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Electrical Resistivity Tomography and 3D Modeling for Groundwater Salinity Assessment in Volcanic Islands: A Case Study in Los Cristianos (Tenerife, Spain)

Pedro Carrasco-García [1,*], José Luis Herrero-Pacheco [1], Javier Carrasco-García [2] and Daniel Porras-Sanchiz [3]

[1] Department of Cartographic and Terrain Engineering, Polytechnic School of Avila, University of Salamanca, Av. Hornos Caleros, n° 50, 05003 Ávila, Spain; joseluis.herrero@inge.es
[2] Técnicas Geofísicas S.L., 05003 Ávila, Spain; tgeofisicas@gmail.com
[3] Geoland Services S.L., 28008 Madrid, Spain; dporras@geoland.es
* Correspondence: retep81@usal.es; Tel.: +34-920-353-500

Abstract

Groundwater management in volcanic islands represents a complex challenge due to the scarcity of surface resources, the strong heterogeneity of volcanic terrains, and the constant threat of marine intrusion. In Tenerife (Canary Islands, Spain), current regulations establish that only saline or brackish waters are permitted for exploitation, to be subsequently desalinated through reverse osmosis for urban and touristic supply. In this context, it is essential to develop geophysical methodologies capable of accurately characterizing subsurface salinity and optimizing the location of new boreholes. The present study applies Electrical Resistivity Tomography (ERT) profiles in the Los Cristianos area (Arona, Tenerife), later integrated into a three-dimensional model using Oasis Montaj software Version 2025.1. The results allow for the differentiation of four geoelectrical domains. The 3D modeling enabled a detailed characterization of the conductive domain, delineating the geometry of the marine intrusion. The findings confirm that the combination of ERT and 3D modeling constitutes an effective, replicable, and economically efficient methodology for precisely locating saline horizons and selecting the most suitable drilling sites, thereby providing an objective basis for the sustainable management of water resources in volcanic islands.

Keywords: electrical resistivity tomography (ERT); 3D geoelectrical modeling; seawater intrusion; volcanic islands; hydrogeophysics; groundwater salinity; borehole siting

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1. Introduction

Groundwater management in volcanic islands represents a permanent challenge due to the scarcity of surface resources and the almost exclusive dependence on groundwater aquifers [1]. In territories such as Tenerife (Canary Islands, Spain), more than 90% of the supply comes from wells and galleries [2]. This situation is further aggravated by the increasing pressure of tourism, which in the archipelago exceeds 12 million visitors annually, demanding a robust and sustainable water infrastructure [3].

Unlike other continental regions, where groundwater resources can be managed through artificial recharge or the exploitation of freshwater, in the Canary Islands regulations stipulate that only saline or brackish waters may be extracted (mainly for desalination purposes), with the aim of preserving freshwater reserves for subsequent desalination through reverse osmosis plants [2]. In this way, freshwater resources are protected from overexploitation, while brackish or saline water becomes the main input to meet both

tourist and agricultural demand. This regulatory framework assigns a central role to the determination of hydrochemical water quality during the exploration phase, particularly salinity and electrical conductivity [4].

Within this context, geophysical methods have been consolidated as key tools for the indirect characterization of the subsurface. Among them, electromagnetic (EM) methods—such as Time-Domain Electromagnetics (TDEM) or Frequency-Domain Electromagnetics (FDEM)—have shown strong potential in sedimentary environments and alluvial basins, enabling the identification of aquifers and the delineation of marine intrusion fronts [5–7]. However, in volcanic islands such as Tenerife, these methods face significant limitations. The presence of overlapping basaltic flows, the high magnetization of certain layers, ambient electromagnetic noise, the high resistivity of some materials, and the strong lateral heterogeneity of volcanic terrains generate complex electromagnetic responses that are often difficult to interpret [8]. In addition, the pronounced topography and marked anisotropy of the medium constrain the reliability of 1D or 2D inversions in these contexts [9].

In contrast to these difficulties, direct current electrical methods, and in particular Electrical Resistivity Tomography (ERT), offer substantial advantages. ERT is based on the controlled injection of electric current into the subsurface and the measurement of potential differences at the surface, allowing the construction of two-dimensional resistivity sections. Its strength lies in the ability to detect, with high resolution (typically between 1 and 10 m, depending on electrode spacing and array configuration), lithological changes, particularly resistivity contrasts between basaltic flows, pyroclastic deposits, weathered materials, and sedimentary infill, and most importantly, the transition between freshwater and saltwater-saturated materials [10,11]. This feature makes ERT especially suitable for volcanic islands characterized by complex "layer-cake" stratigraphy with multiple lava flow units, where alternating high and low resistivity layers enhance subsurface discrimination. Recent studies have demonstrated the effectiveness of ERT in identifying marine intrusion in coastal aquifers of diverse geological nature, ranging from carbonate systems to alluvial formations [12–14].

The multi-scale and multidimensional nature of ERT also allows its integration into three-dimensional models using specialized software such as Oasis Montaj [15]. These 3D models represent a substantial advancement in geomatic representation, as they provide volumetric resistivity data that reduce the uncertainty associated with two-dimensional inversions. The spatial interpolation of ERT profiles enables visualization of the geometry of conductive bodies in a 3D framework, facilitating decision-making regarding borehole siting [16,17].

The importance of characterizing saline intrusion in the Canary Islands is not only hydrogeological but also economic and strategic. For the hotel sector, the availability of saline water is even desirable, since its treatment by reverse osmosis ensures the required quality for supply while minimizing the impact on freshwater aquifers [18]. In this regard, the application of ERT combined with 3D modeling is not only a scientific advancement but also a practical tool for water resource planning and management.

The present study focuses on the area of Los Cristianos (Arona, Tenerife), one of the island's main tourist zones, where the pressure on groundwater resources is especially intense. Through the application of Electrical Resistivity Tomography profiles integrated into a 3D model, the objectives are to (i) assess the distribution of geoelectrical domains at depth, (ii) identify conductive horizons associated with saline waters, and (iii) establish objective criteria for borehole siting in a complex regulatory and geological framework. In doing so, this study not only contributes to the hydrogeophysical knowledge of Tenerife but also establishes the basis for a replicable methodology in other volcanic island environments. Previous studies have primarily focused on 2D electrical soundings or hydrochemical

characterizations, often neglecting the three-dimensional variability of volcanic formations and the influence of salinity gradients. This work aims to fill this gap by developing a 3D resistivity model from 2D ERT profiles, providing a novel framework for assessing saline intrusion and supporting borehole placement in volcanic-island settings.

