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Determining groundwater quality based on volcanic terrain: A case study from the Island of Tenerife, Spain

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ABSTRACT

This research analyses the water of 258 significant tunnels throughout the Island of Tenerife used to obtain groundwater and establishes a clear relationship between the qualities of the water and the volcanic lithologies of the island of Tenerife.

Each water sample from each tunnel was taken to an approved laboratory for analysis, where the values of Ca^{2+}, Mg^{+}, Na^{2+}, K^{+}, HCO_3^-, CO_3^{2-}, Cl^-, SO_4^{2-}, NO_3^-, $H_2PO_4^-$, SiO_2 and F, as well as water quality parameters, namely electrical conductivity (EC), hardness, residual sodium carbonate (RSC) and adjusted sodium adsorption ratio (SARaj), were determined.

The tunnels have been grouped according to the mineralogy present in the lithologies crossed by the water. The tunnels on the Northeast and the West of the island have the highest percentage of volcanic terrain lithologies, including basaltic lava and pyroclastic flows, where the main minerals are amphibole, olivine, augite, pyroxene plagioclase. However, the tunnels of the West cross lithologies with ignimbrites and epiclastic deposits and intramontane sediments, leading to an improvement in water quality compared to the Northeast cluster.

This work shows that by drilling holes to search for fresh groundwater in volcanic terrain where surface lithologies can be identified, it is possible to estimate the water quality beforehand.

1. Introduction

The importance of water for animal life and ecosystems on the planet is evident, as it constitutes an indispensable factor for the development of biological processes. However, only 2.5% of the planet's water is fresh water, which is distributed in the polar caps and glaciers (68.7%), groundwater (30.1%) and surface water (1.2%) (Shiklomanov, 1993).

The quality of fresh water depends fundamentally on its physical, chemical, biological and radiological characteristics. Water acquires certain chemical characteristics when it is in the atmosphere or when it is present in evapotranspiration processes. These characteristics can be altered when it infiltrates into rock, where it can undergo complex and drastic changes in its physical, chemical and biological composition as a consequence of its interaction with the environment. The modifications in the water's composition will also depend on both the duration and location of the interaction. Table 1 shows the main substances dissolved in natural groundwater (Freeze and Cherry, 1979).

In groundwater, constituents generally appear in ionic forms as almost completely dissociated salts, and in partially dissociated molecular forms.

The limited availability of freshwater, coupled with the increasing pollution of available sources, poses a major challenge in the continuing search for safe and adequate water (Ayers and Westcot, 1985). This is due to many circumstances, ranging from the properties that water acquires as it flows through different areas of the planet to increasing pollution (Malakar et al., 2019).

This study focuses on the island of Tenerife, where groundwater collection is essential. The volcanic environment of the island presents a unique opportunity to study and identify tunnels according to the volcanic terrains they pass through and how the different lithologies impact groundwater composition.

The latest studies carried out in this field of research are more related to assessing the suitability of groundwater for drinking and irrigation, spatial variation of major cations and anions (Groundwater quality assessment using water quality index and GIS technique in Modjo River Basin, central Ethiopia (Kawo and Karuppannan, 2018)). Water qualities are also studied based on specific zoning (Groundwater Quality Assessment in a Volcanic Mountain Range (South of Gran Canaria Island, Spain) (Ruiz-García et al., 2019),). Other studies investigate the

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Table 1
Common substances in groundwater (Freeze and Cherry, 1979).

Constituents		
Majority	Minority	Trace
Anions: ($HCO_3^- + CO_4^{2-}$), Cl^-, SO_4^{2-}, NO_3^- Cations: Ca^{2+}, Mg^{2+}, Na^+, K^+, NH_4^+ Others: CO_2, O_2, SiO_4H_4, SiO_2	Anions: F^-, S^{2-}, SH^-, Br^-, I^-, NO^{-2}, PO_4^{3-}, BO^{3-}Cations: Mn^{2+}, Fe^{2+}, Li^+, Sr^{2+}, Zn^{2+}.	Al^{3+}, Ti^{4+}, Co^{2+}, Cu^{2+}, Pb^{2+}, Ni^{2+}, Cr^{3+}, etc.

influence on the suitability of groundwater quality for irrigation. The evaluation considers factors such as the sodium adsorption ratio, sodium percentage, permeability index, and residual sodium carbonate of the groundwater to determine its suitability for irrigation (Subba, 2018). However, this article is innovative in that it deals with water quality as a function of the terrain crossed.

The island of Tenerife, with an area of 2034.38 km^2, a maximum elevation of 3718 m, a population of 927,993 inhabitants and an average of 490,788 tourists per month (2019 data) (Canarian Institute of Statistics (Instituto Canario de Estadística) 2022) is located in the archipelago of the Canary Islands in Macaronesia, in the North Atlantic Ocean off the coast of Africa. The island of Tenerife is a volcanic island that is mainly supplied by groundwater, both for drinking and irrigation purposes. Most of the groundwater is obtained through 1124 water collection tunnels with a total annual volume of 51.6 hm^3 (Cabildo de Tenerife, 2015).

The need to investigate the impact of geological factors on water quality, which may have significant implications for human consumption and agricultural use, is evident. This research topic is significant as it can help determine water management strategies on volcanic islands, such as identifying suitable areas for groundwater extraction and monitoring the quality of available water sources.

