HYDROGEOLOGY AND NATURAL PROCESSES OF PRECIPITATION AND SURFACE WATER: A STUDY ON AGGREGATES FROM A LIMESTONE-CLAY QUARRY

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ABSTRACT

The hydrological and hydraulic models allowed a great advance in the study of the hydrographic basins, for which different models were used, which have been accepted worldwide in engineering focused on meteorology, hydrology, hydraulics and other areas related to the management of water resources. The groundwater quality was generally good and is associated with the type of rocks and geology of the basin. This article uses different approaches to determine the behavior of the basins present in the area of a limestone-clay quarry, based on the need to demonstrate the non-existence of large watercourses in the area that demand the use of a drainage system, considering that the exploitation of the quarry is done intermittently, depending on the demand.

Keywords: soil behavior, hydrographic, precipitation, drilling equipment, physical and chemical analysis.
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RESUMEN
Los modelos hidrológicos e hidráulicos permitieron un gran avance sobre el estudio de las cuencas hidrográficas para ello se utilizaron diferentes modelos, los cuales han sido acogidos a nivel mundial en la ingeniería enfocada en meteorología, hidrología, hidráulica y otras áreas relacionadas con el manejo del recurso hídrico. La calidad del agua subterránea en términos generales resultó buena y está asociada con el tipo de rocas y geología de la cuenca. Este artículo emplea diferentes enfoques para poder determinar el comportamiento de las cuencas presentes en la zona de una cantera de caliza-arcilla, ello en función a la necesidad de demostrar inexistencia de grandes cauces de agua en la zona que demanden el uso de un sistema de drenaje, considerando que la explotación de la cantera se realiza de manera intermitente, dependiendo de la demanda.
Palabras clave: comportamiento del suelo,hidrográficas, precipitación,equipos de perforaciones, análisisfísicos y químicos.

INTRODUCTION

Mining, an activity linked to the exploitation of natural resources, is responsible for major negative environmental alterations, particularly soil degradation. But it is also through mining that all the resources necessary for the development of humanity and the social well-being of mankind are obtained (ALEXIS MONTES DE OCA-RISCO & MAYDA ULLOA-CARCASSÉS, 2013).

Surface waters are regulated by the presence of reservoirs located in the upper part of the basin. Hydrogeochemistry studies the chemical composition of water, mainly of ions and dissolved majority and minority compounds (ALEXIS MONTES DE OCA RISCO ET AL., 2018).

With the increase in the human capacity to transform the natural environment, an imbalance has arisen between the damage caused and the capacity of the environment to recover from it. But, at the same time, we cannot do without mining because it is the basic activity dedicated to obtaining geo-resources to supply society with the raw materials necessary to improve its quality of life, progress, and destiny (CARBONELL, 2003).

When the extraction of materials is carried out without planning the exploitation, it causes problems that continue until after the activity is abandoned. In addition, unplanned mining can also cause other problems such as loss of topsoil, surface water contamination, dust emissions and noise emissions (BRADSHAW, 1993).

The limestone and clay quarry is exploited on an occasional basis depending on market needs, which is why the quarry does not have drainage systems with the riverbeds present in the area. Still, since it is exploited on an occasional basis, this presents a situation of stability, but this is counteracted by the foresight of the personnel who are focused on maintaining stability in the quarry to avoid unnecessary movement of material.

METHODOLOGY

Climatological characteristics

For the characterization of the climate of the quarry site, data from the nearest meteorological station with high numbers of data have been used as shown in TABLE 1:

- Average annual temperature 14°C
- Monthly average of the maximum daily temperatures (June, August): 38°C
- Monthly average of minimum daily temperatures (December, January): 5.45°C (5.45°F)
- Average annual rainfall: 469.7 mm.

TABLE 1. Average monthly precipitation (mm)

MES	AVERAGE MONTHLY PRECIPITATION

JANUARY	42.80 mm
FEBRUARY	43.00 mm
MARCH	32.20 mm
APRIL	53.00 mm
MAY	47.30 mm
JUNE	26.10 mm
JULY	9.80 mm
AUGUST	20.40 mm
SEPTEMBER	30.90 mm
OCTOBER	48.90 mm
NOVEMBER	58.70 mm
DECEMBER	56.60 mm

Source: Meteorological Station of arganda del rey 3182 (2015).

