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Article

Isophreatic curves of groundwater wells in the upper zone of Cerro de Hula, Santa Ana, Francisco Morazán

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ABSTRACT

The research is part of a master's research thesis, the aim of which is the generation of groundwater well curves in Cerro de Hula, located south of the capital of Honduras, which serves as a baseline to understand the movement of groundwater flow in the area preliminarily. To achieve this, groundwater level surveys were carried out in the field in April 2022 (dry season), which were analyzed, processed, and interpolated using the Kriging method in ArcGis software. The main findings show the survey of 21 groundwater extraction points, belonging to shallow and deep wells that supply around 2900 people in the area, and that the preliminary water movement according to the isophreatic curves corresponds to a radial flow, with curves ranging from 5 m deep of the water table remaining in the western part of the area (highest part), and moving downwards to the 100 m deep curves (eastern region). It is conclusive to mention that this is a preliminary tool for managing the area's underground water resources.

Keywords: groundwater, water table, isophreatic curves, radial flow.

INTRODUCTION

The study area is located south of the capital of Honduras, the city of Tegucigalpa, specifically in Cerro de Hula, between the municipalities of Santa Ana, San Buenaventura, and Ojojona, belonging to the department of Francisco Morazán, with an area of 18.7 km2.

Within the study area are two of the main villages of the municipality of Santa Ana, El Limón and La Bodega (see Figure 1), identifying around 11 communities (between villages and hamlets) with an approximate population of 3,287 people, living in 727 homes[1].

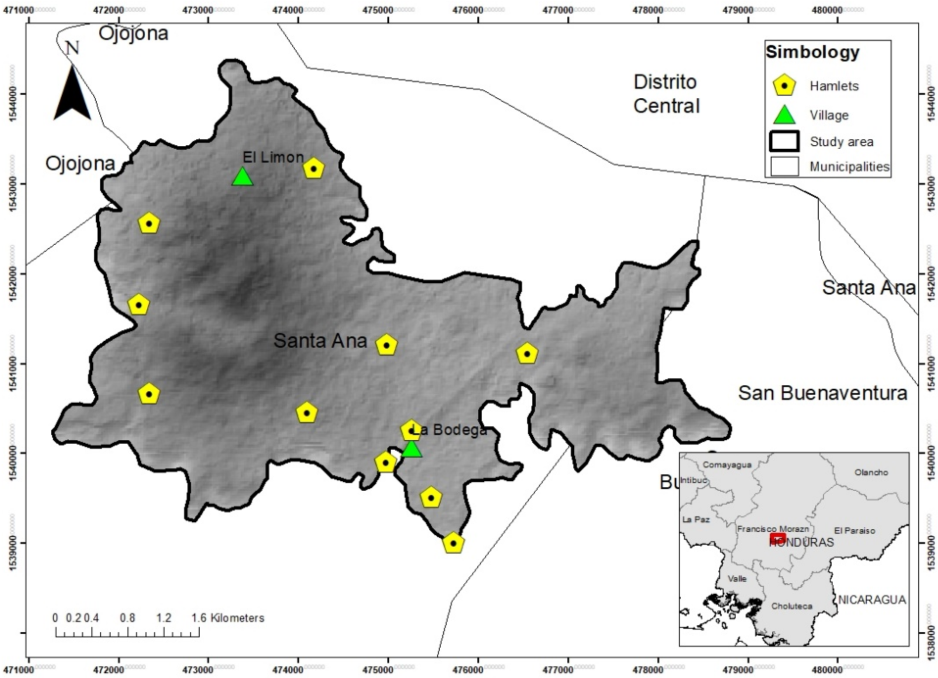

Figure 1: Location map of the study area and main villages and hamlets.

Land use in the study area is dominated by pastures and crops, broadleaf forest and deciduous secondary vegetation, with 35.4%, 35.3%, and 23%, respectively (see Figure 2 and Table 1). It is essential to highlight that the abundance of pastures and crops is consistent with the area's predominant economic activities (agriculture and livestock) and that, between the urban area and bare land, they add up to 1.2%[2].