2. Materials and Methods

2.1. Study Area

The study area is located in the municipality of Arona, in the southern sector of Tenerife, within the tourist zone of Los Cristianos (Figure 1). Geologically, this region belongs to the southern massif of the island, characterized by the superposition of basaltic lava flows from different eruptive episodes and the presence of interbedded pyroclastic deposits [10]. The lava flows, with ages ranging from the Pliocene to the Quaternary (Figure 2), exhibit marked heterogeneity in their physical properties: some are highly compact and of high resistivity, whereas others, intensely fractured and altered, favor fluid circulation [11].

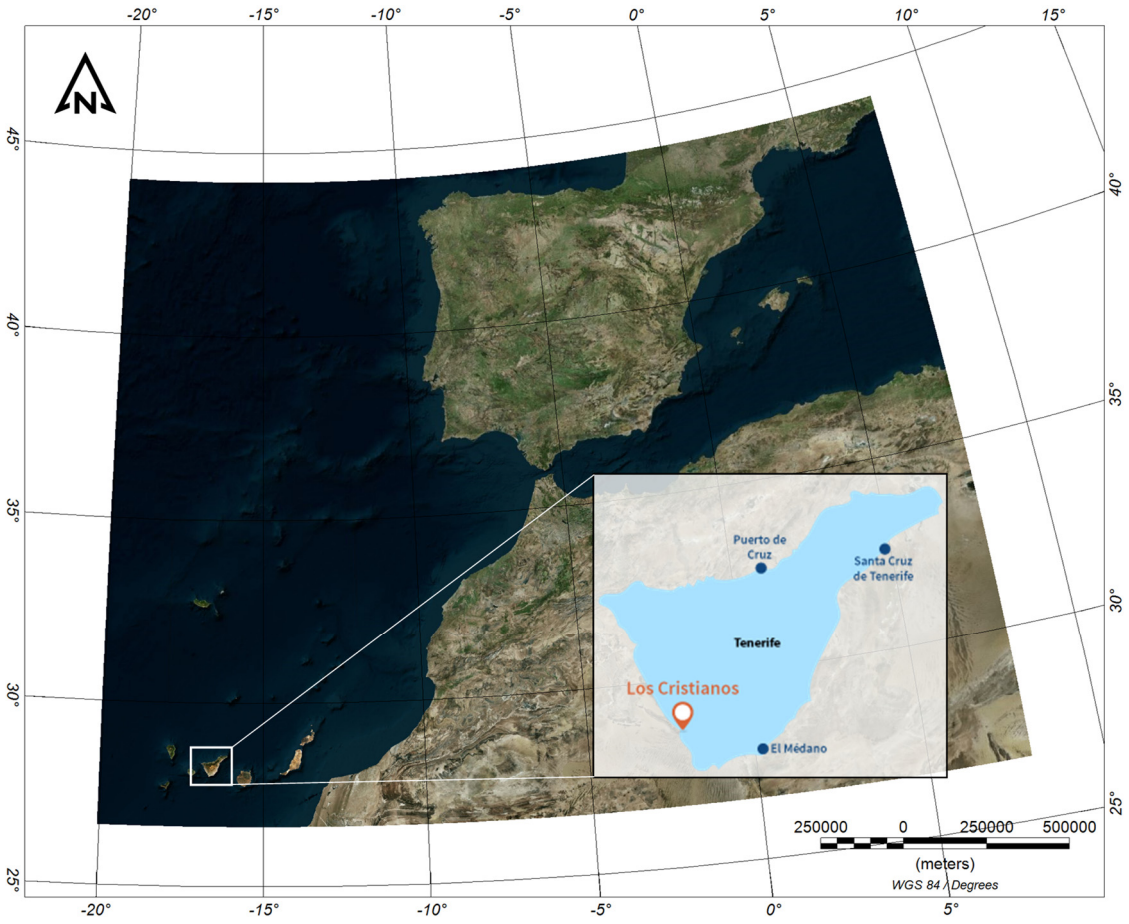


Figure 1. Geographical location of Los Cristianos (Tenerife, Spain).