Geological and geomorphological characteristics

Geology of the study area

The study identified rock masses of different types whose structural characteristics (fractures, diaclases, faults, folding) would condition the aquifer. In addition, the geological survey will allow determining the geological characteristics and conditions oriented to the hydrogeological interpretation of the Chilca Creek, for which studies related to its lithology and stratigraphy have been developed. The geological formations or groups, igneous masses and unconsolidated deposits, in order from oldest to youngest, are described below:

Stratigraphy

These outcrops in the upper part are located on both margins surrounding the two flanks of the creek. The rocky structure comprises intrusive igneous rocks of the coastal batholith and volcanic and sedimentary rocks of the Casma Group.

The study is developed based on the information published by the Instituto GeológicoMinero y Metalúrgico (INGEMMET, 2020) in their geological quadrangles at scale 1:75 000 m. that comprise the study area, describing the most important aspects for the project that can be observed in TABLE 2 as it is that the chronostratigraphy of the study area is observed that is developed through their formations and their lithostratigraphy as well as the area that they have in the concession.

TABLE 2: Stratigraphy.

CHRONOSTRATIGRAPHY		LITHOSTRATIGRAPHY	
ERA	SYSTEM	GEOLOGICAL UNIT	SYMBOL
CENOZOIC	QUATERNARY	ALLUVIAL DEPOSITS	Qh-al
	PALEOGEN	MIRACLE TRAINING	PN.m
		CASHEW TRAINING	P-c
		CHOTA FORMATION	KsP-ch

Source: Instituto Geológico Minero y Metalúrgico (INGEMMET, 2020).

- **Chota Formation (KSP-CH)**

Its lithology is transitional and is represented by 3 to 4 m of red sandy and somewhat calcareous layers, with intercalations of calcareous silt-clay levels of marine origin. It consists of silty claystone, mudstone, and red sandstone. This group occupies an area of 56.30 ha, which represents 4.02% of the study area, and its thickness reaches a maximum of 200 m. These formations were recognized by Wilson and Reyes (1964). Lithologically, it is composed of a mixture of sandstones, siltstones, and fine conglomerates of medium to a thick layer of a reddish color. Instituto GeológicoMinero y Metalúrgico (INGEMMET, 2020).

- **Cajaruro Formation (P-C)**

Its light coloration and whitish tones distinguish it. The Cajaruro formation is approximately 180 m thick, made up of light gray silty claystone, somewhat yellowish at the base, with gray-white calcareous levels and some light sandstones. The stratification is thin, and some strata contain charophytes and tuffaceous levels; it covers an area of 398.46 ha representing 28.46% of the study area (Instituto GeológicoMinero y Metalúrgico-INGEMMET, 2020).

- **El Milagro Formation (PN-M)**

It consists of a crescent-grain sequence of lacustrine to fluvial origin. It is distinguished by its reddish to variegated coloration; it is characterized by reddish to reddish-brown and dark gray. Lithologically it consists of conglomerates, sandstone and clays; it reaches an average thickness of approximately 100 meters. Due to their coherence, the conglomerates form vertical escarpments, and external geodynamic effects can excavate or disintegrate them if the slope is relatively steep. The sandstones are quartzaceous and feldspathic, fine to medium-grained and of varied colors, mostly intercalated with shales of different colors. The sandstones and clays have different porosity and permeability, which, added to other factors, make their behavior different from erosive processes. This unit is the most widely distributed in the study area, occupying an area of 581.52 ha, representing 41.53% of the study area (Instituto GeológicoMinero y Metalúrgico-INGEMMET, 2020).

The study was carried out in the mining concession that constitutes the non-metallic substance deposits quarry, which has an extension of 1,400 ha, with an exploitation area of 0.43 ha.