The approach used is a combination of geological and hydrological analysis. The study aimed to determine the qualities of groundwater samples taken in water collection tunnels drilled throughout the island of Tenerife (Spain) from 258 tunnels. The study provides useful information on the areas where the water is suitable for human consumption and irrigation.

The method used in this study consisted of collecting 258 groundwater samples from important water catchment tunnels drilled throughout the island of Tenerife. The samples were then analysed to determine their physical, chemical, biological and radiological characteristics. The lithologies traversed by each tunnel were also identified and the tunnels were classified into five groups based on their location on the island.

2. Methods

2.1. Selection of freshwater collection tunnels on the volcanic Island of Tenerife

Freshwater on the volcanic island of Tenerife is mostly obtained from groundwater aquifers. To collect fresh groundwater, tunnels are drilled throughout the island in a straight line with a single access point (Fig. 1). Once they cross the water aquifer, drilling stops. These tunnels are underground hydraulic works measuring 2 m high and 2 m wide and a depth that in most tunnels exceeds 3 km. The tunnels are built with an upward slope of 2%, so the water inside the tunnel flows from the end of the tunnel to the mouth by gravity. By way of example, Fig. 1 shows some photographs of the entrance to a tunnel with its water collection point and the end of the tunnel, where we can see how the water comes out of the aquifer.

Tenerife is a volcanic island that, due to different volcanic formation processes, exhibits various lithologies across its different regions. To investigate these lithologies, tunnels distributed throughout the island were selected. Each tunnel crosses predominant lithologies in its respective area, such as basaltic pyroclasts, trachybasaltic pyroclasts, phonolite flows, tuffs, ignimbrites, epiclastic deposits, intramontane sediments, and minor volcanic lithologies. Specifically, 7 tunnels were chosen in the Northeast zone, 12 in the West zone, 35 in the South-Southwest zone, 50 in the Central-West zone, and 154 in the Central-East zone.

After selecting the tunnels, a water sample was taken from each one and sent to an approved laboratory for analysis. This study relies on combining a knowledge of the geology crossed by each tunnel with the analytical results of the water samples.

2.2. Water samples

In this study, water samples were taken in 258 tunnels distributed throughout the island (Fig. 2), out of a total of 1124 water supply tunnels. These water samples were taken at the tunnel entrance, whose position was determined using UTM (Universal Transverse Mercator) coordinates.

The samples were collected with water sampling bottles, sterilized as per ISO 5667-3/ISO 19458 standard, to avoid any type of external

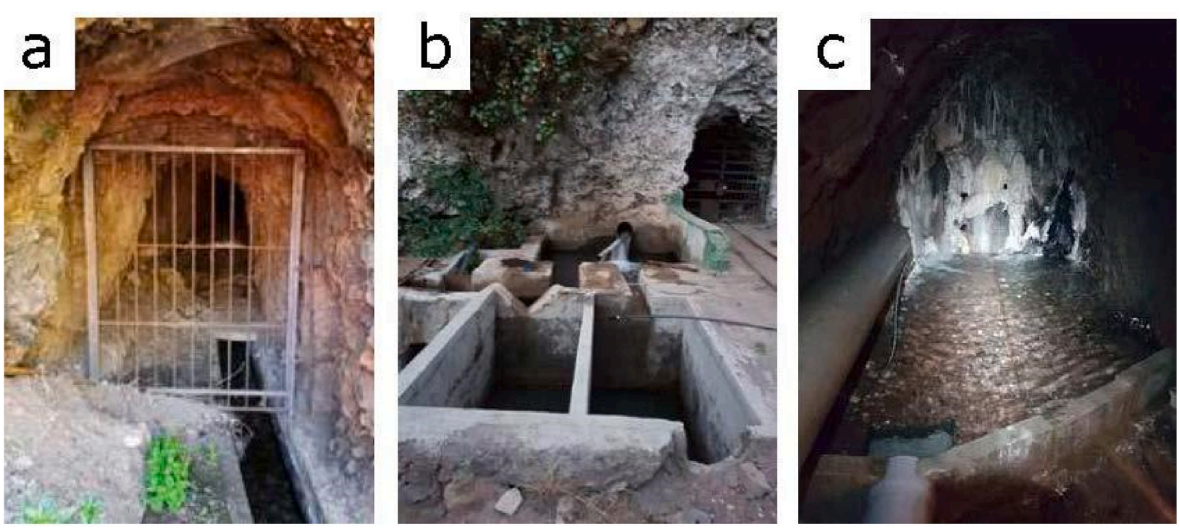

Fig. 1. Groundwater tunnel a) the tunnel mouth, b) water collection c) tunnel end.

