluid by gravity. In the following figures (Fig. 6., Fig.7), it is shown the calculation of distance and slope from the geothermal source to the Tambo and the current infrastructure of the Pinaya's Tambo.

Note: Information regarding the Pinaya Reservoir depth is not available because there have not been developed any geophysical measurement.

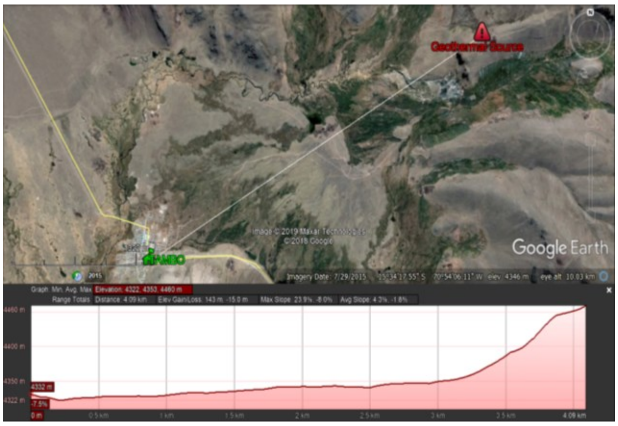

Fig. 6. Calculation of distance and slope from the geothermal source to the Tambo (Own elaboration).

Fig. 7. Main infrastructure of Pinaya's Tambo (MIDIS, 2019).

The Tambo selected assists a population of 2500 people and 870 households (CENEPRED, 2018), however this assistance is just for visitors, not for overnight in the building. The actual capacity of the Tambo is for 20 people, and it has an area of 350 m^2 to be heated with the geothermal fluid. It is proposed them, the provision of heat to the building, along with the construction of a 150 m^2 greenhouse, and a shelter (200 m^2) for 90 animals to help at least one animal per family. The following figure shows the area of the existing Tambo an the projected facilities (greenhouse and shelter).

Fig. 8. Location of existing and projected facilities (Own elaboration).

Table 1. Characterization of prioritized locations

N°	Geothermal source	Department	Province	Tambo associated	Flow [L/s]	T [°C]	pH	[Ca] ppm	[Mg] ppm	[NA] ppm	[K] ppm	[Fe] ppm	[CL] ppm	[Hg] ppm	[Li] ppm	[Mn] ppm	[Al] ppm	Distance [m]	Bound of source [m]	Bound of Tambo [m]	Slope %
1	Aguas Calientes-Pinaya	Puno	Lampa	Pinaya	3	81	---	335	34	3200	170	3.13	5209	2	6.5	0.51	1	4076	4459	4332	3.12%
2	Pinaya 1	Puno	Lampa	Pinaya	---	81	6.58	0	0	0	0	0	0	0	0	0	0	3705	4384	4334	1.35%
3	Pasanoccollo	Puno	Melgar	Ichucahua	7	75	7.1	174	31.6	1688	91	0.01	982	0	6.96	0.06	2	5423	3941	3938	0.06%
4	Agua termal Cachichupa	Puno	San Antonio de Putina	Tupac Amaru Ayrampuni	2	36	6.4	651	101.1	7723	67	2.4	13195	5	6.2	0.43	1	10111	3845	3853	-0.08%
5	Agua termal Uchu Uma	Puno	Carabaya	Upina	2	52	8.7	10	0.66	151	5.4	0.04	100	5	1.04	0.01	2	7246	4085	3875	2.90%
6	Agua termal Vizcacha	Moquegua	Mariscal Nieto	Huaytire	3	31	8.7	36	2.8	27	2.1	0.5	7	5	0.07	0.03	1	18015	4598	4478	0.67%
7	Balneario Pojcpoquella	Puno	Melgar	Tocco Tocco	20	36	6.4	396	133	2124	67	0.15	2956	5	11.4	0.48	2	4163	3915	3924	-0.22%
8	Baños Pacchanta	Cuzco	Quispicanchi	Pucarumi	3	63	6.4	374	21.1	489	69	1.17	565	5	16	0.16	0.3	6030	4314	4086	3.78%
9	Baños Pampacancha	Cuzco	Quispicanchi	Pucarumi	1	47	7.2	44	6.36	152	4	0.57	39	5	0.97	0.06	0.2	5194	3944	4085	-2.71%
10	Collpa Apacheta	Puno	Puno	Huarijuyo	2	54	6	270	50	850	45	2.38	1229	2	1.88	1.5	0.11	12361	4112	3994	0.95%
11	Qatsile	Puno	Melgar	Quinsaayayo	1	36	6.8	154	22.7	335	32	0.44	85	5	2.06	0.21	2	6030	4064	4028	0.60%
12	Tolapalca	Puno	San Roman	Charamaya	3	45	6	440	95	2600	55	3.75	3765	2	2.38	0.41	1	17592	3883	4146	-1.49%
13	Untu Uma-San Luís	Puno	Azangaro	Machariri central	2	38	6.8	427	56.3	288	20.7	0.4	107	5	0.39	0.12	1	10989	3876	3910	-0.31%
14	Baños Geomedicinales Ccaccatu	Cuzco	Calca	Pampallacta	1	22	6.4	543	103	135	25	0.01	196	5	0.86	1.81	1	1881	3898	3890	0.43%
15	Collpapampa	Puno	Puno	Aymaña	0.5	23	6.5	3750	600	17500	1250	9.5	48562	2	33.5	17.13	0.22	22397	2734	4208	-6.58%
16	Paqcha	Puno	Huancane	San Pedro de Huarisani	1	21	8.3	16	5	10	7	0.1	21	5	0	2	1	8887	3843	3894	-0.57%
17	Q. Chungara	Tacna	Tarata	Kallapuma	0.01	24	6.5	57	13.5	810	82	0	1353	0	5.5	0	0	3206	4294	4270	0.75%
18	Sondajes - Pozo 1	Tacna	Tarata	Capazo	0.01	30	---	69	0.5	1320	87	0	2950	0	14.3	0	0	13589	4251	4396	-1.07%
19	Tacalaya Norte	Tacna	Candarave	Huaytire	2	24	5.5	58	38	118	23	0.3	11	0	0	0	0	14476	4659	4478	1.25%
20	Yanaoca - Uccurmina	Cuzco	Canas	Hanccoyo	3	22	6.4	670	170	256	12	0.14	480	5	0.47	0.04	0.1	10143	3896	4045	-1.47%

Source: (INGEMMET, 2019).

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