GEOLOGICAL, HYDROGEOLOGICAL AND GEOTECHNICAL CHARACTERISTICS OF THE LIMESTONE AND CLAY QUARRY

Geological Characteristics: The continental sedimentation of the endorheic character of the Tagus Basin corresponds to alluvial deposits coming from the central system that passes through intermediate sediments to flow into the basin deposit in intermediate sediments. According to their depositional and lithological environment, these materials are divided into three lithostratigraphic units.

Lower Unit: Three lithofacies can be distinguished, a terrigenous facies made up of alluvial fan deposits, landslide flows, flood plains and distributary channels, an intermediate facies that relates terrigenous materials with gypsum and anhydrite evaporites with clays deposited in saline lake environments.

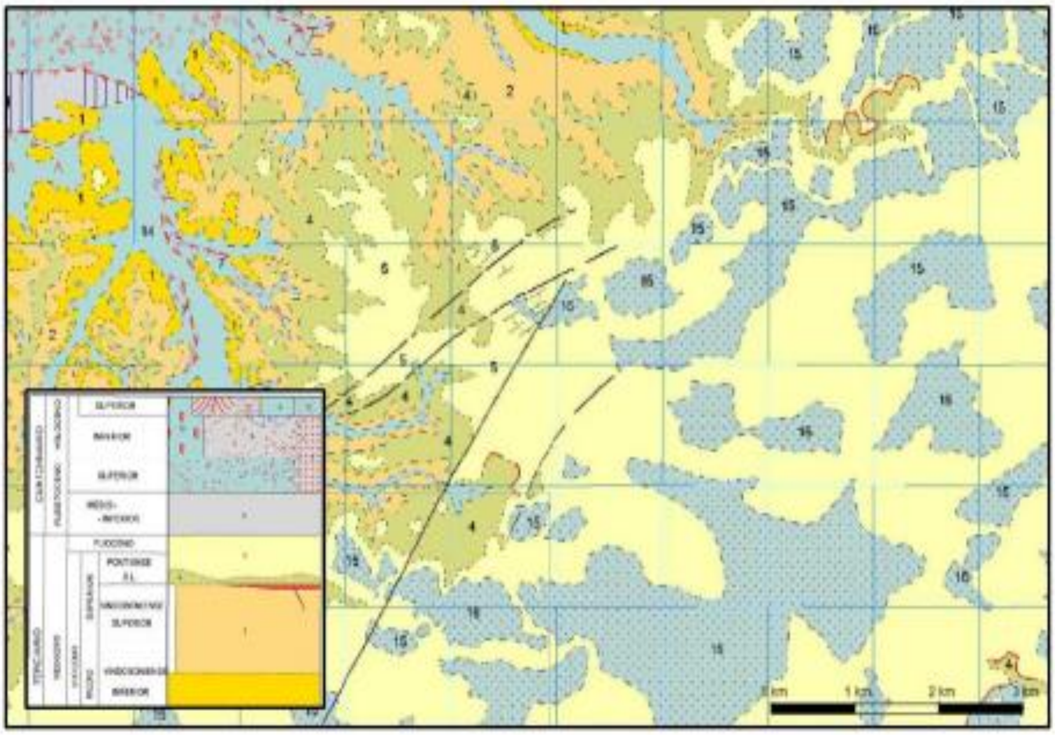
Intermediate Unit: Terrigenous sediments fundamentally carbonate with presence of gypsum towards the central parts of the basin.

Upper Unit: the materials that compose this unit at its base are very erosive channeled facies formed by materials of diverse nature: conglomerates in the massive banks of metric power, horizontal structure and creamy white, grayish color.

The underlying materials correspond to a fluvial detrital unit with significant facies variations and strengths; gravels and conglomerates from limestone and clay quarries.

The lithological units outcropping in the study area belong to the paramo series (MIOCENE, PILOCENE AGE). With Quaternary materials deposited discordantly at the top (Figure 1).

Figure 1: Detail of the area on a geological map.



ource: Geologic Map 1:50000 IGM Sheet

Hydrogeological characteristics

The study area belongs to the Tagus hydrographic basin, specifically within the basin and is located within the hydrogeological unit. The total surface area of the system is about 2,200 km^2 , that corresponding to the aquifer (outcropping surface) is about 1,800 km^2 .

