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FACULTAD DE INGENIERÍA

Escuela Académico Profesional de Ingeniería Civil

Tesis

Vertical Electrical Sounding Method to Detect Groundwater and Design of A Tubular Well for the Pampas District - Peru

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Diego Jose Julian Salvador
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Para optar el Título Profesional de
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Vertical electrical sounding method to detect groundwater and design of a tubular well for the Pampas district – Peru

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Abstract

In recent years, the occurrence of unexpected meteorological events during the dry season and population growth have generated shortages in the supply of drinking water in the city of Pampas. This situation led us to look for new search strategies for natural water sources, even underground. Faced with this problem, the possibility of detecting and parameterizing these sources was raised, while the design of a tubular well was raised that allows the economic extraction of water from the aquifer studied through the use of geophysical techniques, generating profile images of geological maps. of the strata and the location of the possible water table of the study area. The preferred locations for locating groundwater collections are alluvial fans and fractured valley bottoms. Using the Schlumberger array, eleven (11) VESs have been made, up to a depth of 150 m.

For the field tests, a resistivity meter that we have manufactured by hand was used, this will emit current to the subsoil obtaining layers and horizons through their resistivities, these values vary in the range of 6.32-125.23 Ω.m. The PQWTS-150-Water Detector equipment was also used to measure the depth of the semi-confined aquifer and to know its groundwater flow, the value is 33.33 l/s, this value refers to the three celestial layers that can be seen in the image. description of the profile of the geological map, in this profile clayey, silty, sandy, gravel soils and a combination of them were found. This point 11 was taken in the nursery of the Daniel Hernández district, this area is flat, quite humid and its depth is 51m -115m. In addition, this aquifer has good hydrogeological possibilities making surface recharge possible. The water table was also determined, it is found at a depth of 4-8 m. With the data obtained lines above it was useful for the calculation and design of the tubular well.

In conclusion, the designed well has a depth of 115 m and a thickness of 64 m, with a drilling diameter of 18 inches and equipped with a submersible pump with a 25 HP motor, achieving a flow rate of 1000 l/min, which complies with the water requirement of the population. In order to verify the quality of the water from this well, a physical-chemical and bacteriological analysis was carried out.

Keywords Hydrogeology, Vertical Electrical Sounding (VES), Resistivity and Groundwater

1. Introduction

The growth and support of human societies has always been related to the availability and easy access of fresh water for direct consumption, agriculture, cattle raising and Industry [28]. One of the reasons for the water shortage is population growth, that's why we worked out this geoelectric research (VESs) applied to groundwater and the tube well design for its exploitation as an alternative solution [22]. This study will focus on the urban population of the Pampas district which requires 17 l/s of water.

The results of the geophysical investigation allowed locating the ideal aquifer (favorable structures for the storage of groundwater in sufficient quantity and quality) and the tube well design that adjusts to the hydrogeological characteristics of the area. This has been carried out through the hydrogeological survey of the terrain previously mapped on the surface with the ArcGis 10.5 software and Google Earth.

Villaroya's work [1] locates favorable structures for groundwater storage in sufficient quantity and quality. This has been achieved through the hydrogeological survey of the terrain (inventory of water points) and the application of geophysical techniques (VES), based on the analysis of the terrain response trough the passage of electrical current in fracture zones previously mapped on the surface. via satellite images.

As part of calculation and design procedure, we could indicate a sequence of steps for the correct design of a tubular well, in our case this well has a depth of 115 m, with a drilling diameter of 18 inches and equipped with a submersible pump with a 25 HP power engine, achieving a flow of 1000 l/min which guarantee population water requirement.

2. Geological Framework

2.1 Region's Geology

The Huancavelica's territory presents many lithostratigraphic characteristics, such as the Pucara Group, the Chambara formation from the Upper Triassic and Lower Jurassic, these are characterized by gray limestones in thin to medium layers and horizons with chert nodules [3].

2.2 Local Geology

In the Pampas province there is an extensive shale outcrop with subordinate proportions of sandstones. This is accord to McLaughlin's description [2] as the Excelsior Series, this group is characterized by the shales' sequence that gradually pass to lower parts where the schists and locally to gneiss, in this one there are small occurrences of amphibolites. In other words, the Excelsior group is made up of dark gray shales interspersed with gray and greenish-gray sandstones that pass into schists and gneiss.

2.3 Study Location

In Figura 1 shows the ubication of the Pampas district at 3,276 m. a. s. l.. Its geographic coordinates are: West longitude 74º 52' 02"5.1, South latitude 12º 23' 42, UTM zone 18 and Latitudinal strip L [20].

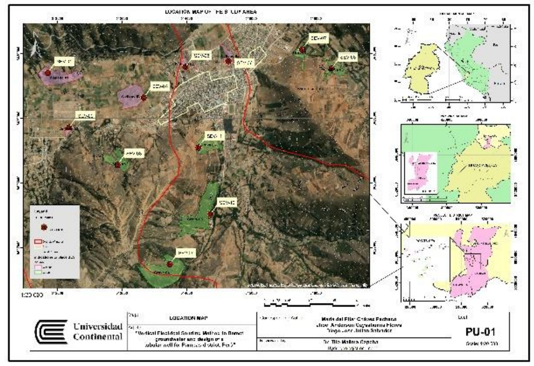

Figure 1. Geographical location of Pampas district

2.4 Hydrogeology

The Pampas district shows a drainage system made up of rivers, springs, puquials (waterholes) and streams that flow into the Mantaro river. The Upamayo river is the most important source that flows through this district, its tributaries are the streams: Llamacancha, Machuhuasi, Lindahuayjo, Yanahuayjo, Tablahuayjo and Chinchihuayjo [20]. In Figure 2A shows the drainage areas of the 7 study sub-basins, these are shown in their entirety of Pampas and Santiago de Tucuman districts; whose largest extension is the Upamayo sub-basin with 151.17 km2 and the smallest extension is the Corinto sub-basin with 8.71 km2. Also, in Figure 2B shows the hydrogeological map of Pampas.