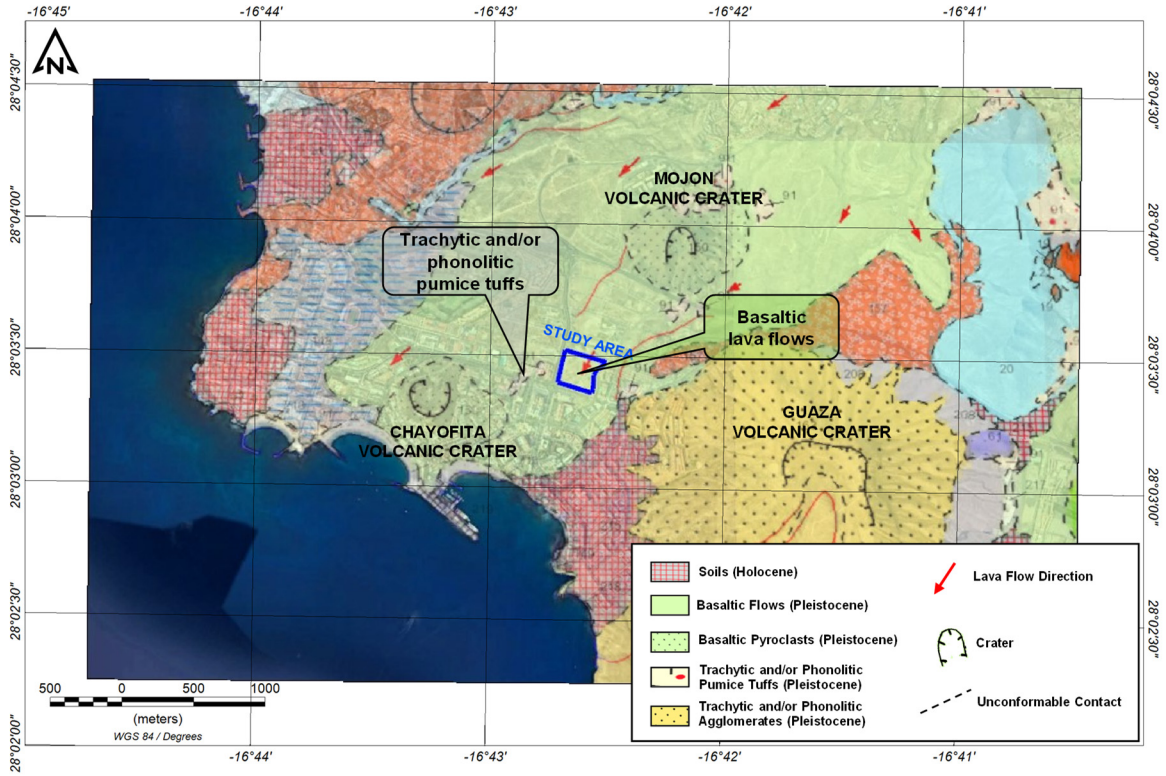


Figure 2. Simplified geological map of Los Cristianos, based on IGME cartography (https://info.igme.es/cartografiadigital/geologica/) (accessed on 25 September 2025) [10].

The hydrogeology of the area is strongly conditioned by its coastal setting. The proximity to the sea promotes the intrusion of marine water into the groundwater aquifers, particularly in those located at low altitudes. This phenomenon of saline intrusion has been widely documented in volcanic islands [12–14] and represents one of the main constraints for groundwater exploitation in Tenerife [2]. Accurate identification of the depth and thickness of the levels affected by saline water is, therefore, crucial to ensure adequate abstraction from both a regulatory and an economic perspective.

2.2. Applied Electrical Method

The method selected for this study was Electrical Resistivity Tomography (ERT), widely recognized as one of the most effective techniques for characterizing seawater intrusion in coastal aquifers [15,16]. Unlike electromagnetic methods, which are affected by factors such as the strong magnetization of basalts, the presence of ambient electromagnetic noise, the high resistivity of certain materials, and the lateral heterogeneity of volcanic terrains [7], ERT is based on the injection of direct current into the subsurface and the measurement of the resulting potential at the surface.

The apparent resistivity obtained depends on multiple factors: lithology, degree of fracturing, porosity, and, most significantly, the salinity of the pore fluid. Indeed, electrical resistivity is a good proxy for both hydraulic conductivity and the salinity content of groundwater [17]. The electrical resistivity of the subsurface is inversely related to the salt concentration of pore fluids: increasing ionic content enhances conductivity. This relationship follows Archie's Law and is influenced by the parent material, porosity, and drainage conditions. In the study area, the main lithological units controlling this behavior are ignimbrites, basaltic flows, and pyroclastic deposits. In volcanic environments, the contrasts between fresh (resistive) materials and saline (conductive) horizons are sufficiently marked to be clearly detected by ERT [18].

For the present study, two main ERT profiles were designed (Figure 3), crossing at the point selected for drilling, with effective lengths of 240 m for ERT-1 and 340 m for ERT-2. A Syscal Pro multielectrode system (Iris Instruments) was employed, with 25 and 35 electrodes, respectively, at a spacing of 10 m. These configurations allowed an investigation depth exceeding 100 m, suitable for detecting the freshwater–saltwater interface in the area.