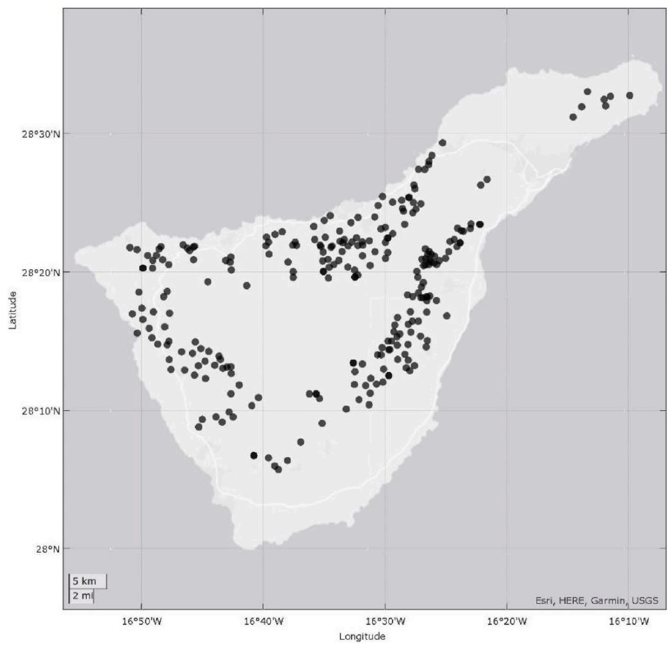

Fig. 2. Distribution of groundwater tunnels studied on the island of Tenerife, Canary Islands, Spain.

contamination. The water sample taken at the exit of each tunnel was then sent to an approved laboratory for analysis, where the values of Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, HCO_3^-, CO_3^{-2}, Cl^-, SO_4^{2-}, NO_3^-, $H_2PO_4^-$, SiO_2 and F, and certain water quality parameters, namely electrical conductivity (EC), hardness, residual sodium carbonate (RSC) and adjusted sodium adsorption ratio (SARaj), were determined. Data obtained from the Island Water Council of Tenerife database, https://www.aguastenerife.org/(CIATF (Island Water Council of Tenerife) 2022).

2.2.1. Electrical conductivity

Each water sample was taken to an approved laboratory to analyse the anions, cations, pH, conductivity, etc. Because of the ionic content of water, it becomes electrically conductive, meaning that as the ionic concentration increases, so does the conductivity.

2.2.2. Residual sodium carbonate

An RSC value of <1.25 is classified as good for agricultural use; values between 1.25 and 2.5 indicate average quality; and values > 2.5 are not recommended for agricultural use. When the difference is negative, the RSC value can be assumed to be zero (Hopkins et al., 2007).

$$RSC\ (meq/L) = (HCO_3^- + CO_3^{2-}) - (Ca^{2+} + Mg^{2+})$$

2.2.3. Water hardness

Water is classified by its hardness. A value of 0–60 mg $CaCO_3$/l indicates soft water; 61–120 mg $CaCO_3$/l is moderately hard water; 121–180 mg $CaCO_3$/l is hard water; and more than 181 mg$CaCO_3$/l is very hard water.

2.2.4. Adjusted sodium adsorption ratio

Calcium and magnesium cations have an antagonistic effect on sodium. The Sodium Adsorption Relationship (SAR) is calculated by the formula below, as determined by the Wilcox (1955) classification of irrigation water (Lesch and Suarez, 2009).

$$SAR = \frac{Na^+}{\sqrt{\frac{Ca^{2+}+Mg^{2+}}{2}}}$$

Where: Na^+ is the concentration of sodium in water, expressed in meq/l. Ca^{2+} is the concentration of calcium in irrigation water, expressed in mel/l. Mg^{2+} is the concentration of magnesium in irrigation water, expressed in mel/l. The SAR values obtained are usually low, so an empirical correction factor has been introduced that takes into account the presence of anions such as CO32- and HCO3- that influence the dissolution or precipitation of alkaline earth salts, depending on the theoretical pH of the irrigation water (pHc) that is in contact with the limestone and in equilibrium with CO 2. This is how the adjusted SAR (SARaj) is obtained:

$$SARaj = \frac{Na^+\ [1 + (8.4 - pHc)]}{\sqrt{\frac{Ca^{2+}+Mg^{2+}}{2}}}$$

2.3. Characterization of geological units

Volcanic islands are created by the gradual accumulation of volcanic materials (lavas, pyroclasts, etc.); however, this activity is not constant or intense over time. This generates the existence of stratigraphic units with different mineralogical compositions, and as a result groundwater flow crosses different hydrogeological units.

According to the Insular Hydrological Plan of Tenerife (Cabildo de Tenerife, 2015), the following simplified hydrogeological units are present on the island (Fig. 3): sedimentary deposits, volcanic formations (Teide-Pico Viejo), predominance of basalts, trachybasalts, lavas and phonolitic pyroclasts, trachytic lava flows and pyroclasts, basaltic lava flows and pyroclasts.

As Fig. 3 shows, the island of Tenerife was formed due to the superposition of stratigraphic units. These stratigraphic units were interrupted by Philonian intrusions and intense secondary fracturing (volcanic dike), which causes the permeability to reach maximum values vertically, but in the transverse direction (summit-sea) it is made very low by the presence of dikes. As a consequence of these dikes, the water table has a staggered profile, increasing the thickness of the saturated zone significantly (Fig. 4a). Therefore, as the tunnels cross the terrain horizontally, they traverse different hydrogeological units (Fig. 4b) until they reach the saturated zone, where they drain the aquifer.