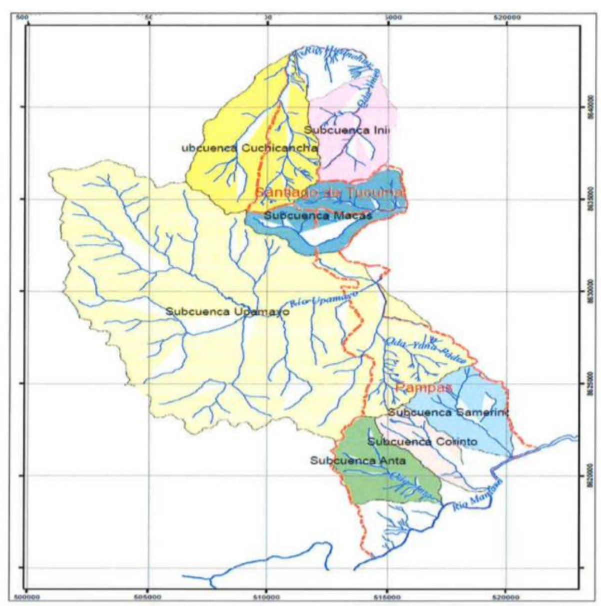

Figure 2A. Sub-basins that make up the Pampas district

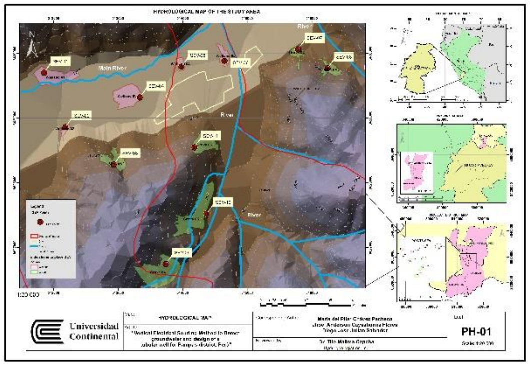

Figure 2B. Hydrological map of the Pampas district

2.4.1 Precipitation

Pampas has a slight variation of monthly rainfall by season. The rainy period lasts 7 months, from October 7 to May 6, with an interval of 31 days of rainfall of at least 13 millimeters. March is the rainiest month in Pampas, with an average of 27 millimeters of rain. In conclusion the precipitation is up to 980 mm per year [20].

2.4.2 Conceptual Hydrogeological Model

The formulation of an acceptable and realistic conceptual model is the most important stage in the application of this. In addition, it must include physical environment simplifications, boundary conditions, the model objective and its method.

The hydrogeological system is made up of an upper phreatic subsystem and a resistant impermeable lower subsystem (basal layer), with the following boundary conditions: [3]

a) The topographic surface and the impermeable and the basal layer constitute the limits of the system in the vertical sense.

b) A semi-confined aquifer is made up of permeable layers whose feeding sources are the waters that infiltrate the sub-basin upper part, as well as the infiltrations of the bed on both banks on Upamayo river, irrigation channels and agricultural areas.

c) The direction of groundwater runoff throughout the Valley and it's parallelly oriented to the river direction, from West to East.

e) The climate has two pronounced seasons: dry season from June to September and rainy season from October to May, reaching up to 980 mm of annual precipitation.

f) Average annual temperatures vary between 11 to 16ºC.

2.4.3 Aquifer

It's a stratum or geological formation that allows water circulation through pores or cracks. They provide economically benefits to mankind in appreciable quantities to cover its needs. Similarly, an aquifer is a water geological reservoir at a greater depth, which can be pumped later [20].

For this case, we observed a semi-confined aquifer. Where the wall (lower part) and/or the roof (upper part) that encloses them is not totally impermeable but an aquitard; because this material allows a very slow vertical water infiltration, which feeds the main aquifer. It can be done in one direction or another and even vary over time depending on the relative position of their piezometric levels. In the research area, the groundwater recharge sources are precipitation, infiltration, and induced recharge from surface water. Much of the precipitation recharge is during the winter from October to May [4].

a) Water Quality in Aquifers

In Figure 3 shows the level of the free and semi-confined aquifer, the water contribution is due to infiltration from the micro-basin highest areas, so the water quality is good [20]. In addition, the physical, chemical and bacteriological analysis was carried out to guarantee that it is in optimal conditions for human consumption [16].

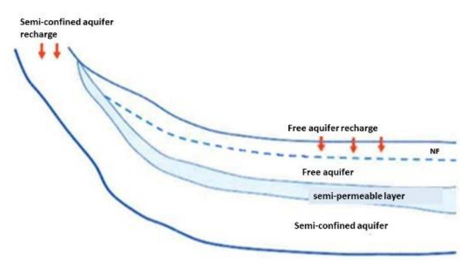

Figure 3. The aquifers conformation in the Pampas Valley

2.4.4 Water Table

The water flow direction through soils, whose trajectories and pore pressures are extremely complex due to the random way in which permeability can vary from one point to another and also different directions. One way to schematize the water flow is by flow lines, which represent the path taken by moving water particles.

In the study area, the water table depth is between 4 m - 8 m and the hydraulic gradient does not exceed the value of 1.20 % [3].

2.5 Groundwater

The groundwater volume represents 30.1% of the total fresh water on earth. Groundwater is product of meteoric water that falls to the surface like rain or snow, that infiltrate soil, filling fissures and cracks in consolidated rocks, and unconsolidated soil pores [27]. In the study area, the fluvial runoff is quite uniform and well distributed, its significant values depend on surface runoff, these are determined by rainfall.

The world's second largest freshwater reserve is found underground. In other words, the largest usable freshwater reserve in the world is right under our feet. In order to build regulations for an appropriate extraction as well as its good quality, it's vital to know the groundwater properties [27].

For that reason, this article studies the geophysical method which gives good results in groundwater exploration, opening new alternatives to face water scarcity [5].

There are four mechanisms that feed groundwater [5].

a) Surface water infiltration.

b) Air condensation that circulates through rock porosities.

c) Sea Infiltration into subsoil and distillation of this by Earth internal heat.

d) Juvenile waters.

2.5.1 Water Balance

It's the difference between underground water availability of a tube well in comparison to population's water demand [29].

The P11 well has underground water in its three layers of light blue color that gives us 33.33 l/s, and the urban population demands 17 l/s, where it is observed that the supply is greater than the demand. Therefore, we affirmed that this water supply from the well will cover satisfactory the urban population needs of Pampas city [3].

3. Materials and Methods

3.1 Rock resistivity

According to Romero [6]. Resistivity is one of the physical properties with the greatest variability in geophysical prospecting.

The main physical property of rocks or formations involved in electrical measurements is resistivity, which is defined as the resistance that opposes a cube of width unit to the passage of 1 ampere electric current, which circulates perpendicular to its two sides, between them there is a potential difference (voltage) of 1 volt, the measure unit for resistivity is the ohm-meter. In Table 1 shows this reason, it is inappropriate to speak of an exact value for a rock, but rather to speak of a values range [7].

Table 1. Electrical resistivity according to the type of material [8].