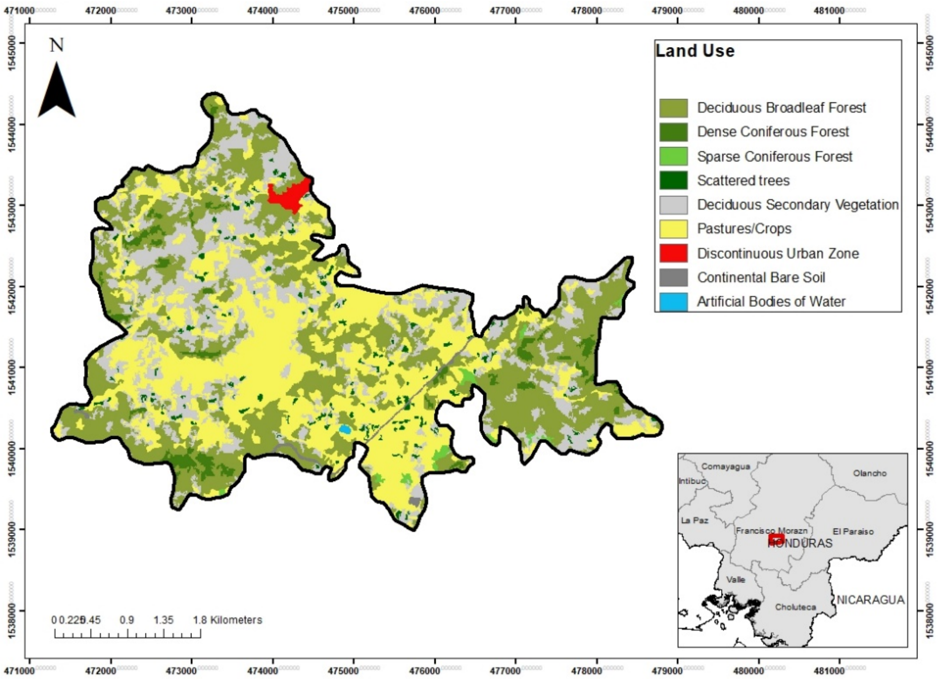

Figure 2: Land use map in the study area.

The distribution of land use by percentage is shown in the following table:

Land Use	Area (Ha)	%
Scattered trees	33.8	1.8%
Dense Coniferous Forest	47.2	2.5%
Sparse Coniferous Forest	12.6	0.7%
Deciduous Broadleaf Forest	658.5	35.3%
Artificial Bodies of Water	1.2	0.1%
Pastures/Crops	661.6	35.4%
Continental Bare Soil	11.5	0.6%
Deciduous Secondary Vegetation	429.3	23.0%
Discontinuous Urban Zone	11.7	0.6%

Table 1: Land uses study area.

The climate is characterized by relatively high rainfall, with average annual precipitation between 1197 mm and minimum values of 1126 mm, and average annual temperatures between 22.6°C, the maximum value, and 21.5°C, the lowest value[3].

Morphologically, this study area has elevations exceeding 1460 meters above sea level (masl), reaching its highest part in Cerro de Hula with approximately 1700 masl (see Figure 3), considered one of the central hills in the area's municipalities. This hill has been considered in geological studies as a water shield volcano, where the activity has now ceased, and according to the presence of rocks, it is regarded as a fractured basaltic dome located in the western part of the work area, where the basaltic lava flows that have given it this table-like morphology[4] originated. Therefore, it has a rugged relief due to fractures, faults, and other geological structures. Moreover, as Ruiz (2015) indicates, prior to the volcanic event, rocks' high erosion and sedimentation rates led to numerous fluvial terraces, which is evident today[4].

Among the geological formations present in the study area are the Quaternary basalts, a series of lava flows of basalt-to-basalt andesite type; the Padre Miguel basalts are dark gray to black basalts[5], and in some areas of red color, this is a product of iron alteration. These basalts present a porphyritic to aphanitic texture, with some plagioclase minerals and a little augite and olivine visible, and Quaternary alluvium (see Table 2), which presents unconsolidated materials of gravels, coarse to fine sands and clays, a product of the alteration of the pyroclastic rocks and basalts.[4, 5, 6, 7].