In this research, the UTM coordinates of the end of each tunnel are determined using the official map of the underground water collection works on the "Island Water Council of Tenerife" (https://www.aguastenerife.org/) (Cabildo de Tenerife, 2015). Then, the geological units

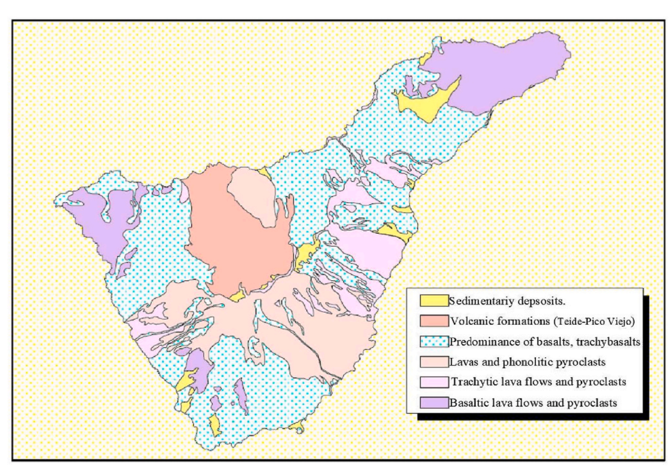

Fig. 3. Hydrogeological units of Tenerife (Cabildo de Tenerife, 2015).

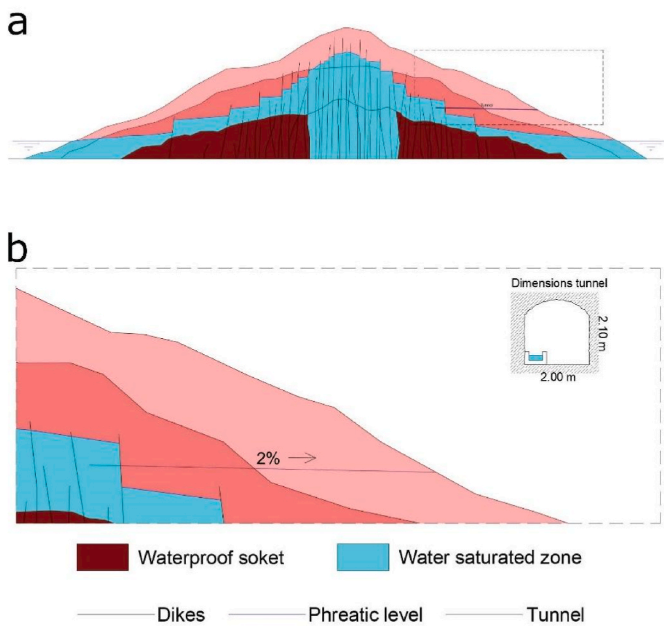

Fig. 4. Cross-section of the island of Tenerife, a) identification of saturated zone in dikes and b) tunnel to the aquifer.

crossed by each tunnel in a 1 km^2 area around the end of the tunnel in question are identified using the "Territorial Information System of Canarias_IDECanarias" (https://visor.grafcan.es/visorweb/), which contains all the geological units of the island (Fig. 5).

Table 2
Lithologies identified in the area where the groundwater tunnels are located on the island of Tenerife.

Code	Lithology
L1	Basaltic lava flow and pyroclastic (main minerals: amphibole, olivine, augite, pyroxene plagioclase)
L2	Trachybasaltic lava flow and pyroclastic (main minerals: augite, plagioclase, amphibole, olivine)
L3	Trachytic lava flow and pyroclastic (main minerals: plagioclase and pyroxene)
L4	Phonolite lava flow (main minerals: amphibole, hauyna, pyroxene, plagioclase, biotite)
L5	Tuffs
L6	Ignimbrite
L7	Epicelastic deposits and intramontane sediments
Other	Minority volcanic lithologies.

3. Results

3.1. Grouping of tunnels by lithology

Groundwater samples were taken in 258 of the most representative tunnels around the entire island, out of a total of 1124 tunnels (Fig. 2).

The tunnels are grouped by the mineralogy present in the lithologies crossed in an area of 1 km^2 around the end of the tunnel. Evidently, there is a natural grouping of tunnels, depending on their location on the island, since when two tunnels are found in the same area, the volcanic terrains they cross are similar. Table 2 shows the lithologies identified.