This is a fundamentally flat area, where there are no river courses. Surface drainage is in a northwest direction towards the edge, located 1km away from the quarry. In general, in the Quaternary basin of the Tagus there is an important deep aquifer that is housed in the extensive and deep mass of Quaternary detrital deposits, which is derived by lateral change of phases towards the center of the basin.

The existing piezometers show an open circulation of water from the central and elevated areas of the moorlands towards the edges, with a generalized northeast-to-southwest gradient that coincides with the slope of these formations towards the center of the basin.

Geotechnical characteristics

The Quaternary fill of the pit is limited by the morphostructural lines mentioned above, delimiting an eastern basin of the pit to the east, between the mountain range and the first foothills of the basin. Consequently, the slopes analyzed in the quarry are made up of limestones and clays.

With the data available in the literature, a corrected RMR value of around 55 has been determined. This value is within class III of the rock mass, medium class, and a simple compressive strength value of the intact rock of around 70 MPa has been considered.

From the data of the intact rock and through the RocLab program, the output parameters for the rock massif shown in TABLE 3 have been obtained.

TABLE 3: Rock mass parameters

R.C. (Mpa)	Hoek-Brown breakage criterion			Mohr-Coulomb Rotation Criterion		Tensile strength rock mass	Overall compressive strength of the rock mass	Modulus of deformation of the rock mass
	mb	s	a	C (Mpa)	Φ(°)	σ (MPa)	σ cm (Mpa)	Em (Mpa)
	0,311	0,004	0,506	0,422	36,86	-0,080	5,124	4,919.47

Source: Own elaboration

DRILLING AND INSTALLATION OF PIEZOMETERS

Drilling for piezometers and observation wells facilitates efficient implementation in agricultural areas, industrial facilities, or any operation with subsurface and aquifer monitoring needs. Such installations include refineries, hydrocarbon storage facilities, mine tailings, stables with industrial volumes, etc.

Drilling for piezometers and observation wells are mainly used for two types of tasks.

A) Monitoring of toxic levels, contamination of aquifers and subsoil.

B) Water table behavior for yield studies.

Piezometer drilling

Two control piezometers were drilled to determine the hydraulic parameters and groundwater quality control in the area of influence of the quarry.

The following figure shows the Ingetrol Explorer Plus WL drilling rig in the middle of drilling Piezometer No 01 (Pz-01) surrounding the quarry. 594

Figure 2. Piezometer Drilling 01 (Pz-01)

Source: DMG Drilling Peru observation wells.

Installation of piezometers

Once the drilling was completed, the piezometers were cased with blind and slotted

PVC pipes according to their technical design, which will be used for the purposes mentioned in this study. The installation of the piezometers (Pz-01 and Pz-02) complied with the Standard Operating Procedures (SOP) necessary to guarantee the quality and safety of the installation of control piezometers.

This stage includes the part of the piping installed in the piezometers; in Pz-01, there is a drilling of 26.90 m and 19.68 m of piping, in Pz-02 25.40 m was drilled and 19.61 m of piping was installed.

Figure 3. Installation of 2 Blind Pipe in Pz-01.

Source: DMG Drilling Peru observation wells.

Geomorphologic parameters of the micro-basins

The hydrological cycle, in which a watershed is a fundamental part of the study of the response to incoming precipitation, involves various processes that alter the runoff at its outlet. These processes involve the geomorphology of the watershed in which climatology is the most important factor, the type and use of the soil, the vegetation cover or the level of urbanization.