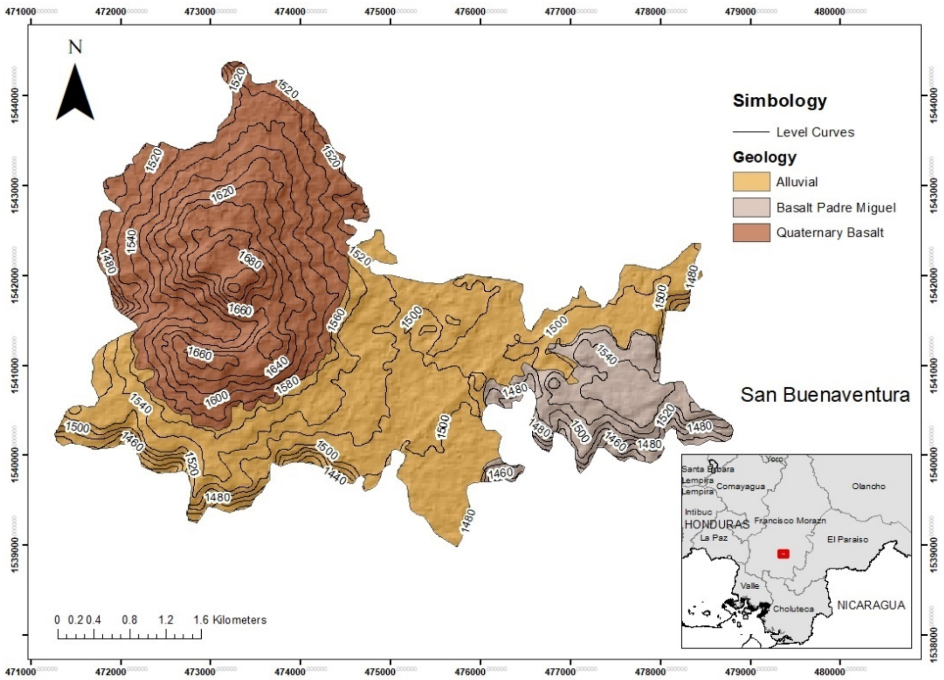

Figure 3: Geological map of the study area.

The proposed lithological column is as follows:

Period		Unit	Litology
Quaternary		Qal	Unconsolidated alluvial sediments: sandy, clayey and sandy clayey, with an approximate thickness of 20 m.
		Qvc	Quaternary basalts: lava flows of the basalt to andesitic basalt type, approximately 100 m thick.
Terciario		Tpb	Basalt Padre Miguel: black to dark gray basalt, approximately 120 m thick.

Table 2: Lithological column of the area.

Therefore, the hydrogeology of the place is primarily conditioned by the area's geology, with two types of aquifers: fractured and porous (see Figure 7). The fractured aquifer is dominated by the geological structures present, the basalts found as a product of lava flows, generating outcrops of igneous rocks in some places, and this set of structures is called a fractured aquifer. Due to its high degree of fracturing, this type of aquifer suggests high permeabilities, which could indicate that it is a potential groundwater recharge zone conditioned by other elements such as land use, slope, and soil type[4].