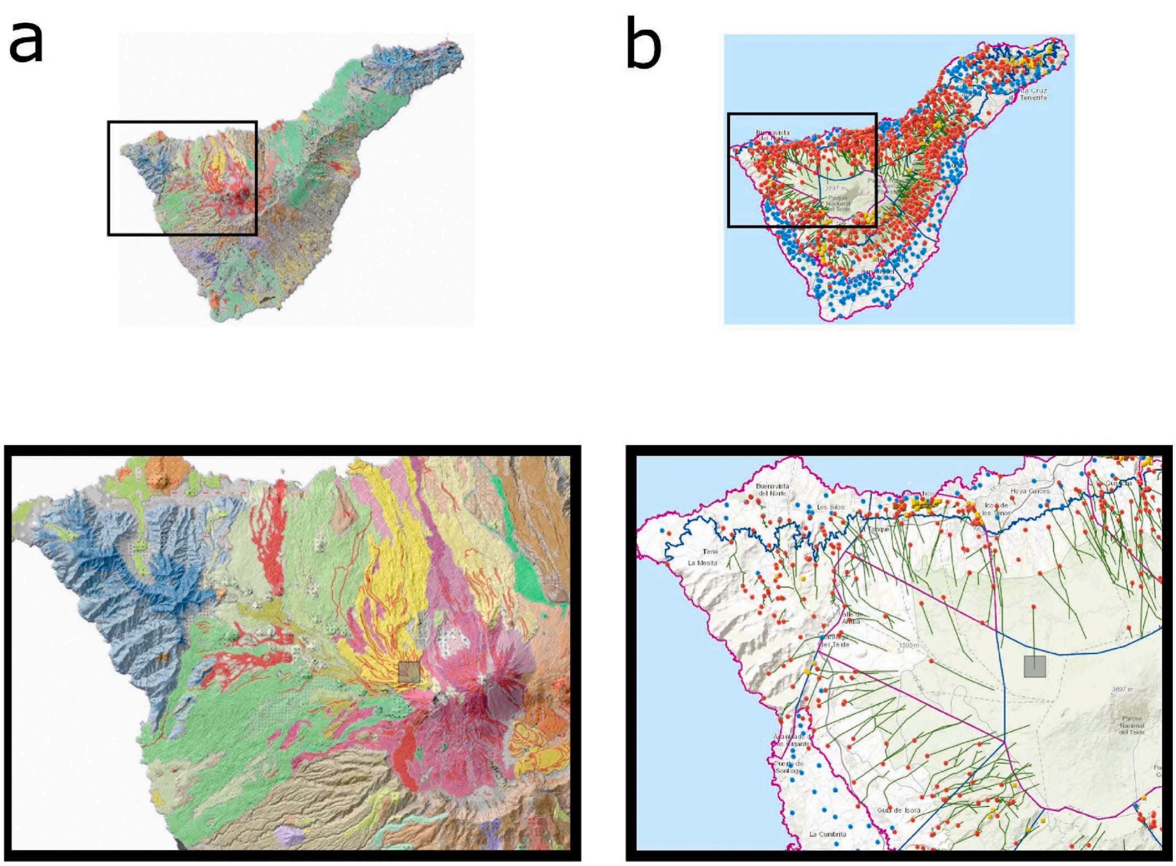

Fig. 5. Geological map and underground water collection works on Tenerife. In a), each colour represents a different lithology. In b), the red dots represent the tunnel entrances and the green lines are the tunnel layouts. The blue dots are water wells. The grey rectangle represents an area of 1 km^2 around the end of the tunnel. (Territorial Information System of Canarias_IDECanarias, https://visor.grafcan.es/visorweb/, Island Water Council of Tenerife, https://www.aguastenerife.org/) (CIATF (Island Water Council of Tenerife) 2022; Grafcan 2022).

The 258 tunnels were clustered based on their minerals using the Euclidean distance. The algorithm used for computing the distance between clusters was the weighted average distance. This clustering was performed using Matlab R2022a (MathWorks, Inc). Table 3 shows the five clusters found, including the number of tunnels and the lithologies present in each cluster, and Fig. 6 illustrates the geographical distribution of the clusters.

3.2. Water analysis by tunnel grouping

From each tunnel studied, a total of 258, two aspects were considered: a) the lithological characteristics through which the tunnel ran and b) the chemical characteristics of the water extracted at the tunnel exit point. As seen in previous sections, the set of sampled tunnels was grouped into five clusters based on the lithologies traversed, coinciding with five different areas of the island of Tenerife (Fig. 6).

For several years, a water sample was collected and analysed annually for each tunnel, yielding the values of Ca^{2+}, Mg^{+}, Na^{2+}, K^{+}, HCO_3^-, CO_3^{2-}, Cl^-, SO_4^{2-}, NO_3^-, $H_2PO_4^-$, SiO_2 and F^- (an average of 8 samples per tunnel). The value given for each parameter in the tunnel was the arithmetic mean.

A total of 7 tunnels were chosen in the Northeast zone, 12 in the West zone, 35 in the South-Southwest zone, 50 in the Central-West zone, and 154 in the Central-East zone. The chemical characteristics of the water for each conglomerate or zone were calculated as the average of the values from all the tunnels previously calculated for each tunnel, belonging to that particular conglomerate. Table 4 shows the average chemical analysis of the water in each lithological zone (Fig. 6).

4. Discussion

Once the tunnels were grouped based on the lithologies crossed, and the water samples taken in each tunnel were analysed, the water quality parameters were computed. The data obtained from the water analysis were used to calculate the mean value for electrical conductivity (EC), the values for water hardness, residual sodium carbonate (RSC), as well as the adjusted sodium adsorption ratio (SARaj) for each cluster of tunnels (Table 5) (see Table 6).

The data in Table 5 show how the Centre-West zone is characterized by having higher values of EC, Hardness, CSR and SARaj than the other zones.

The comparison of the water qualities of each tunnel, and their grouping based on similar qualities, revealed a coincidence with the clustering of tunnels with the same lithology. Obviously, there is a natural grouping of tunnels, depending on their location on the island, since nearby tunnels in the same area cross similar volcanic lithographies with comparable water qualities. In other words, there is direct evidence that the water quality can be predicted if the surface lithology through which the groundwater tunnel runs is known.

Table 3
Clusters of tunnels based on the terrain crossed.