Soils / rocks	Resistivity (ohm-m)
Groundwater in Granite and Hypogenic rock	20-100
Groundwater in limestone and haulage	20-50
Brackish waters	01-10
Surface drinking water	20-300
Sea water	<0.2
Distilled water	>500
Clay	10-100
Limestone and sandstone	50-3000
Slate	50-300
Metamorphic rock	100-10000
Gravel	100-10000
Grit	130-1000
Slime	30-500

3.1.1 Apparent Resistivity

The apparent resistivity (Ra) is the resistivity obtained by applying the data obtained on a heterogeneous medium, and the following equation: [9]

$Ra = Ke \times \Delta v / I$

Where Ke is a coefficient that depends on the type of electrode device used; Ra apparent resistivity; I, current intensity measured in A and ΔV voltage expressed in V.

In Figure 4 shows the electrode device is a geometric arrangement that exists between a pair of current electrodes A and B, and another pair of potential electrodes M and N. A very common geometric arrangement is the one used in the Schlumberger method [9].

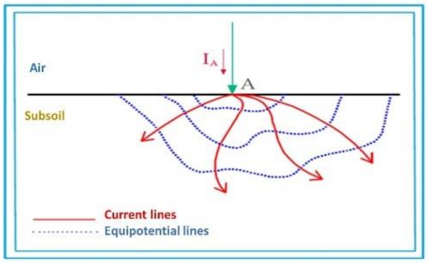

Figure 4. Current flow in a natural environment [10].

3.2 Schlumberger Array

We applied the symmetrical type of Schlumberger arrangement [10]. Which began with the installation of the resistivity meter, and was also set at a central point for the device location. In Figure 5 shows the electrodes AMNB are arranged in line symmetrically, where the MN distance is much smaller than the injectors AB's. Generally, AB must be greater or equal to 5 MN. From the device location, electrodes A and B were extended in opposite directions which were extended to certain measurements between 1 m - 50 m. Then voltage was applied to electrodes A and B to determine the electric current in mA. At the same time, we distributed the potential electrodes M and N, to determine the difference in power mV) [19].

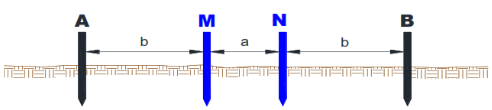

Figure 5. Shlumberger device [18].

3.3 Geophysical Prospecting Methods

Geophysical prospecting methods, within the prospecting techniques diversity, four main groups stand out; 1) gravimetric, 2) magnetic, 3) electrical and 4) seismic. The first two are for natural field and the remaining two of artificial field (with the exception of some modalities). In other words, in the gravimetric and magnetic methods study disturbances that certain structures or bodies produce on pre-existing fields, such as gravity and the geomagnetic field, while in the electric and seismic methods it is the prospector himself who creates the study physical field; which has the advantage of providing the most appropriate characteristics for our purpose. This does not mean that superiority relations can be established between one and the other, since the effectiveness depends on the proposed problem [12].

3.3.1 Vertical Electrical Sounding (VES)

According to Calixto [13] for the application of the VES's, the main requirement is that the geological formations to be distinguished present sufficient resistivity contrast to make possible their electrical differentiation. Regarding the horizontality of the strata, the VES's are applied to the geological strata whose maximum inclination slope of terrain is 12%.

In this research work, we carried out a geological and hydrogeological reconnaissance. The VES's were strategically located according to the indications for the groundwater detection, for this we used the geomorphological plane intercepted with the normalized differential water index (NDWI), which allows to know the vegetation hydration and the soil humidity, likewise we identified the water masses and areas of high humidity saturation through satellite images analysis(Google Earth software) which are useful to delimit the masses of water with the geological formations of soil as well as the possible location of groundwater . Finally, we used to outline it, the ArcGis 10.5 Software [4].

To measure the aquifers depth, we explored with the PQWT S-150-Water Detector equipment at a depth of 150 meters with a simple frequency-33. The operating principle uses the natural electric field as the source of electromagnetic field work, based on the resistivity differences of underground rocks, minerals or groundwater, to measures the natural electric field in the soil with different components of the electrical frequency field [21].

We also used the resistivity meter for data collection, this equipment has been assembled by the researchers, it allows us to measure the resistivity up to a depth of 150 m and to know the geoelectric stratification of the subsoil and the contamination of the aquifer. The investigation depth depends directly on the separation of the AB electrodes, since the revised theory [11] specifies that the reach depth of the current lines is half the separation of the current injector electrodes.

The materials used for the assembly are detailed below: 12-volt motorcycle batteries, which generate direct current (with a rectifier it is converted to direct current) and these are connected in series. With the help of a component, the current selector can achieve different application voltages to inject and obtain different readings for the same electrode arrangement. The average will be calculated from the obtained data, representing the ground apparent resistivity [6]. The researchers also used Solid blue THW 12 light cables. In Figure 6 shows for the measurement equipment, we used the digital multimeter, which is an instrument that measures electrical magnitudes such as currents and potentials (voltages), or passive electrical magnitudes like resistance; the measurements can be made for both direct current and alternating current. Regarding millivoltmeters, the reviewed literature [6] suggests that they have a large input impedance, greater than one MΩ (Mega ohm). Currently there are devices of 10 MΩ and up to 100 MΩ input impedance, this minimum impedance limit provides greater accuracy, because when reading the voltage, we connect the millivoltmeter in parallel with the ground and even when its impedance is small.

Figure 6. Equipment to measure soil electrical resistivity

The electrode arrangement is detailed below. In the first place, the current electrodes, these are electrical conductors and in this case they are placed at the end of each cable in the line (AB), or current emission line; These electrodes can be made of different materials, some better conductive than others, and common nails can be used with an appropriate length that is easy to handle in the field; the 20 cm ones are chosen

Finally, the power electrodes, these are placed at the end of the line (MN) corresponding to the potential cables, these electrodes have to be "non-polarizable" and according to Romero [6] : "In general lines these electrodes consist, in a copper tube embedded in a porous glass containing a saturated solution of copper sulfate in crystals. In Figure 7 shows the tube and the glass are wrapped in a rubber or plastic cover, except for the lower part that is exposed because is the one that makes ground contact. When a current passes through the circuit, it decomposes a small part of the sulfate, but this is immediately renewed by dissolving an equivalent amount of the same salt, present in the form of crystals, so that the sulfate solution always remains at the same concentration, avoiding the electrode polarization [6].

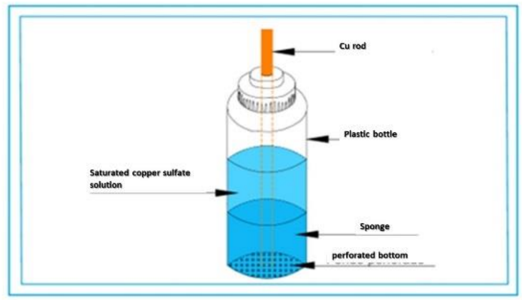

Figure 7. Non-polarizable potential electrode [6].