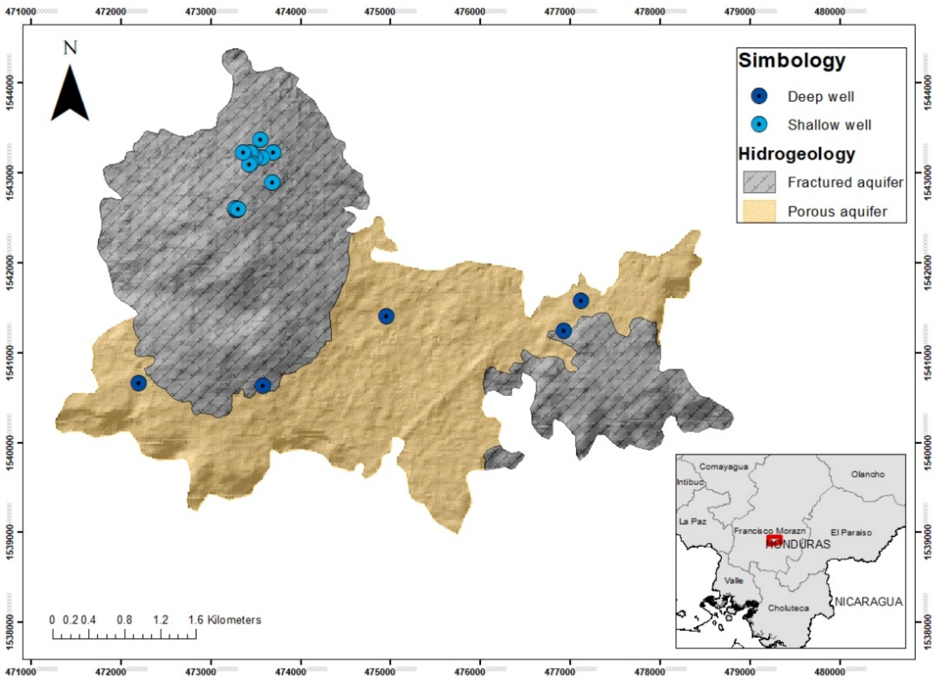

Figure 4: Hydrogeological map of the area under study and distribution of water sources identified and analyzed.

According to Simmons (1969)[8], the study area features valley soils, characterized as alluvial soils that cover much of the country's surface and are suitable for intensive cultivation. These are mainly found in valley and terrace elements.

In line with the morphological and geological description, the study area is suggested to be a basaltic dome structure that has undergone erosion processes to form the terraces. Therefore, the present hydrography is of ephemeral drains that feed water bodies around the lower parts, mainly Qda. El Trapiche, Río Ojojona, Qda. El Sauce, Qda. Agua Fría, and Qda. Sicacatare, part of the surface water sub-basins Verdugo, Grande, and Texiguat, belong to the Choluteca River Basin.[9].

Due to its great height, Cerro de Hula's primary water supply source is groundwater. This area has recently become an area of importance for the capital of Honduras since a large percentage of its population commutes to the city of Tegucigalpa for work[10]. Approximately 90% of the population of the municipality of Santa Ana is employed by companies that engage in different economic activities in Tegucigalpa[11]. Moreover, there are opportunities to obtain housing in new developments at a lower cost [12], supplied mainly by groundwater sources. Therefore, it becomes essential to conduct studies of the area's underground water resources, which can serve as management tools for underground water resources to stop or reverse these processes of groundwater depletion.

Among the main findings is identifying 21 groundwater supply sources in the area, of which 8 were surveyed in a study of the Adaptation Fund Project in 2014, and the remaining 13 points have been analyzed during this research. Out of the total wells, 5 are deep wells exceeding 150 m in depth, and 16 are shallow wells whose depths do not exceed 15 m. From these points, it was possible to measure the water table levels in April 2022, from which the isophreatic curves of the water in the study area have been constructed.

MATERIALS AND METHODS

The methodology used has been, first, data collection in the field. For this, field trips were carried out in April 2022 to update the healthy inventory in the area, where data collection forms were created and completed together with the local population and representatives of the entities managing the registered water source. This form collects the following aspects: general data, georeferencing of the source, data from the underground source, and physical data of the well. The physical information of the well includes depth, diameter, extraction pump, extraction flow rate (when it could be measured), and groundwater level, the data of which was the main one used to achieve the study's objective. All this information was recorded and adjusted in Excel for subsequent analysis.

For the construction of the isophreatic curves, the measured values for all the obtained points, whether from shallow or deep wells, were taken, understanding from its geology that there is a layer of fractured basalt with a depth exceeding 100m. This information created a grid of points with the spatial location and one of its properties, the measured water table level. With this information, the interpolation was carried out using the Kriging method, defined as a method for geostatistical analysis of data variation. This means that it analyzes the behavior of data in space by studying variograms[13, 14].

This method has been applied in mining, geology, and hydrology, as it is a flexible spatial interpolation method. For example, one practical application is for the design of sampling networks, as Kriging is a method that can be used for data analysis in geohydrology[15, 16, 17, 18].

During the geostatistical analysis, the geostatistical analyst tool available in the ArcGIS software was used[19, 20]. With this tool, an initial exploratory analysis was first performed, in which it was possible to visualize how the data are distributed, spatial trends, and outlier values. Subsequently, a random sample of the data was taken to generate the interpolation model, and another sample was used to validate this model. Next, the interpolation model was made using the Kriging method with the generated random sample. Finally, this generated model was validated with the data that were not included in the previously mentioned random sample, meeting the statistical quality standards and which best fit the behavior of the data. Once the interpolation model was created, the isophreatic curves were generated every 5 meters.