Zone	Nº tunnels	Lithology present	%
Northeast	7	L1	98.4%
		Other	1.6%
West	12	L1	90.1%
		L6	4.6%
		L7	4.0%
		Other	1.3%
South – Southwest	35	L1	39.1%
		L4	58.4%
		Other	2.5%
Centre – West	50	L1	32.4%
		L2	28.5%
		L3	13.5%
		L4	16.5%
		L7	6.8%
		Other	3.2
Centre – East	154	L1	55.0%
		L2	23.3%
		L3	8.1%
		L4	7.3%
		Other	6.3

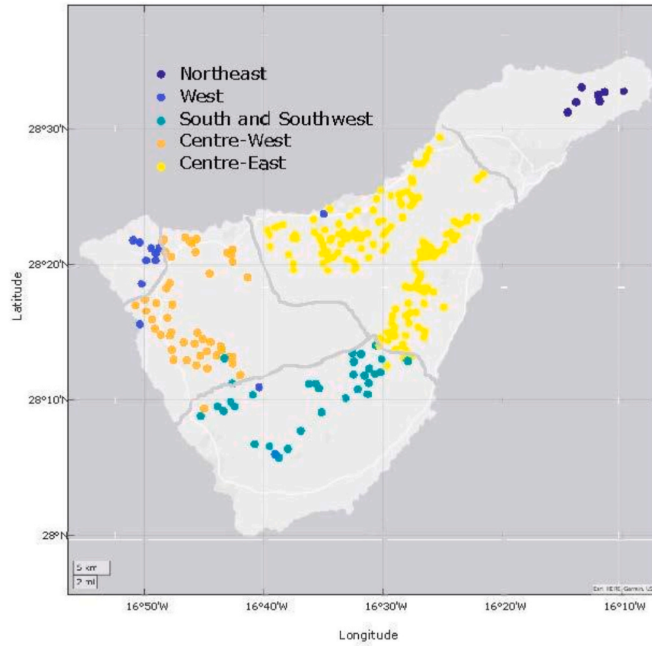

Fig. 6. Geographical distribution of the clusters defined by their lithologies.

Fig. 6 shows the distribution of the 258 tunnels around the island of Tenerife, and Fig. 7 shows the SARaj of each tunnel. Therefore, the data show that the quality of the water correlates with the location of the tunnel, or, in other words, that it depends on the lithology present in each zone.

The data show that better water quality, with smaller SARaj parameters, is found in the Northeast and West clusters. From a lithological point of view, Fig. 8 shows the tunnels of the Northeast cluster and the West have the highest percentage of volcanic terrain crossed, belonging to lithology L1 (basaltic lava flow and pyroclastic, main minerals; amphibole, olivine, augite, pyroxene plagioclase), 98% and 90% respectively. In both clusters, the water quality is good based on the SARaj, with values of 5.921 and 5.618, respectively, which are twice as low as in other areas. However, the tunnels of the West cluster also cross lithologies L6 (ignimbrites) and L7 (epicelastic deposits and intramontane sediments), at smaller percentages of 4.6% and 4.0% respectively, leading to an improvement in water quality compared to the Northeast cluster.

In the South-Southwest cluster, we see that the L1 lithology has decreased significantly to 39.1%, the L4 lithology (phonolite lava flow, main minerals: amphibole, hauyna, pyroxene, plagioclase, biotite) is present with 58.4%, and the SARaj worsens with a value of 7.289.

In the case of the Centre-West and Centre-East clusters, we observe that the percentage of L1 lithology is not as high, 32.4% and 55.0% respectively, with values that are in the same range as in the South and Southwest cluster (58.4%). However, the SARaj is worse in these clusters than in the South and Southwest clusters. The differences could be due to the lithologies present in these regions. The presence of the L2 and L3 lithologies correlates with significantly worse water quality based on the SARaj, with values of 13.869 and 11.382 respectively. In the case of the Centre-West and the Centre-East clusters, the occurrence of the L2 lithology (trachybasaltic lava flow and pyroclastic, main minerals: augite,

Table 4
Chemical properties of the water in each lithological zone.

Zone	Nº tunnels	Ca^{2+} meq/l	Mg^{+} meq/l	Na^{2+} meq/l	K^{+} meq/l	HCO_3^-meq/l	CO_3^{2+} meq/l	Cl^-meq/l	SO_4^{2+} meq/l	NO_3^-meq/l	$H_2PO_4^-$meq/l	SiO_2 mg/l	F^-mg/l
Northeast	7	0.783	0.934	3.550	0.174	2.734	0.058	2.328	0.376	0.050	0.001	37.040	0.263
West	12	1.400	1.882	3.739	0.193	4.615	0.073	1.648	0.603	0.281	0.004	52.972	0.350
South - Southwest	35	0.762	1.139	3.541	0.394	4.981	0.210	0.346	0.127	0.133	0.005	72.450	0.656
Centre-West	50	1.859	4.381	8.978	0.756	12.509	0.246	1.097	1.970	0.118	0.006	73.296	0.979
Centre-East	154	0.606	2.346	6.086	0.516	7.746	0.337	0.616	0.676	0.124	0.003	50.501	0.771

Table 5
Quality parameters of the water in each lithological zone.

Zone	Nº of tunnels	pH	EC (mS/cm)	W. hardness	RSC	SARaj
Northeast	7	8.210	0.573	8.594	1.076	5.921
West	12	8.016	0.698	16.435	1.407	5.618
South-Southwest	35	8.198	0.541	9.523	3.289	7.289
Centre-West	50	7.858	1.586	31.127	6.663	13.869
Centre-East	154	8.417	0.844	14.786	5.130	11.382

plagioclase, amphibole, olivine) is 28.5% and 23.3%, respectively, while the appearance of the L3 lithology (trachytic lava flow and pyroclastic, main minerals: plagioclase and pyroxene) is 13.5% and 8.1% respectively, with lithology L4 representing 16.5% and 7.3%.