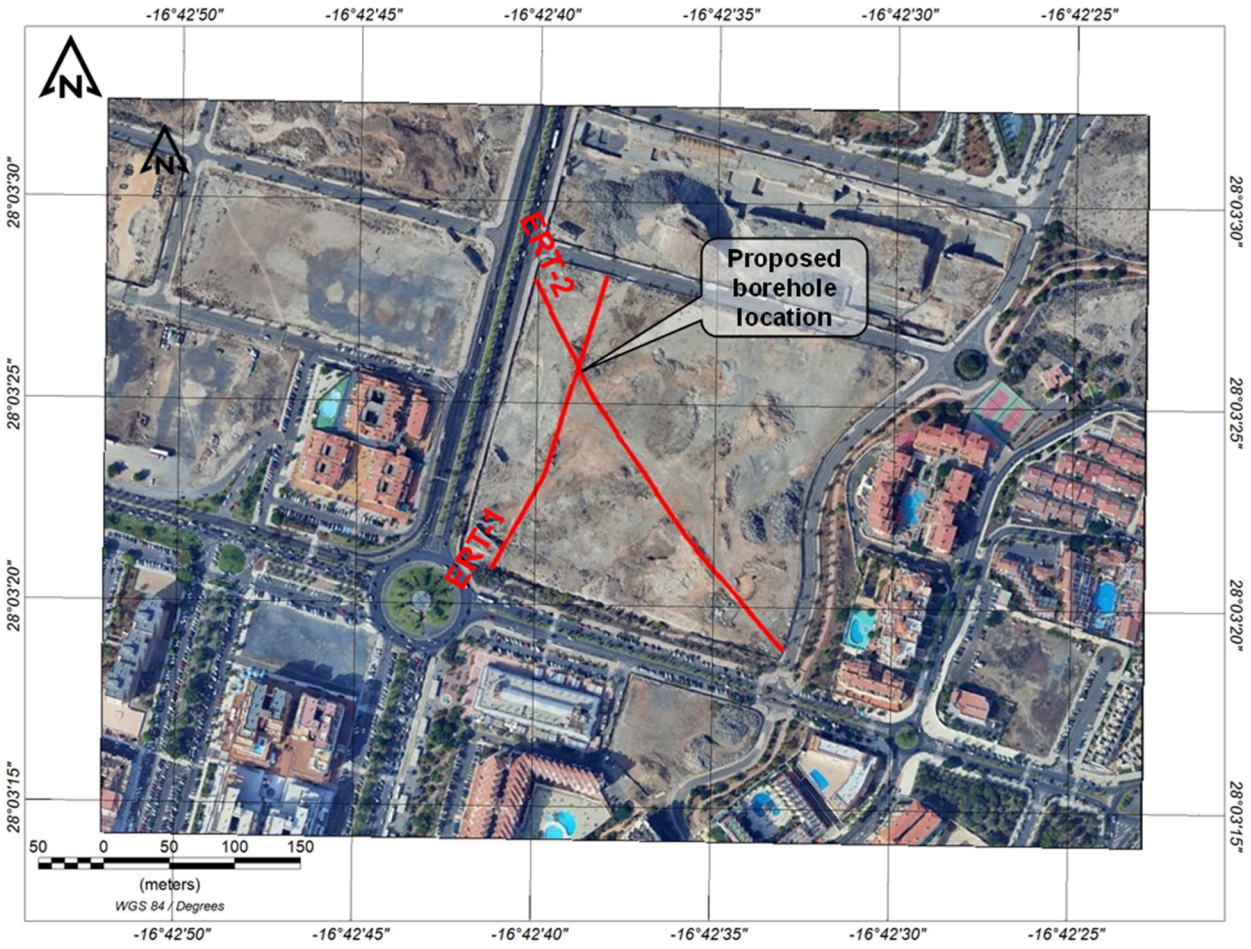


Figure 3. Layout of the electrical resistivity tomography profiles in the Los Cristianos site.

Both Wenner and Pole–Dipole configurations were used. The former provides greater vertical sensitivity and a better signal-to-noise ratio, while the latter allows for improved lateral resolution and greater depth of investigation, which is essential in environments where seawater intrusion exhibits irregular variations [19]. The combination of both arrays ensured more robust coverage and enhanced the ability to interpret complex structures.

2.3. Data Acquisition and Quality Control

Data acquisition was carried out following standard applied geophysics protocols [20]. For profiles ERT-1 and ERT-2, using the pole–dipole configuration, a total of 276 and 561 apparent resistivity measurements, respectively, were collected, generating pseudosections representative of the subsurface electrical potential distribution.

Quality control procedures included the removal of spurious values and measurements with instrumental errors, normalization of the data according to array geometry, and the application of robustness filters to minimize the influence of outliers. Finally, the quality of the inversions was evaluated through the calculation of the root-mean-square (RMS) error, which in all cases remained around 10%, a value considered in the literature as an optimal

fitting threshold [21]. These procedures ensured that the resulting models were consistent and suitable for hydrogeological interpretation.

2.4. Data Inversion

The acquired data were inverted using Res2DInv software version 3.5 (commercial software; available at https://www.geotomosoft.com) (accessed on 25 September 2025), applying smoothness-constrained least squares inversion [22], which aim to generate smooth and geologically plausible models (Figure 4). This type of inversion is particularly useful in environments with progressive gradients, such as those associated with seawater intrusion [23].

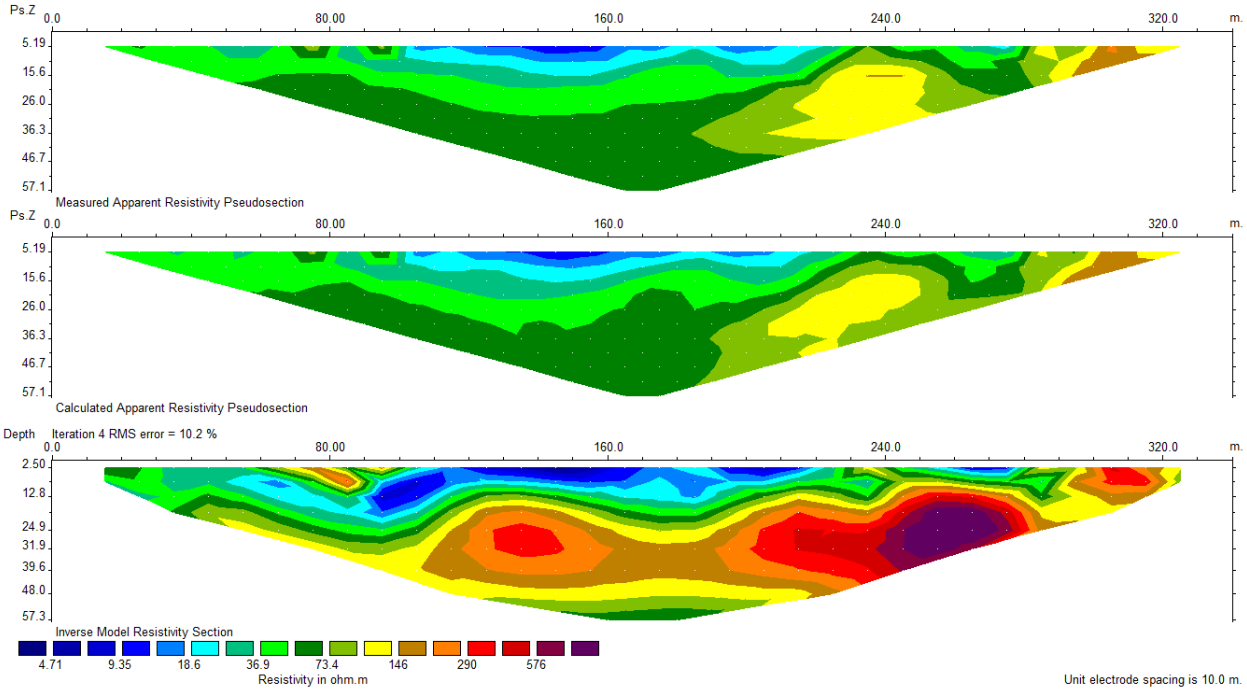


Figure 4. Example of apparent resistivity pseudosection and corresponding inverted model for profile TE-1 (Wenner configuration), obtained using Res2Dinv software Version 3.5.

In addition, robust inversion schemes were also tested in the profiles to reduce the influence of extreme values [24]. In all cases, the final models showed a satisfactory fit between measured and calculated data, with acceptable RMS values.

2.5. Integration and 3D Modeling

To obtain a continuous spatial view, the results of the ERT profiles were integrated into a three-dimensional model using Oasis Montaj software [17]. Each inverted 2D section was georeferenced and subsequently interpolated using kriging algorithms to generate a volumetric resistivity cube. The 3D voxel model was constructed in Oasis Montaj using $27 \times 30 \times 15$ cells with a uniform 10 m resolution. The resistivity distribution was obtained by ordinary kriging interpolation of the inversion results from the two 2D ERT profiles. The inversion of each profile was carried out using a smoothness-constrained least squares algorithm, applying a 3% relative data error and a damping factor of 0.25. The depth of investigation reached approximately 100 m, consistent with the electrode spacing and array configuration (Polo-Dipolo, maximum spread 340 m).