In the study area, measurements were made corresponding to a zone of great depth of unconsolidated rocks, then based on its effective porosity it can be inferred that certain types of fractured and jointed metamorphic rocks can act as semi-impermeable rock, confining some thickness to the aquifer [4].

For the field tests, we used a resistivity meter, this will emit current to the subsoil, obtaining layers and horizons through their resistivities, which were developed to determine the quantity and quality of the groundwater that serves to supply the population. For this purpose, 11 VESs were executed. These surveys were distributed in the districts of Pampas and Ahuaycha. After that, we chose 5 surveys based on their upper bound. From these 5 profiles, one (P11) was chosen. This point is located in the nursery of Daniel Hernández district, it has hydrogeological possibilities for the location of a tubular well and to achieve the capture of groundwater. In addition, the point area is flat and quite humid. Approximately at a depth interval of 51 m-115 m, there is surface recharge water saturating, making the terrain soft and this water will be used for irrigation. Considering the three layers, quantitatively taken water gives a flow of 33.33 lt/s at the level of the semi-confined aquifer. See the following Figure 8 that shows the geomorphological map of the VESs location and in Table 2, we can see their respective geographical coordinates.

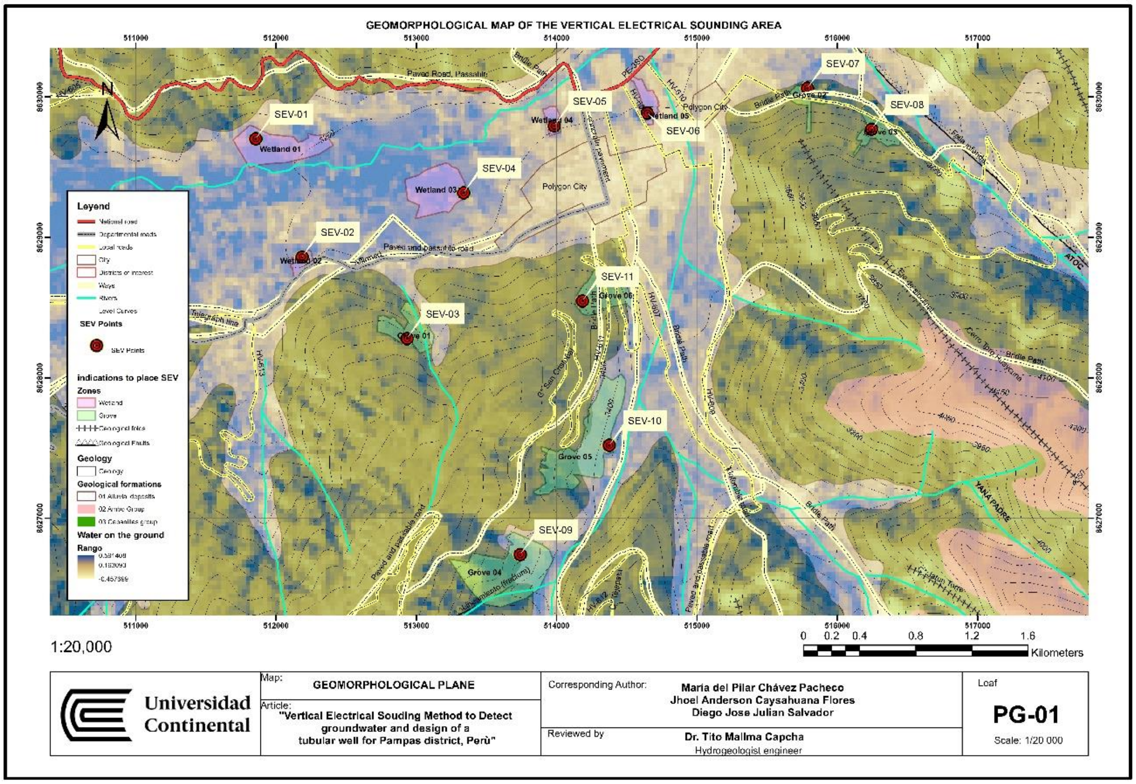

Figure 8. Geomorphological location map of the 11 VESs

Table 2. Cardinal points of the 11 VESs

Item	Drilling	North	East	level (m.a.s.l)	Geological Formation	Study Depth (m)	Reference
1	VES-01	8629702	511854	3257.25	alluvial deposits	150.00	Ruta-3sd Highway – Right Side - Wetland 01
2	VES-02	8628860	512184	3245.72	alluvial deposits	150.00	Affirmed Street - Left Side - Wetland 02
3	VES-03	8628280	512932	3457.63	Cabanillas Group	150.00	Affirmed Street - Right Side - Arboleda 01
4	VES-04	8629318	513336	Geological formation	Study Depth (m)	Reference	Affirmed Street - Left Side - Wetland 03
5	VES-05	8629793	513981	3244.66	alluvial deposits	150.00	Rigid Pavement Street - Left Side - Wetland 04
6	VES-06	8629885	514645	3247.15	alluvial deposits	150.00	Highway Pe-3sd - Right Side - Wetland 05
7	VES-07	8630062	515786	3288.07	Cabanillas Group	150.00	Bridle Path Hv-610 - Left Side - Arboleda 02
8	VES-08	8629769	516243	3410.21	Cabanillas Group	150.00	Bridle Path Hv-610 - Right Side -

Item	Drilling	North	East	level (m.a.s.l)	Geological Formation	Study Depth (m)	Reference
							Arboleda 03
9	VES-09	8626740	513739	3530.27	Cabanillas Group	150.00	Road to Cerro San Cristóbal – Left Side - Arboleda 04
10	VES-10	8627519	514374	3347.64	Cabanillas Group	150.00	Road to Cerro San Cristóbal – Left Side - Arboleda 05
11	VES-11	8628547	514182	3460.76	Cabanillas Group	150.00	Road to Cerro San Cristóbal – Right Side - Arboleda 06

3.4 Tube Well

Generally, in cylindrical shape a well is a vertical hole excavation or tunnel that perforates the earth to a sufficient depth to reach what is sought, since reserves from the groundwater table or fluids such as oil. In order, to prevent deterioration and collapse the walls are secured with brick, stone, cement or wood [14].

3.4.1 Tube Well Design

The sequence to design a well begins with the certainty of the aquifer existence that will be exploited and its water quality. See figure 9. Continuing with the description of hydraulic parameters. Until here, the "possibility" is defined and only then we will present the "requirements" in terms of "possibility" flow and manometric height that the pump must deliver, with which it is selected and then the dimensions of the well are established [23].