The L5 lithology (tuffs) appears primarily in the Centre-West cluster, which apparently causes a worsening of the water quality, based on the SARaj, with respect to the Centre-East cluster, which does not exhibit the L5 lithology.

The RSC parameter correlates with SARaj, allowing similar relationships to be established between water quality and the lithology present in a zone. The Centre-West cluster and the Centre-East cluster give RSC values of 6.663 and 5.130, respectively, which are much higher than those obtained for the North-East, West and South-Southeast clusters, with values of 1.076, 1.407 and 3.289.

In the case of the EC parameter, the results are similar. For the Centre-West and Centre-East tunnel groupings, the EC is 1.586 mS/cm and 0.844 mS/cm respectively, compared to the values obtained for the Northeast, West and South-Southeast tunnel groupings, with values of 0.573 mS/cm, 0.698 mS/cm and 0.541 mS/cm, respectively.

Groundwater samples analysed from tunnels drilled across the island have provided a relatively complete dataset covering a wide range of geological conditions. The tunnels were grouped according to the lithologies they passed through and water samples from each tunnel were analysed to calculate mean values for various water quality parameters. Note that the water quality is better in tunnels crossing mainly basaltic lava flows and pyroclastic lithologies compared to other areas. Thus, knowing the volcanic lithology present in an area provides insight into the water quality, which yields useful information for water resource management.

Overall, this study has the potential to provide valuable information on the hydrogeology of Tenerife and could have implications for groundwater management not only on the island, but also in other areas with similar geological characteristics.

There are recent studies that examine groundwater quality by identifying lithologies in a given region, using the Entropy Weighted Water Quality Index (EWWQI) and the Total Chronic Hazard Index (TCHI) to assess the health risks associated with contaminants such as NO_3^- and F^- (Subba, 2021). There are also novel studies on groundwater quality, geochemical types of groundwater, mechanisms regulating groundwater chemistry, the relationship between groundwater levels and chemistry, the genetic classification of groundwater quality, the geochemical evolution of groundwater, and the impact of land use activities on groundwater (Subba, Sunitha, Rashmirekha and Kumar, 2022). There are further studies in this research area that explore how geochemical characteristics influence groundwater chemistry and quality, and how human activities negatively impact water quality. In the study, the objective was to understand the origin of these geochemical characteristics and assess groundwater quality, enabling the implementation of corrective measures to ensure safe water for the local community (Subba Rao, dinakar, Sravanthi and Kumari, 2021). However, this study establishes a relationship between the volcanic geology present on the island of Tenerife and water quality, allowing us to determine the quality of water obtained when it passes through specific lithologies. The results of this study hold practical significance when making decisions related to the search for freshwater.

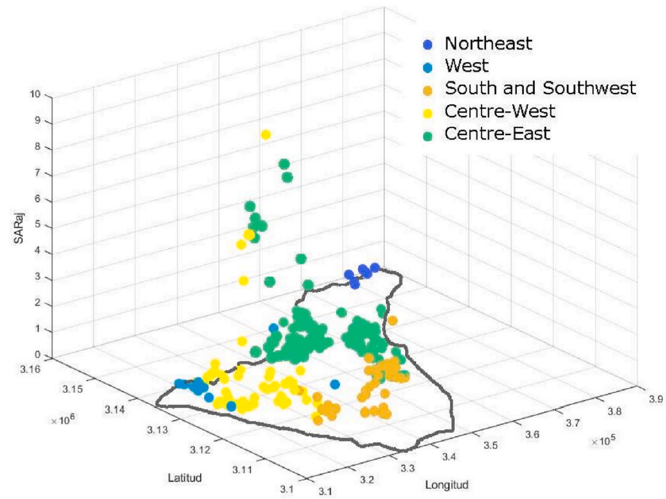

Fig. 7. SARaj of each tunnel studied in Tenerife.

5. Conclusions

This research involved 258 significant tunnels distributed around the island of Tenerife, for the purpose of obtaining fresh water.

Table 6
Averaged percentage of lithologies, and mean SARaj for each zone defined in Tenerife.

Zone	L1 (%)	L2 (%)	L3 (%)	L4 (%)	L5 (%)	L6 (%)	L7 (%)	Others (%)	SARaj dS/m
West	**90.1**	0.0	0.0	0.0	0.0	4.6	4.0	1.3	5.618
Northeast	**98.4**	0.0	0.0	0.0	0.0	0.0	0.0	1.6	5.921
South-Southwest	39.1	0.0	0.0	**58.4**	0.0	0.0	0.0	2.5	7.289
Centre-East	55.0	**23.3**	**8.1**	7.3	0.0	0.0	0.0	6.3	11.382
Centre-West	32.4	**28.5**	**13.5**	16.5	**6.8**	0.0	0.0	3.2	13.869