The materials and equipment used for this update, verification, and well census were GPS and Solinst 101 metric probes.[21], plastic bucket, tape measure, stopwatch, camera, clipboard, field forms, and pencils. Excel and ArcGIS software were used for the analysis.

RESULTS

Among the main results is the census of new groundwater sources in the study area, of which 13 of 21 were analyzed for constructing the isophreatic curves. Of the total number of water wells used for the analysis, 5 belong to deep wells, and the rest belong to shallow wells (see Table 3).

Code	Registration Status	Community	X	Y	Z	Type of water source	Population supplied
CEA-01	New	Cerrito de Ayastas	476937	1541249	1523	Deep well	325
LB-01	Registered	La Bodega	474958	1541413	1511	Deep well	1440
LE-01	New	Los Encinos	473298	1542594	1657	Shallow well	5
LE-02	New	Los Encinos	473555	1543371	1580	Shallow well	5
LE-03	New	Los Encinos	473690	1542897	1612	Shallow well	4
LE-04	Registered	Los Encinos	473704	1543229	1595	Shallow well	5
LE-05	New	Los Encinos	473580	1543178	1605	Shallow well	8
LE-06	Registered	Los Encinos	473503	1543178	1619	Shallow well	10
LE-07	Registered	Los Encinos	473462	1543223	1608	Shallow well	6
LE-08	Registered	Los Encinos	473448	1543231	1606	Shallow well	2
LE-09	New	Los Encinos	473453	1543120	1610	Shallow well	15
LE-10	New	Los Encinos	473433	1543100	1605	Shallow well	15

LE-11	New	Los Encinos	473372	1543237	1597	Shallow well	5
LE-12	New	Los Encinos	473456	1543226	1600	Shallow well	6
LE-13	New	Los Encinos	473280	1542597	1649	Shallow well	520
LE-14	New	Los Encinos	473292	1542590	1661	Shallow well	
LE-15	New	Los Encinos	473282	1542609	1649	Shallow well	
LE-16	New	Los Encinos	473312	1542599	1652	Shallow well	
LP-01	Registered	Los Patios	472203	1540666	1551	Deep well	80
LQB-01	Registered	Las Quebra-ditas	473588	1540641	1583	Deep well	325
YPC-01	Registered	Yastepec	477125	1541584	1510	Deep well	150

Table 3: Data from groundwater wells analyzed.

The depths of the wells under study, for the case of shallow wells, do not exceed 15 m, while deep wells range from 70 m to 153 m (see Figure 5).