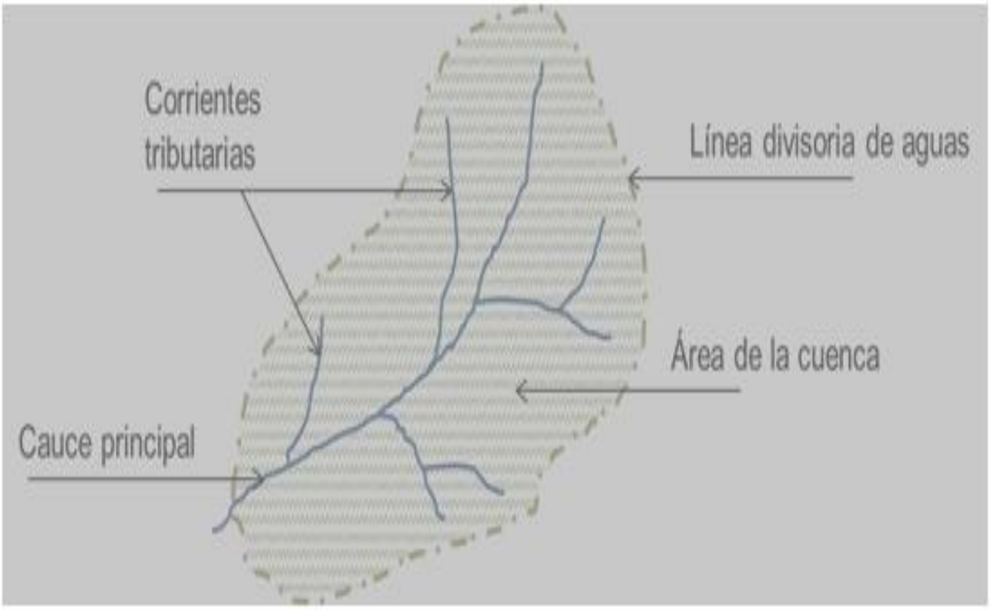
There are calculable parameters that consider the importance of these processes for comparisons and to establish related basins preliminarily. The most studied geomorphological properties of a basin are presented below: The calculation of the parameters of the basins under study has been performed automatically by the WMS (Watershed Modelling System) software, through its various modules such as TR-55, TOPAZ, etc. and are as follows:

- A = Area of the basin.
- BS = Average slope of the basin.
- AOFD = Average of the flow distance between the watershed and the flooding area.
- L = Length is the basin.
- Shape = Shape factor of the basin
- AVEL = Average elevation of the basin.
- MFDS = average slope of the central part of the basin.
- MSL = Maximum length that the surface water line of the watershed travels.

Basin area

The surface of the land in the waters of precipitation flows to the same evacuation point through secondary channels or streams that join a main channel. Figure 4. Components in a watershed waters from precipitation, ponds or glaciers that the soil has not infiltrated are called surface runoff and move from points of higher elevation to points of lower elevation by the effect of gravity.

Figure 4: Components in a watershed.



Source: Prontubeam, 2015.

Length of the main channel: This parameter usually coincides with the length of the longest channel, and is a very representative criterion of the length of a basin. It can be measured considering the entire sinuosity of the channel or the length of the channel axis.

Basin perimeter: This is the length of the watershed boundary and forms the contour of the basin area. When comparing watersheds of the same area, this parameter is useful to differentiate the shape of the watershed. That is, whether it is elongated or rounded.

Watershed shape: Several parameters associated with the area ratio, perimeter or the length of the longest watercourse, defined as the distance from the point of the watershed outlet to the farthest upstream point, are used to identify the shape characteristics.