This geomatic approach allows the three-dimensional distribution of geoelectrical domains to be visualized, reduces interpretative uncertainty, and optimizes the selection of drilling zones. The 3D modeling (Figure 5) therefore represents an essen-

tial step in the practical application of geophysics to water resource management in volcanic environments [25].

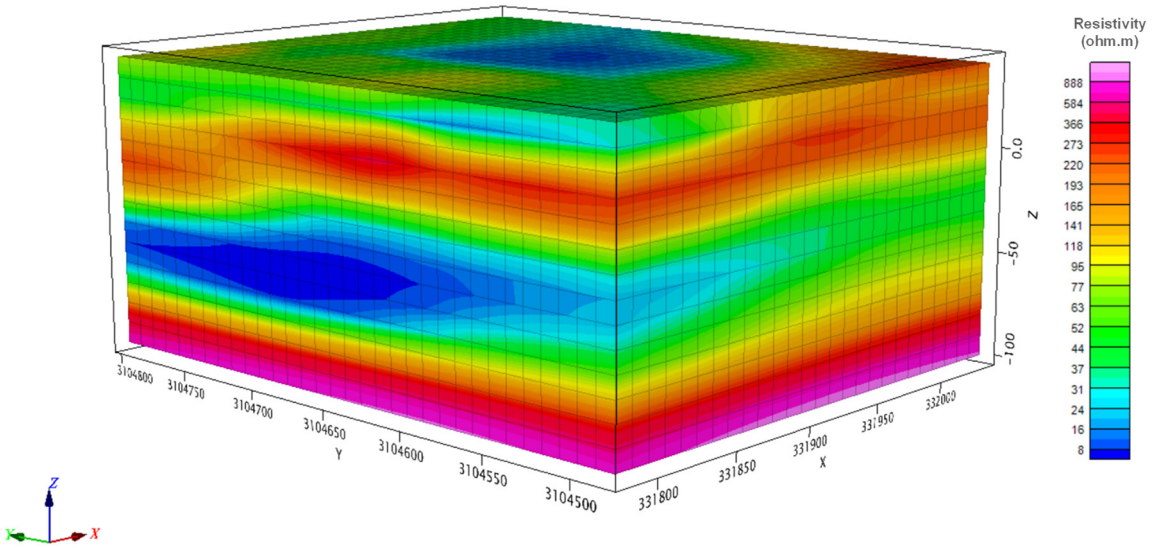


Figure 5. Three-dimensional model generated in Oasis Montaj.

3. Results

3.1. Electrical Resistivity Tomography Profiles

The Electrical Resistivity Tomography (ERT) surveys carried out in the Los Cristianos site provided two-dimensional resistivity sections (Figure 6) with an investigation depth of nearly 100 m, sufficient to intercept the horizons of greatest hydrogeological interest.

In profile TE-1, oriented south–north, three main units can be distinguished. The shallow zone is dominated by ignimbrites (pumiceous pyroclastic flow deposits) and silty sands (<75 Ω·m) mainly composed of reworked volcanic materials. At depths between 10 and 15 m, a layer of basaltic scoria and massive basalts with intermediate resistivities (75–500 Ω·m) appears, corresponding to slightly altered materials with a low degree of saturation. In the basal part of the profile, at around 60 m depth, a horizon of volcanic formations saturated with saline water develops, characterized by resistivities below 20 Ω·m, which constitutes the main marker of marine intrusion in this sector. Although no direct physicochemical soil analyses were carried out, the interpretation of saline horizons is supported by resistivity values below 20 Ω·m, which are consistent with those reported for saline and brackish groundwater in volcanic coastal aquifer.

Profile TE-2, oriented northwest–southeast, reveals a similar configuration, though with the presence of four units. At the surface, ignimbrites and silty sands of moderate resistivity outcrop again, followed by basaltic scoria and massive basalts with higher resistivity. In this case, however, the conductive domain, corresponding to volcanic formations saturated with saline water, dips towards the northwest. Additionally, in the deepest part of the section, an extra package of high-resistivity massive basalt is identified, acting as the electrical basement of the system.

The comparison between both profiles indicates that saline intrusion is shallower towards the coast, consistent with the hydrogeological gradient expected in coastal volcanic systems, where the freshwater–saltwater interface advances inland under the influence of marine pressure [12,14].