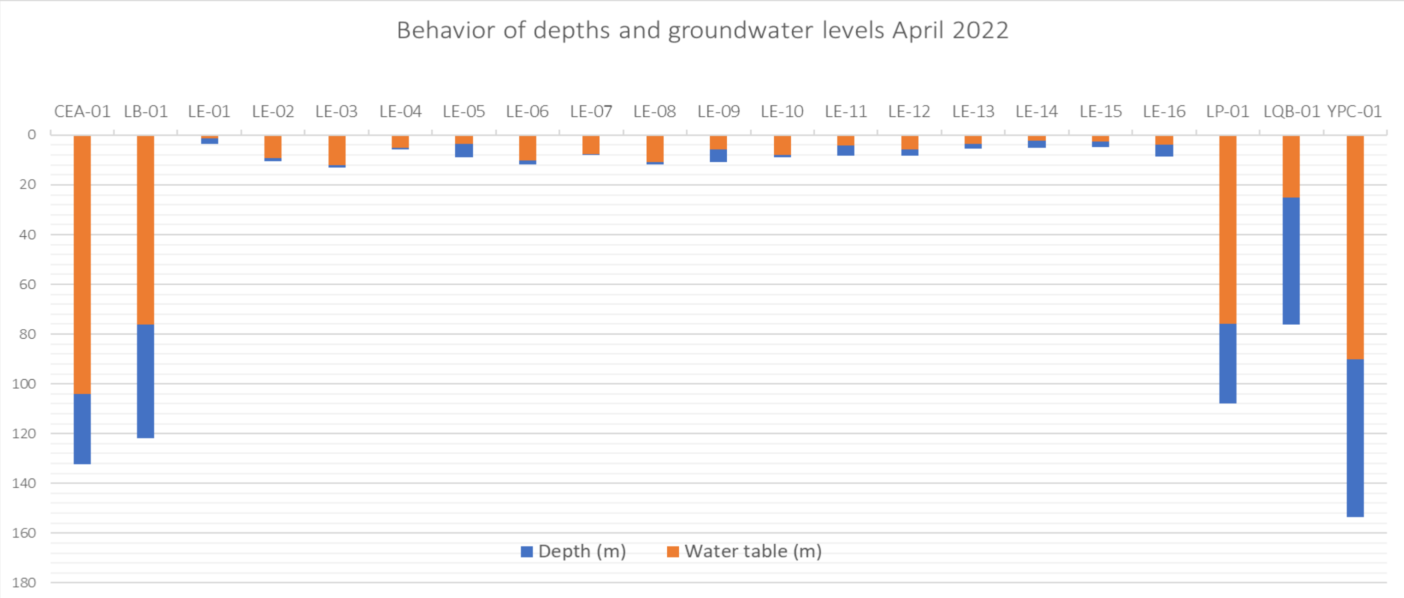

Figure 5: Graph of the behavior of the depths and groundwater levels of the wells under study.

It is essential to highlight that the population supplied by these wells is around 2900 people, which are distributed, as can be seen in Figure 6 and Table 3.

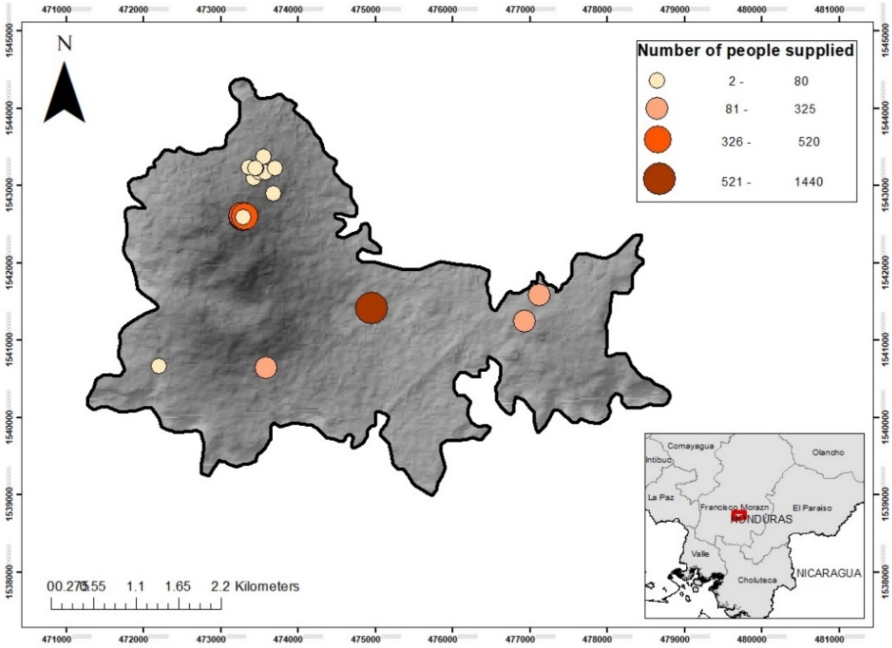

Figure 6: Population-supplied map.

Upon analyzing groundwater wells, the isophreatic curves were constructed. These curves range from the 5m contour located at the highest point of Cerro de Hula, situated to the west of the study area, and the lowest curve presents at over 100m, found in the deepest part of the well belonging to the community of Cerrito de Ayasta on the eastern side of the study area. (see Figure 7).