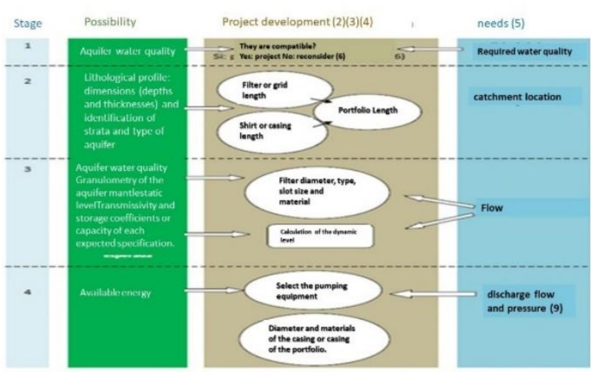

Figure 9. Well design schematic [15].

Point eleven (P11) is the most stable for proper drilling. This profile achieves a constant piezometric level because of its stable internal pressures and the ability to self-supply. In order to present the design of a tube well in Pampas district, we projected future population for a period of 20 years (2042) by taking prevalent population demography data. Population growth was calculated using the geometric method and with information from the National Institute of Statistics and Informatics - INEI [30], (see Annex A-08). With a population growth rate of 2.08% (see Annex A-09), we estimated a current population of 8,702 inhabitants by 2022 (see Annex A-10) and future population by 2042 will be 13,129 inhabitants (see Annex A-11).

3.4.2 Well Depth and Diameter

The well depth will be taken based on the aquifer thickness. The well diameter is related to the performance and also to the diameter of the submerged pump (and its respective pipes) [27].

For this case, Figure 10 shows an aquifer at a depth of 115 meters, which will be the depth of the tubular well (total drilling depth) [27].

Layer 1: 75-51=24m
Layer 2: 101 – 75=26m
Layer 3: 115-101=14m
Aquifer Thickness b=64 m

3.4.3 Sizing of Tube Well Elements

a) Grid diameter

If we consider a slot opening of 2 mm, according to the calculations of minimum opening in prefilters [17].

b) Hydraulic Conductivity Calculation (K) and permeability degree

For this, the calculation of the transmissivity (T) as a function of the flow rate (Q) obtained according to the VES of point 11 according to the equations:

$$K = \frac{T}{b} \qquad (1)$$

Where:
T: Transmissivity
b: Aquifer thickness

T = 333.33 m2/d y b= 64.00 m

K = (333.33 m2/d) / (64.00 m)

K = 5.20 m/d

The hydraulic conductivity according to the terrain type is a sandy gravel with intercalation of sandstones and micaceous shale in medium strata, see Annex A-04, therefore, K varies from 1 to 1000 m/day (see Annex A-05).

The results indicate that a flow of 33.33 l/s, we found a medium-high transmissivity (see Annex A-01) with a proportional transmissivity of 333.33 m2/day, a diameter of 12" is recommended, according to Annex A-02 for optimal tubing diameter [17].

c) Filter and grid opening

The filter will be made of stainless steel based on Landeo's recommendation [17] as shown in Annex A-03, as the water exploitation area belongs to an open perimeter and possibly with contamination risk by bacteria due to corn and potatoes crops, which is the trade of the Pampas area.

d) Inlet velocity as a function of hydraulic conductivity

Obtained from Aguilar [24] whose value is V=1cm/s for values of K=5.2 m/day (See table 13 of Annex A-06).

e) Calculation of the opening area of the grids

To find the opening area of the grilles, it is determined with the formula:

$$Q = V \times A \quad (2)$$

$$A = Q / V \quad (3)$$

A = (0.033 m3/s) / (0.01 m/s)

A = 3.33 m2

f) Calculation of the area per meter of infiltration in the aquifer: It is shown in equation 4.

$$f = A/h \quad (4)$$

f = (3.333 m2) / (64.00m)

f = 520.781 cm2/m

Where:

f : infiltration rate.

A: Total minimum area of all slots in the well.

H: the depth of the aquifer

If we stablish a slot opening equal to 2 mm, according to the minimum opening calculations in prefilters, we will have an infiltration area in the vertical basket f = 912 cm²/m, according to (Annex A-07).

912 cm²/m > 520.781 cm^2/m

As the value of "f" is greater than the infiltration calculation, then it does comply with the design. Therefore, the results of the pipe and the opening of these filters are obtained:

Filter diameter = 12"

Thickness = 5/16"

Weight per linear meter = 61.7 kg

Number of slots = 912

infiltration area =912 cm²/m=0.0912 m^2/m

Therefore, the final diameter of the filter turned out to be the same as the pre-design:

Ø Commercial filter ≥ Ø predesign = 12"

g) Filter length calculation

For the pipes entered, they must reach the depletion level of the well from there the filter pipe is entered [17].

Finally, we found the total length of the filter pipe:

$$L = Q / (Ao \times Vp) \quad (5)$$

L = 0.033 m3/s / (0.0912 m2/m) x (0.01 m/s)

L = 36.18 m

Donde:

Q = Caudal (m^3/s).

Vp = Velocidad óptima de entrada (m/s).

Ao = Área abierta de longitud de rejilla (m^2/m).

L = Longitud del filtro (m).

4.3.9 Static height (He)

It is the difference in elevations between the catchment points and the maximum pumping head [4].

$$He=C_f-C_e \quad (6)$$

Where:

Cf: initial point elevation

Ce: electric pump point elevation

He = 3460.76 - 3409.76 m.a.s.l.

He = 51.00 m.a.s.l.

h) Blind intubation length

It is from the beginning of the drawdown of the well to where the aquifer begins plus the length of the accessories that are at the entrance of the well, being:

$$Lc= H_e + L_a \quad (7)$$

Where:

He: Static height

La: Accessories length

Lc= 1.3 m + 51.0 m = 52.3m

i) Blind pipe diameter

The diameter of the blind pipe is the same diameter as the filter pipe (see Annex A-02). It will be used Black iron material.

j) Gravel Pack Length

It's calculated as the sum of the aquifer thickness (3 layers) this is equal to 64m (see Table 6)

k) Gravel diameter

According to Beckmann [25] suggests the following: any type of materials, no matter how fine, it can be controlled with a filter made up of graded gravel, with particles limited to between ¼ and ½ inch in diameter. Therefore, the most commercial ¼" is used.

l) Gravel Pack Thickness

According to Aguilar [24], it is considered that there is a need for a pre-filter when there is the presence of fine sand and uniform grain size, but to avoid puncturing of the material during its placement, only the 3" filter is required.

m) Overall drilling diameter

This is given as the sum of the diameter of the blind pipe plus 2 times the thickness of the gravel pack.