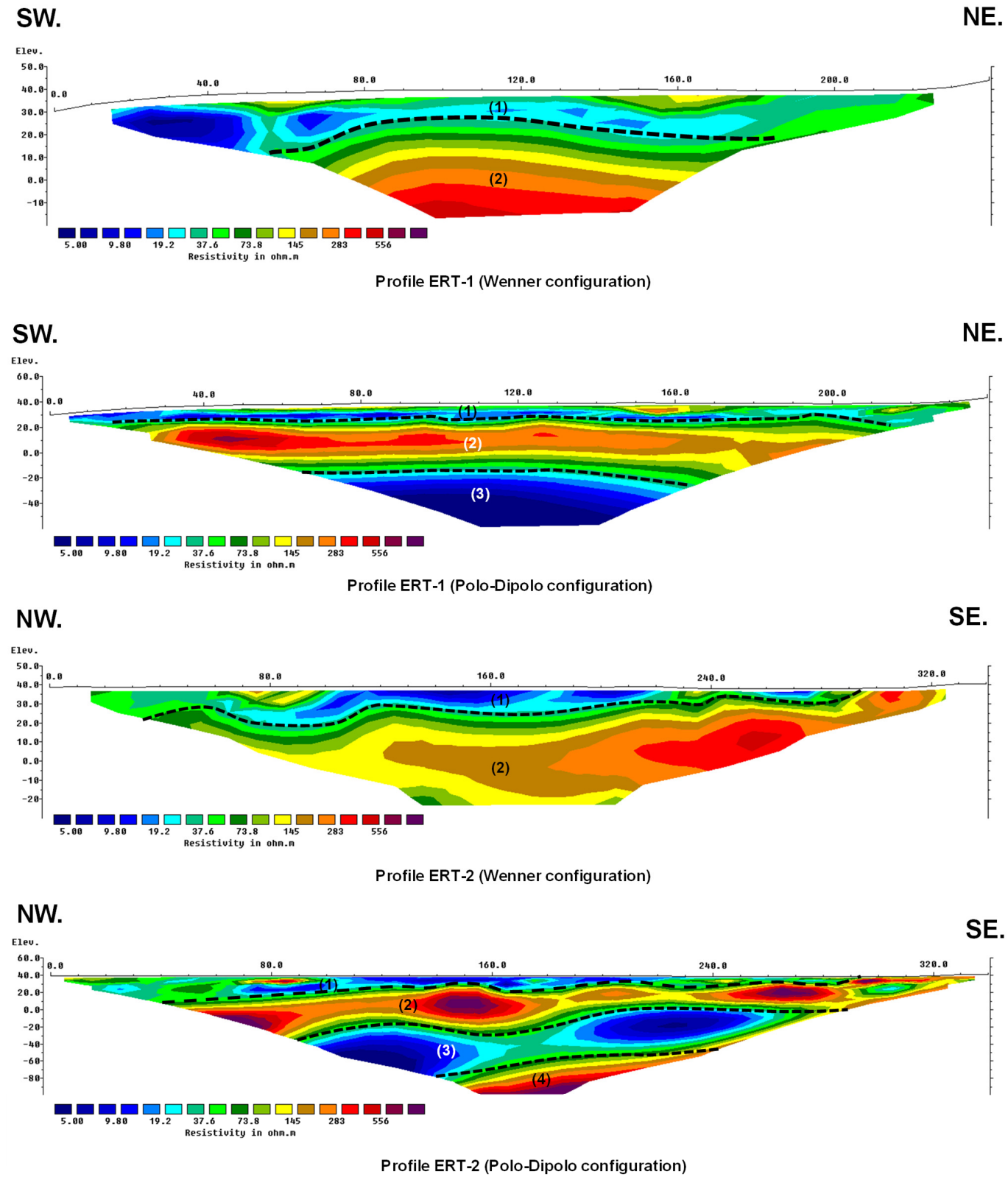


Figure 6. Inverted resistivity models obtained from profiles ERT-1 and ERT-2.

3.2. Identification of Geoelectrical Domains

The three-dimensional interpolation of the profiles using Oasis Montaj allowed the construction of a volumetric resistivity model that provides a continuous spatial view of the distribution of geoelectrical domains (Figure 7).

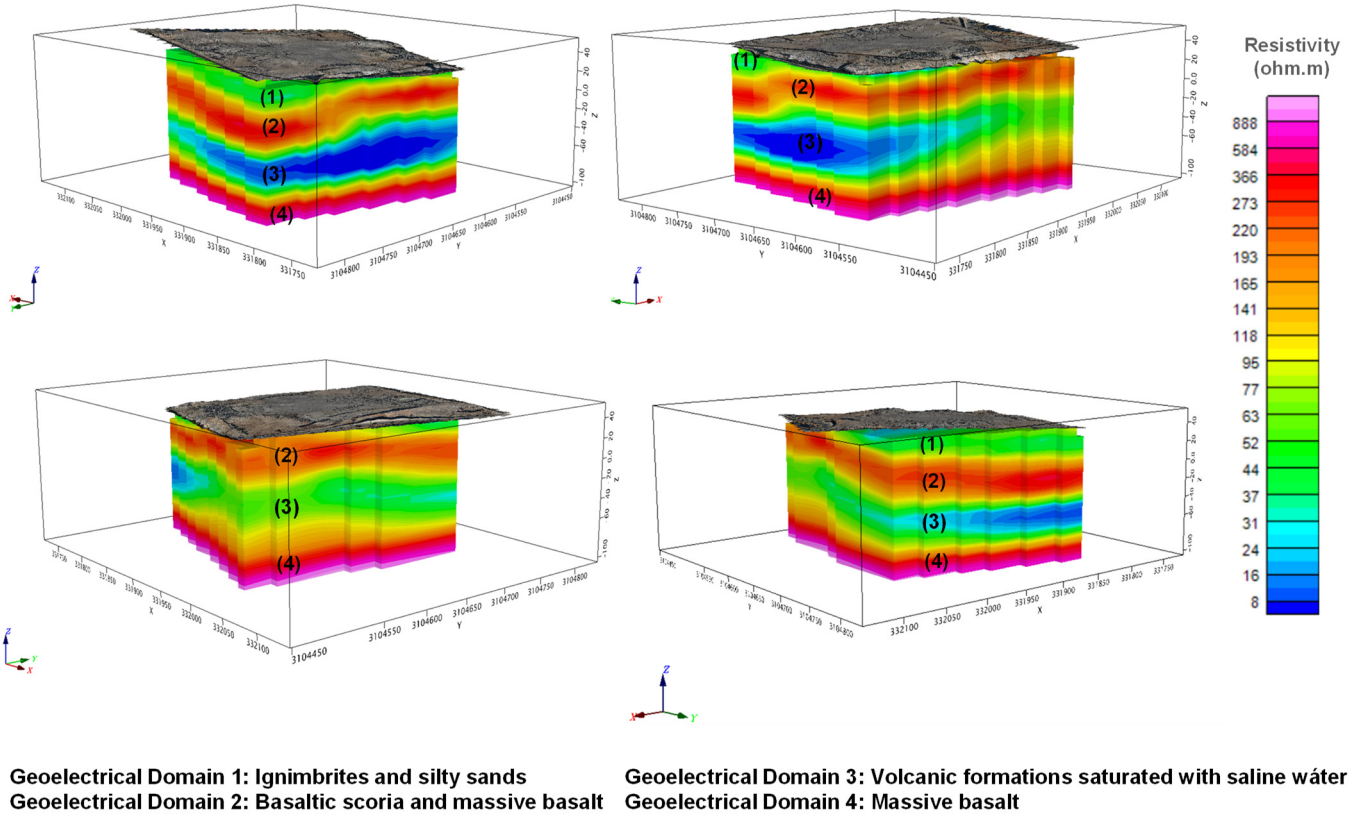


Figure 7. Different views of the 3D model showing the identified geoelectrical domains.