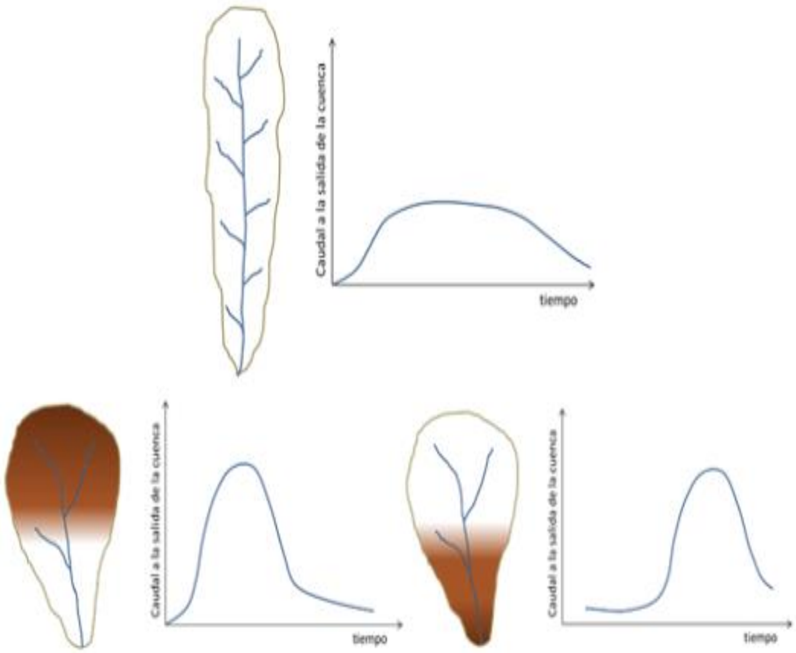
Coefficient of compactness or Gravelius index

It establishes the relationship between the perimeter of the watershed and the perimeter of circumference of an area equivalent to the surface of the corresponding watershed. This index represents the shape of the basin surface, according to its delimitation, its influence on runoff and the hydrograph resulting from precipitation (LÓPEZ CADENAS DE LLANO & MINTEGUI AGUIRRE, 1987).

Otherwise, this index is based on a comparison with an ideal circular basin with its channels arranged radially and flowing into the central point (LÓPEZ CADENAS DE LLANO, 1998).

In elongated watersheds, discharges are smaller in volume because the main watercourse is longer than the secondary watercourses and the times of concentration for precipitation events are different, as shown in TABLE 1.

Influence of the hydrological network configuration on discharges Figure 5.



On the other hand, the following table shows the shape that a basin can take according to approximate ranges of the Shape Factor (SEE TABLE 4).

TABLE 4: Approximate Form Factor Ranges

Form factor (approximate values)	Shape of the basin
<0,22	Very elongated
0,22 a 0,30	Elongated
0,30 a 0,37	Slightly elongated
0,37 a 0,45	Neither elongated nor widened
0,45 a 0,60	Slightly widened
0,60 a 0,80	Widened
0,80 a 1,20	Very wide
>1,20	Surrounding the drain

Source: Perez, 1979.

ANALYSIS AND RESULTS

The main objective of this project was to study the economic and technical feasibility of exploitation studies of limestone and clay quarries belonging to the geological formation of the quarries.

Two research piezometers have been drilled and installed, and both are operational for hydrogeological monitoring. Drilling for piezometers and observation wells facilitates an efficient implementation in agricultural areas, industrial facilities or any operation with subsoil and aquifer monitoring needs.

The results obtained in the different sections of the study, observing the stability of slopes, and methods of starting by different drilling, loading and transport to the plant with the means available to the operation, are satisfactory as stated in the report, so it appears that the project is technically feasible. Furthermore, according to the economic study, for a critical rate of return of 10%, a net present value of 10,582,932 EUR and an internal rate of return of 66% is obtained, so it appears that the project is also economically viable.

CONCLUSION

Remote sensors are systems or instruments for capturing information from an object at a distance (remote sensor). Remote sensing refers to acquiring data from the earth's surface with a remote sensor and processing and interpreting that data. More specifically, remote sensing is the capture of the physical characteristics of the earth's surface based on measurements of reflected and emitted radiation from each component of that surface.

The rainfall network used in the study area, specifically in the micro-watershed of the Jahuanga Creek, Cantera, which is a tributary of the Engatadora Creek, which forms one of the effluents of the Utcubamba River, and neighboring micro-watersheds such as; micro-watershed of the El Valor Creek, S/N Creek 04, 05 and 06, are formed by the stations of Chachapoyas, ChiriacoBagua Chica and Naranjillo, controlled by SENAMHI.

Using specific software, SEGEMAR processes satellite data, mainly for geological mapping, identification and characterization of areas with hydrothermal alteration, identification of different types of rocks, determination of morpho-structural features, identification of drainage, infrastructure, topography and slopes, among others.

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