$$Dt=Dtc+2 \text{ x } ep \quad (8)$$

Dt= 12"+3"+3"=18"

Where:

Dtc: blind pipe diameter

ep= gravel pack thickness

In which we used the regulations ASTM-A53, ASTM-A120.

n) Calculation of flow design

According to the General Directorate of Environmental Health (DIGESA) [26], the rural endowment in the sierra (high Andes) is 50 l/d. For this, we used the table of reference consumption values for an urban population according to its geographical location (see Annex A-12). Therefore, the total demand can be seen in Annex A-13.

o) Finding the average flow rate (Qp)

$$Qp\left(\frac{L}{s}\right) = \frac{Total\ daily\ allocation}{24h*3600s} \quad (9)$$

Q_p = (737450 l/d) / (1d / 86400 s) = 8.53 l/s

p) Calculation of the maximum daily flow

The average flow rate value is used to calculate the maximum daily flow rate (Qmd) and maximum hourly flow rate (Qmh).

$$Q_{md} = Q_p \ x \ K_1 \quad (10)$$

Q_{md} = 8.53x 1.3 = 11.08 l/s

Where:

Q_p: average flow (l/s)

K_1: Variation coefficient

q) Maximum hourly flow (Qmh)

$$Q_{mh} = Q_p \ x \ K_2 \quad (11)$$

Q_{md} = 8.53 x 1.5 = 12.79 l/s

Where:

Q_p: average flow (l/s)

K_2: Variation coefficient 2

r) Pumping Flow Calculation

$$Q_b = Qmd \text{ x } (24/N) \quad (12)$$

Q_b = 11.08 x (24/8) = 33.3 l/s

Where:

Q_b: pumping flow (l/s)

Q_{md}: Maximum daily flow (l/s)

N: Number of hours in use.

s) Head Loss (Hf)

The head loss is due to the accessories through the groundwater will pass in the pumping installation and conduction line until it reaches the cistern, in this case we used the Hazen Williams formula, also according to the type of pipe material for this case is made of smooth steel and has a coefficient of C=150 [17].

$$Hf = 10.764 * \frac{Q^{1.852}}{C^{1.852} * D^{4.781}} * L \quad (13)$$

t) Loss of pressure through conduction pipe

Table 3. Loss of pressure in the conduction pipe

Pumping flow (m3/s)	Hazen Williams Coefficient (C)	Internal diameter (D)	Length(L)	H (m)
0.0333	150	0.254	100	0.13
H_{f1}=0.13m				

u) Kinetic energy

$$Hc = \frac{V^2}{2*g} \quad (14)$$

V: flow rate (m/s)

g: acceleration of gravity (m/s2)

$$V=4Q/\pi*D^2 \quad (15)$$

V: flow rate (m/s)
g: acceleration of gravity (m/s2)
Then:
V=(4 x 0.0333)/(3.1416 x 0.2542)= 0.66 m/s
Hc=(0.662 m/s)/(2 x 9.81m/s)
Hc=0.022 m.

v) Total dynamic height

$$H_{dt} = H_e + H_f + H_c \quad (16)$$

Where:
H_{dt}: overall dynamic height
H_e= static height
H_f=Head loss
H_c= Kinetic energy
H_e=51.00 m
H_f=0.13 m
H_c=0.022 m.
H_{dt}=51.252 m

w) Submersible electric pump

For a tubular well of previously detailed dimensions, we proposed the use of a submersible electric pump with the following characteristics (See Annex A-14, A-15).

Table 4. Electric pump dimensions

Description	Brand	Model	Power	Flow	H
Submersible electric pump	Pedrollo	6SR225G/250	25.00 HP	1000 l/min	83 m.

4. Results

The main results are described as much as qualitative and quantitative interpretation for records of the Vertical Electrical Surveys, as well as the physical-chemical and bacteriological water analysis, which helped considerably to decide which aquifer of the 11 points plumbed is the right one to install the tube well.

4.1 Vertical Electric Sounding

In Table 5 shows with the results obtained, favorable areas for the exploitation of groundwater are related.

Table 5. VES Analysis for Tubular Well Location

Ítem	Plumb	North	East	Level (m.a.s.l)	Initial state	Final state
3	VES-03	8628280	512932	3457.63	Chosen for its high level and suitable for supplying by gravity	Discarded for not having a piezometric profile and/or homogeneous layers
8	VES-08	8629769	516243	3410.21	Chosen for its high level and suitable for supplying by gravity	Discarded for not having a piezometric profile and/or homogeneous layers
9	VES-09	8626740	513739	3530.27	Chosen for its high level and suitable for supplying by gravity	Discarded for not having a piezometric profile and/or homogeneous layers
10	VES-10	8627519	514374	3347.64	Chosen for its high level and suitable for supplying by gravity	It has homogeneous layers but the shape of the profile does not generate internal pressures in the water.
11	VES-11	8628547	514182	3460.76	Chosen for its high level and suitable for supplying by gravity	Chosen for having a Homogeneous profile and layers

The points of VESs 03, 08, 09, 10 and 11 were chosen because they had an adequate elevation to supply by gravity and were discarded because they did not have a piezometric profile and/or homogeneous layers. From these boreholes, VES 11 was chosen because it has a high elevation suitable for supplying by gravity, also because it has a piezometric profile and/or homogeneous layers.

The survey interpretation has shown the presence of geological maps. The results confirm quantitatively the geophysical well method, particularly the vertical electrical sounding method, which reflects that the area has excellent hydrogeological conditions for the accumulation and exploitation of groundwater in terms of quality and quantity that they require for human consumption. In Figure 10 shows where the depths of the aquifer layers are observed with their respective colors range of the rock type.

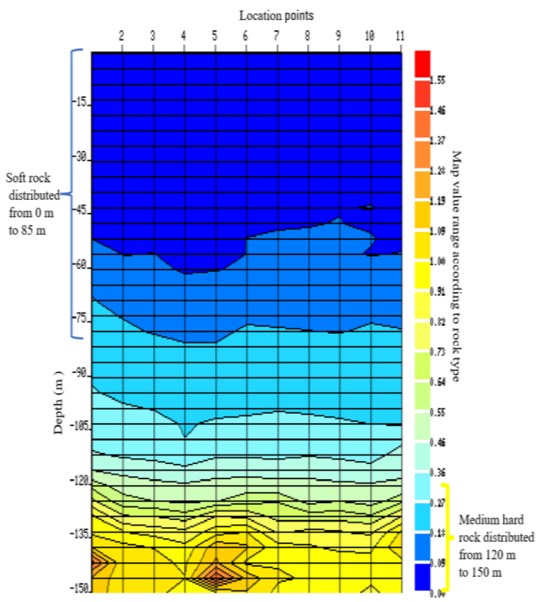

Figure 10. Geological map profile of P11

The result of the geological profile (P11) represents the different layers of rocks, to distinguish them we use colors.