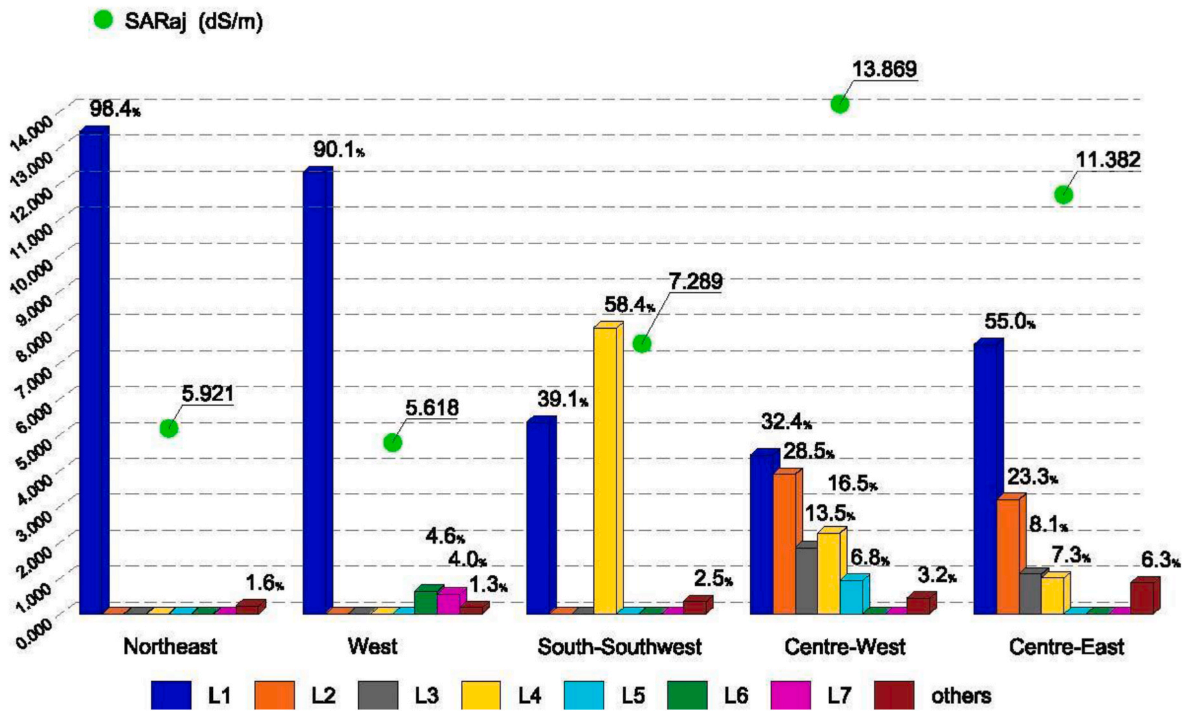

Fig. 8. Averaged percentage of lithologies present, and mean SARaj for each zone defined in Tenerife.

The lithologies crossed have been identified for each tunnel, with the 258 tunnels classified into five groupings: Northeast, West, South-Southwest, Centre-West and Centre-East. The result is a study of the influence of volcanic lithologies on the volcanic island of Tenerife on water quality, as defined by SARaj, RSC, and electrical conductivity. The data show that tunnels with the same lithology have similar water qualities.

This research establishes a clear relationship between water qualities and volcanic lithologies on the island of Tenerife. A comparison of the tunnel groupings with the values obtained from SARaj clearly shows:

- Lithology defined as L1 (basaltic lava flow and pyroclastic, main minerals: amphibole, olivine, augite, pyroxene plagioclase) carries highquality water, based on the values of SARaj, CSR and EC, as evidenced by the values obtained for the Northeast and West tunnel groupings.
- The presence of a lithology defined as L4 (phonolite lava flow, main minerals: amphibole, Hauyna, pyroxene, plagioclase, biotite) improves the resulting water quality considering the SARaj values and the slight increase in EC.
- The presence of L2 (trachybasaltic lava flow and pyroclastic, main minerals: augite, plagioclase, amphibole, olivine) and L3 (trachytic lava flow and pyroclastic, main minerals: plagioclase and pyroxene) leads to a strong deterioration in water quality, as observed in the tunnels of the Centre-West and Centre-East clusters. The significant difference between these two clusters is the notable presence of the L5 lithology (tuffs) in the former, which results in a poorer water quality. Therefore, it can be concluded that the presence of the L5 lithology could explain the worse water quality in that area.

The findings of this study have practical implications for decision making regarding the drilling of freshwater boreholes. By identifying the lithology of the ground in advance, it is possible to estimate the water quality and make informed decisions on whether or not to proceed with drilling. This can save significant costs if the water quality is expected to be poor for irrigation or human consumption, and can also help to forecast and plan water treatment needs if acceptable water quality is expected.

The research on how geological factors influence water quality in volcanic terrains, specifically on Tenerife, has diverse future applications. It can improve water management strategies on volcanic islands, identify suitable areas for groundwater extraction, and facilitate efficient water distribution. Understanding the link between water qualities and volcanic lithologies aids in planning for future water treatment needs, resulting in cost savings and sustainable practices. Policymakers can implement measures to conserve water sources from pollution, ensuring access to clean water. This study may inspire similar research worldwide, providing valuable insights into geology-driven water quality assessments. Overall, it contributes practical solutions for sustainable water resource management, benefiting human consumption and agriculture.

CRediT authorship contribution statement

E. de Miguel-García: Methodology, Analysis, Writing.
J.F. Gómez-González: Methodology, Analysis, Writing.
José L. Cruz: Data collection.

Declaration of competing interest

No conflict of interest.

Data availability

Data will be made available on request.

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