The joint analysis makes it possible to identify four geoelectrical domains consistent with the units interpreted in the sections. At the surface, there is a shallow domain of low to moderate resistivity (<75 Ω·m), attributable to ignimbrites and silty sands. Beneath this, an intermediate–resistive domain (75–500 Ω·m) develops, composed of basaltic scoria and massive basalts, corresponding to slightly altered materials with a low degree of saturation. At the base of both profiles, a deep conductive domain (<20 Ω·m) is identified, corresponding to volcanic formations saturated with saline water, which constitutes the main marker of marine intrusion [26]. In ERT-1, it is located at around 60 m depth, while in ERT-2 it appears at shallower levels and dips northwestward, indicating a landward progression of the freshwater–saltwater interface consistent with the coastal hydrogeological gradient [12,14].

Locally, ERT-2 also reveals a deep package of very high-resistivity massive basalt (>500 Ω·m), which acts as the electrical basement of the system and controls the geometry of the saline wedge.

3.3. Geometry of the Saline Intrusion

The conductive horizon (<20 Ω·m) appears continuously in both profiles, although it shows notable differences in depth. In ERT-1, the level associated with marine intrusion is located at around 60 m throughout the section. In ERT-2, by contrast, the same horizon dips north-westward, reflecting greater inland penetration of salinity.

This lateral variation is highlighted in the three-dimensional model, where the marine intrusion advances at shallower depths in the southern sector of the plot (Figure 8),

closer to the coastline, consistent with previously developed hydrogeological models in Tenerife [11]. Comparative studies in other volcanic archipelagos, such as Hawaii [27] and Cape Verde [28], have documented a similar behaviour: the marine intrusion develops as a saline wedge that progresses inland beneath volcanic materials, with a slope controlled by the natural hydraulic gradient, the permeability of the materials, and the intensity of groundwater exploitation.

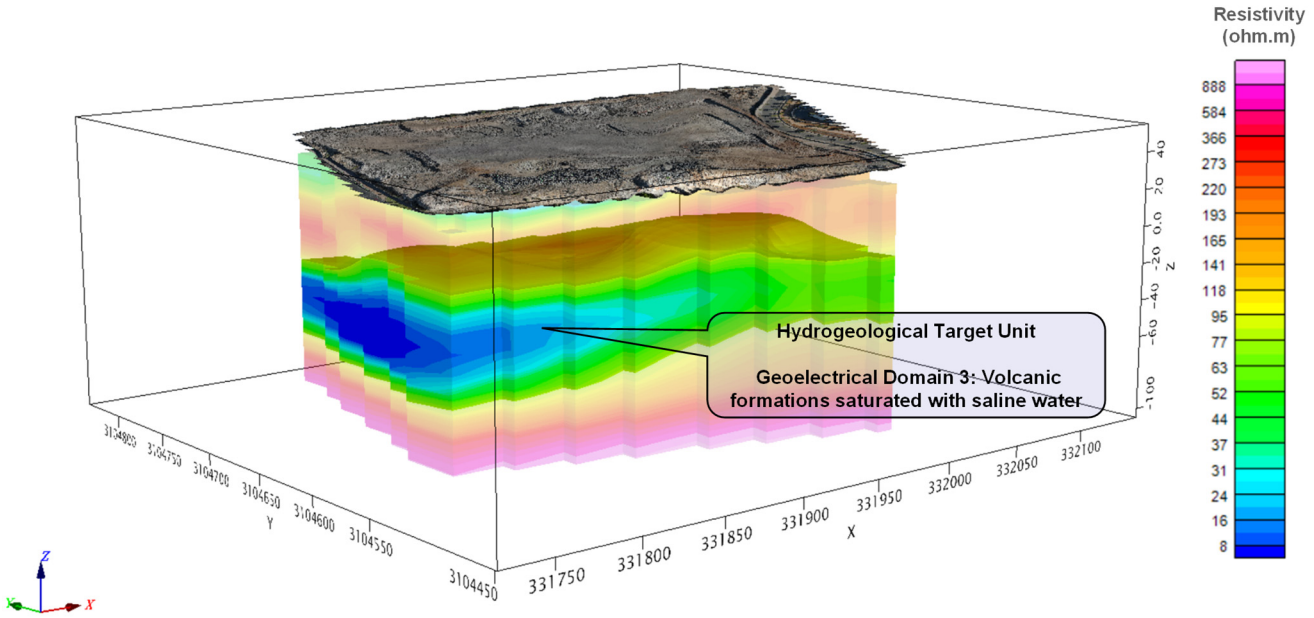


Figure 8. 3D isoresistivity model representing the geometry of the saline intrusion in the Los Cristianos sector.

3.4. Selection of Optimal Hydrogeological Drilling Zones

The integration of results into the three-dimensional model made it possible to identify optimal sectors for the drilling of new wells (Figure 9). These are located within the conductive domain (<20 Ω·m), where permeability increases as resistivity decreases, and where saline water ensures regulatory viability for subsequent exploitation and desalination.

These results are consistent with experiences in other volcanic islands, where drilling in transitional or conductive zones has proven to be more profitable and effective than in exclusively resistive horizons [29]. In particular, studies in the Azores and Cape Verde indicate that intermediate or conductive levels often act as preferential reservoirs for significant yields [26,28].

In the specific case of the Los Cristianos site, the preselected drilling area has proven suitable, although it is estimated that reaching a slightly greater depth than in other parts of the plot will be necessary to intercept the most representative thickness of the conductive domain. This adjustment in the projected drilling depth will increase the likelihood of success, ensuring sufficient yield and water quality suitable for desalination, thereby reinforcing the practical utility of the methodology applied in this study.