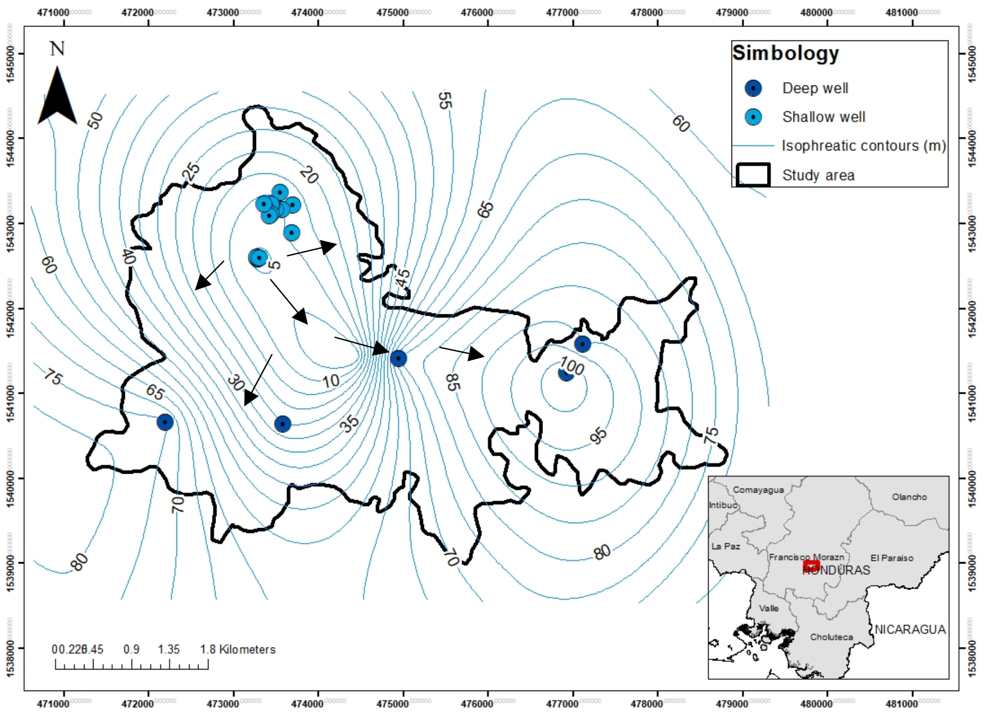

Figure 7: Isophreatic curves map of the study area.

DISCUSSION

The analysis of the isophreatic curves provides a preliminary view of the behavior of the underground flow[22] in the area, which is dominated by its topography, as it is an area with a basalt dome structure at the highest part of Cerro de Hula [23], that over time has undergone erosion, which is why a shallow porous hydrogeological medium is located in the center of the area (see Figures 4 and 7)

This isophreatic behavior observed in the curves of Figure 7 shows that they have a radial flow[24, 25] from the highest point of Cerro de Hula with curves ranging from 5 m deep at the water table level in the western part of the area and moving downwards to the 100 m curves in the eastern region, corresponding to the well of the communities of Cerrito de Ayasta.

This radial behavior converges in the central part of the study area, from the 10 m contour to the 100 m water depth contour, potentially representing a groundwater discharge behavior. In contrast, from the highest part, the 5 m contour to the south shows a potential recharge zone[26].

Analyzing the isophreatic curves is a management tool for underground water resources in the study area, as it preliminarily shows us how the water moves there. This sets a baseline for future initiatives around groundwater study in the region and the country.

This study is just the beginning, mainly in building conceptual and numerical models whose elements aim to describe groundwater[27]. Understanding that a groundwater flow model becomes a fundamental tool to help understand how the system works and what volumes of the mass balance components are available to manage the underground water resource[28] properly.

CONCLUSIONS

Within the study area, 21 underground sources were identified, of which 13 were surveyed during the research, and 8 sources had their information updated but had already been identified in previous studies. Of the total water wells used for this study, 5 are deep wells, and 16 are shallow wells, with depths ranging between 70 m to 153 m and 15 m, respectively.

The obtained isophreatic behavior shows a divergent radial flow from the highest part to the 10 m curve, representing a recharge zone in the study area. Also, a divergent flow is shown between the 15 m and 85 m curves, thus being a potential discharge area for groundwater.

The obtained isophreatic curves are a preliminary water management tool to understand the behavior of the underground flow in the study area, as it is essential for supplying approximately 2900 people.

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Conflicts of Interest: The authors declare no conflict of interest.

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