The light blue color indicates the presence of soft rock and groundwater. It is made up of three layers. The first layer is in the position of points 2-3-4-5-6-7-8-9-10-11, this light blue layer is at a depth of 51 meters to 75 meters deep, the water quantitatively indicates 45 m3/hours. The second layer of light blue color is at a depth of 75 meters to 101 meters deep, the water quantitatively indicates 42 m3/hours. The third light blue layer is at a depth of 75 meters to 115 meters, the water quantitatively indicates 33 m3/hours. Quantifying the three layers mentioned above gave us a flow rate of 120 m3/h. And also, the other layers of the mapping were identified. The green color indicates the presence of aquatic zones at a depth of 115 meters to 132 meters, indicating that the water is quantitatively 12 m3/hour. The yellow color indicates the presence of soft relief at points 2-3-4-5-6-7-8-9-10-11 at a depth of 132 to 145 meters. The orange color means presence of rock formation at a depth of 145 to 150 meters.

In Table 6 shows the VES point 11 (P11) is shown below. The point taken is the road to San Cristóbal hill on the right side grove 06.

Table 6. Apparent resistivity P11 VES

Depth (m)		Thickness (m)	Resistivity in Ohms-meter
From	until		
0	15	15	6.32
15	51	36	78.21
51	75	24	48.50
75	101	26	48.50
101	115	14	48.50
115	132	17	125.23
132	145	13	Medium hard rock formation
145	150	5	Medium hard rock formation

Table 6 shows the depth, thickness and electrical resistivity of point 11.

The first layer is between 0-15m meters and corresponds to the first horizon, of vegetal soil, typically corresponding to a stratum made up of clays and saturated gravel; The latter allow the flow of water, and therefore the aquifer recharge, for this layer shows a resistivity of 6.32 $\Omega\, m$.

The second layer, between 15 and 51 meters deep, corresponds to a layer composed of clay, sand and saturated gravel, with a resistivity of 78.21 $\Omega\, m$.

The third layer, between 51 to 115 m. we found groundwater at this depth. This stratum corresponds to sandstone and gravel, with no compaction with abundant thick sediments and lack of a matrix, which favors water movement. The resistivity is 48.50 $\Omega\, m$, this low value shows that electrical conduction is influenced mainly by the electrolytes of water

The fourth layer, between 115 and 132 meters deep, corresponds to a layer composed medium hard rock formation 78.21 $\Omega\, m$

Finally, the last two layers act as impermeable allowing the horizontal flow of the aquifer over this rock layer of medium hardness.

A) Physicochemical and bacteriological analysis of P11 water

Below are the laboratory results of the physical, chemical and bacteriological analysis of water, which was taken in P11 [16].

The obtained results show that the sample meets the Maximum Permissible Limits in the physical and chemical analysis but does not in the bacteriological analysis, so it is recommended to use chlorination and after that filtration. [See all Annex 16]

4.2 Tube Well Results

Next, the values of the tubular well with their respective quantity are presented in a table.

Table 7. Elements of the tube well

Item	Description	Quantity	Unit
1	Drilling		
2	Drilling depth	115	m.
1.2.0	Drilling method	Percussion	
1.3.0	Drilling diameter	18.00	in.
2.0.0	Blind Pipe		
2.1.0	Blind pipe length	52.3	m.
2.2.0	Blind pipe diameter	12.00	in
2.3.0	Blind pipe material	Commercial Steel/Black Iron	
3.0.0	Filter pipe		
3.1.0	Filter pipe length	36.18	m.
3.2.0	Filter pipe diameter	12.00	in
3.3.0	Filter pipe material	Stainless steel	
3.4.0	Grille opening	2	mm.
3.5.0	Infiltration area	912	cm2/ml
4.0.0	Prefilter		
4.1.0	Gravel Pack Length	64	m.
4.2.0	Gravel diameter	1/4	in
4.3.0	Gravel Pack Thickness	3.00	in.

The illustration of tube well components is also presented for better understanding.

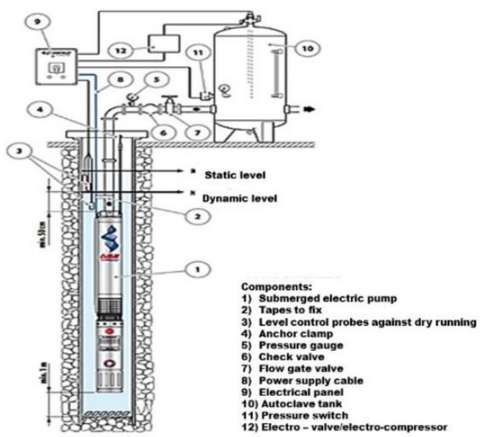

Figure 11. Tube well Components

5. Discussions

5.1 Discussion of VESs

The interpretation of the 11 VESs applied in the study area reveals the presence of non-homogeneous formations consisting mainly of a sequence of soil and rock with different resistivities and thicknesses, having 3 geoelectric layers. The first and second layers are part of the alluvial deposits, which consist of sand, silt and gravel. The third layer is composed of soft rocks.

According to Auge [10] the resistivity of most rocks and dry sediments is high, so they act as semiconductors, or low capacity conductors. In contrast to our research, we can affirm that the stratum corresponds to marls, shales and sandstone, with a lack of compaction, an abundance of coarse sediments and a lack of a matrix, which favors the water movement. So well, there is a low apparent resistance (increase in the conduction capacity of electric current), which indicates that there is abundant water to exploit.

According to Calixto [13] Quaternary deposits constitute an unconsolidated porous aquifer with a thickness of 25 to 40 meters, which is contrasted in this study in the presence of the aquifer in alluvial deposits in the town of Cajamarca. Similar to our research we also have alluvial deposits from 2-41m deep.

The results determines favorable zones for the groundwater exploitation (VESs 03, 08, 09, 10 and 11points), the aquifer would be made up of gravel intercalations, sand and silt with resistivities between 6.32 Ohm-m to 125.23 Ohm-m, which would identify materials with regular to good permeability.

According to Romero [6], low resistivity is also an indicator of water quality, which has greater power and better resistivities, through which underground collection works can be designed.

According to Landeo [17] he mentions his well design with different characteristics from ours, the depth of his well is 70 m and ours is 115 m, his static level is 14.40 m and ours is 51 m. This difference is due to the fact that our aquifer has different stratigraphic layers.

6. Conclusion

The results of the eleven Vertical Electrical Exploration Soundings, with their due interpretation, have led to the conclusion that the materials of the geological strata in the aquifer are: Clay, sand, gravel and a combination of these materials. Soil resistivities vary from 6.32 Ω.m, which corresponds to saturated clays, to 125.23 Ω.m, whose resistivity corresponds to soft rock.

We concluded that the aquifer 11 is lithologically made up of sand and gravel, also it's in a humid state. These characteristics have defined very favorable hydrogeological conditions that can be visualized in the geological mapping, clearly obtaining the aquifer, at a depth between 51 m and 115 m.

The flow required to supply the projected population of the Pampas district is 17 l/s in a pumping period of 1 hour; This is due to the pumping flow for the well is 33.33 l/s according to the calculations made and the geoelectric characteristics, so the well can supply the projected population in a period of 20 years.

7. Recommendations

Regarding groundwater, it is recommended to link with meteorological, geological and geophysical information, in order to study in the nature, functioning and vulnerability of the aquifer systems at local and regional scales.

We recommend that the blind pipe placement must go from level 0.00 to reach 51.252 m. which is below the level of the aquifer.

Finally, in the deepest part of the well, there should be a blind pipe that works as a collector.

8. Acknowledgement

To School of Civil Engineering, Universidad Continental, Huancayo, Peru.

9. Supporting Information

https://drive.google.com/drive/folders/1w9MCdW8TFOGnol1Ltr74eqwNby-X939r

10. References

[1] Villarroya, F., Baba, A. Location of groundwater in the Tiris Ridge (Western Sahara), Madrid: Geogazette, 2015

[2] Mclaughlin, D. H. Geology and physiography of the Peruvian Cordillera, Department of Junín and Lima, Peru: Geol. Soc. Amer. Bull., 1925. pp. 591-632.

[3] Guizado, J., Landa, C. Geology of the Pampas quadrangle, Peru: Ministry of Development, 1964.

[4] Daza, H. F. A. Geoelectric methods applied to underground and thermal water exploration, Chile: University of Concepción Chile, 2012.

[5] United Nations Environment Programme (UNEP), Global Environment Outlook, New York, 2007, 978-92-807-2838-5.

[6] Romero, C. J. W. Geoelectric study and approach to the exploitation of groundwater in the La Victoria-UNC farm, 2019, Cajamarca: National University of Cajamarca, 2019.

[7] Eduardo, A. D., Echeverri. R. O., Hoyos P. F. Geoelectric relations in geotechnical exploration, Colombia: Earth Sciences Bulletin, 2011, 01203630.

[8] Custodio, E., Llamas, M.R. Groundwater Hydrology, Spain : Omega, 2001, 84-282-0281-8

[9] Ñahui, S. G., Ñahui, S. O. Evaluation of the subsoil through geophysical - geoelectric prospecting in the study area of the perimeter fence of the Faculty of Environmental Civil Mining Engineering – UNH, Huancavelica: National University of Huancavelica, 2020.

[10] Auge G. M. Geoelectric methods for groundwater

prospecting, Argentina: University of Buenos Aires, 2008.

[11] Yampasi, S. L. G. Application of the vertical electrical drilling method for the location of groundwater wells in the populated centers of Buena Vista and Miraflores in the district of Sama, province and region of Tacna, Peru: National University of San Augustín de Arequipa, 2019.

[12] Ernstson, K., Kirsch, R. Geoelectrical methods: A tool for hydrogeology Springer Berlin Heidelberg Publishers, Spain: Springer, 2006, pp. 84-117.

[13] Calixto, C. L. J. Geophysical methods for the search for groundwater and pre-design of an extraction well for the company Transavella, in the city of Sagamoso, Boyaca, Colombia: Technological and Pedagogical University of Colombia, 2017.

[14] Ordoñez, G.J. J. Groundwater and aquifers. Lima : Geographical Society of Lima, 2012, 978-9972-602-78-8.

[15] Bellido, N. O. Groundwater, knowledge and exploitation. Argentina: University of Buenos Aires, 2012.

[16] Ramírez, M. Improvement and expansion of drinking water, sewerage and wastewater treatment plant services in the urban area of the districts of Acraquia, Ahuaycha, Daniel Hernández and Pampas, province of Tayacaja, department of Huancavelica, Peru: Regional Government of Huancavelica, 2020.

[17] Landeo, P.J., Limaco, B. T. Design proposal for a tubular well applying the geophysical test technique, carrying out an electrical survey to increase water availability in the Otopongo - Barranca - Lima - Peru sector, Lima: San Martin de Porres University, 2019.

[18] Orellana, E. Geoelectric prospecting in direct current, Madrid: Auditorium, 1972. 84-283-1153-620.

[19] Telford, W.M., Geldart, L.P., Keys, D.A. Applied geophysics. England: Cambridge University, 1976.

[20] Ministerio de Construcción de Vivienda y Saneamiento (MVCS), Territorial conditioning plan of the province of Tayacaja, Perú: District Municipality of Tayacaja, 2012.

[21] Apparao, A., Roy, A. Depth of research in direct current methods. Spain: Geophysical Exploration Society, 1971

[22] Kearey, P., Brooks, M., Hill, I. An introduction to geophysical exploration. Australia: Blackwell Science, 2002.

[23] Marchán, I. J. M. Improvement of the water supply system through a replacement well - irhs-5- Illescas 07 in the Illesca sector, district and province of Sechura, Piura - 2019. Piura : National University of Piura, 2020.

[24] Aguilar, G. Well Design, Online available from https://es.slideshare.net/DavidGarcia143/diseo-de-pozos.

[25] Reckman, A.O. Digital Library National Institute of Agrarian Innovation, Online available from https://hdl.handle.net/20.500.14001/29162,(Quoted on: October 16, 2022).

[26] Dirección General de Salud Ambiental e Inocuidad Alimentaria (DIGESA), Regulation of water quality for human consumption, 2022.

[27] Jiménez, R. R., Rodriguez, C. E. Geophysics applied to the search for groundwater in alluvial deposits, Cuba: Cuban Congress of Geophysics, 2013. 2307499X

[28] Mojica, A. A., Bolivar, D. F., Harris, J. Detection of groundwater in sedimentary soils of the Tocumen Research Extension of the Technological University of Panama through two-dimensional electrical resistivity and seismic refraction imaging during the dry season, Panama: RIDTEC, 2012.

[29] University Institute of Pesticides and Water (IUPA). Transitions and limits of semi-confined aquifers, Spain: Jaume I University of Castellón, 2017.

[30] Instituto Nacional de Estadística e Informática (INEI).Statistical Synthesis 2015,Online available from https://www.inei.gob.pe/media/MenuRecursivo/publicaciones_digitales/Est/Lib1292/libro.pdf