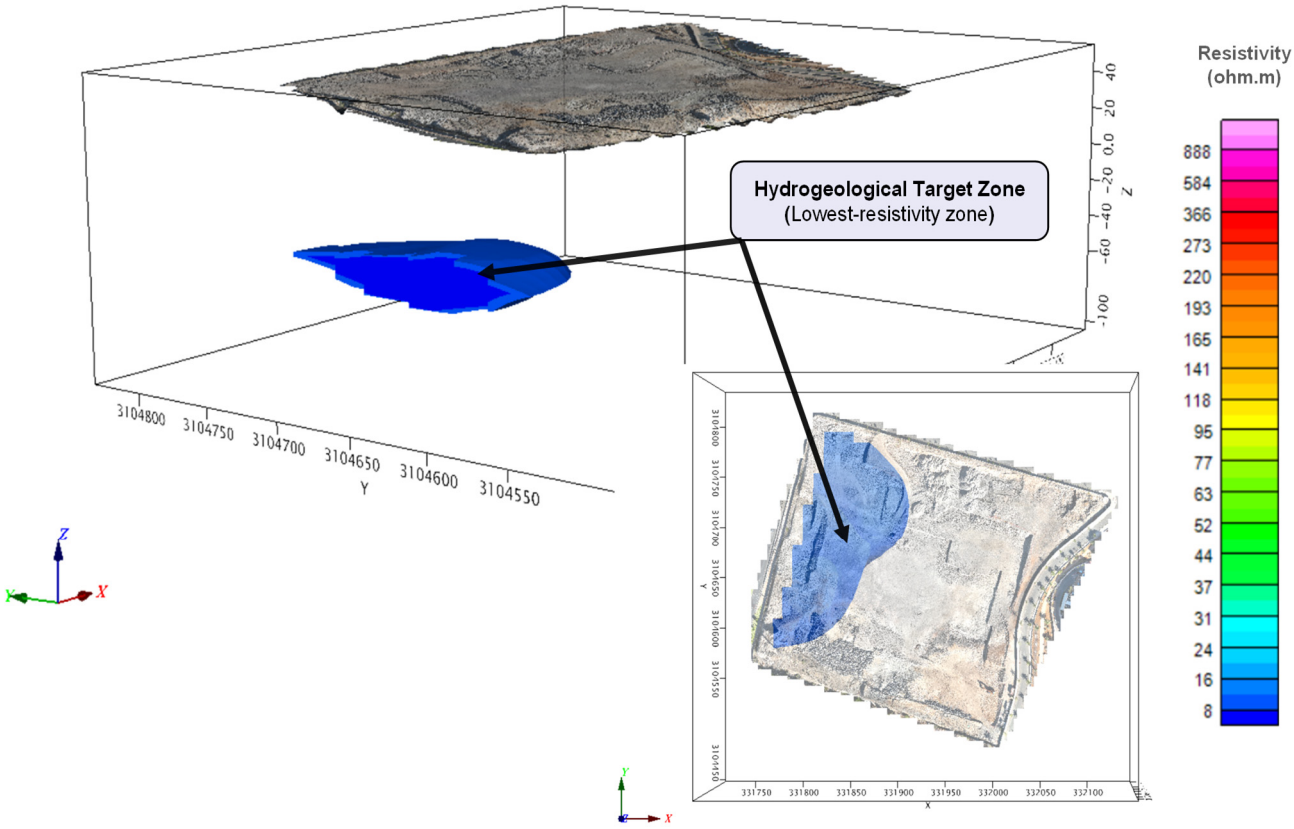


Figure 9. Location of the recommended drilling sector superimposed on the 3D resistivity model.

4. Discussion

4.1. Limitations of Electromagnetic Methods in Volcanic Environments

The results obtained in Los Cristianos confirm that direct current electrical methods (ERT) offer significant advantages over electromagnetic methods (TDEM, AEM) in volcanic settings. In sedimentary environments, EM methods have been widely and successfully applied for the detection of aquifers and saline intrusion fronts [5,6]. However, in volcanic contexts, the presence of strongly magnetized basalts, electromagnetic noise, high resistivity, overlapping lava flows, and lateral heterogeneity of the materials generate complex and often ambiguous EM responses [7,19].

Studies conducted in the Azores [26], Cape Verde [28], and Hawaii [27] highlight the difficulties of EM methods in accurately resolving the geometry of saline intrusions in volcanic systems. In such environments, Electrical Resistivity Tomography has become established as a more reliable alternative, being less sensitive to magnetic susceptibility and electromagnetic noise, while providing more stable resistivity images.

4.2. Effectiveness of ERT for Characterizing Saline Intrusion

ERT demonstrated a high capacity to differentiate geoelectrical domains in Los Cristianos. These results are consistent with international studies where resistivity values below 20 Ω·m have been systematically associated with marine intrusion [13,22].

In Tenerife, this finding is of particular importance, since regulations only allow the exploitation of saline waters intended for desalination [2]. Precisely identifying the position of conductive horizons is therefore not only a hydrogeological issue, but also a legal and economic requirement.

Comparisons with studies in Villafáfila (Spain) [30] and in the saline–evaporitic formation of Barbastro [21] confirm the usefulness of electrical resistivity as an indirect indicator of salinity, reinforcing the validity of the methodology applied in Los Cristianos.

4.3. 3D Modelling as a Decision-Support Tool

The three-dimensional interpolation performed with Oasis Montaj helped reduce the uncertainty associated with 2D inversions, providing a continuous volumetric resistivity model. This geomatic approach represents a key step toward the integration of geophysics into water resource management and planning processes. While the 3D model was internally validated through the consistency of both ERT profiles, additional validation using borehole or hydrochemical data is recommended. Such information would allow quantitative testing of the model and further reduce interpretive uncertainty.

In the literature, the importance of 3D models to overcome the limitations of one-dimensional or two-dimensional inversions has been repeatedly emphasized [9,16]. In Hawaii, for example, three-dimensional models derived from ERT have been used to establish recharge zones and to precisely delineate the saline wedge [27]. In Cape Verde, 3D interpolation has been fundamental in guiding drilling in touristic sectors with high demand [28].

The experience in Los Cristianos reinforces this notion: the identification of the geometry and resistivity of the conductive domain would not have been evident by analyzing individual profiles. Therefore, a 3D model enables a clearer visualization of the lateral continuity of conductive horizons and allows for more solid criteria when siting boreholes, which becomes increasingly relevant as subsurface models grow more complex or when more datasets must be integrated.

The resistivity–salinity correlation can support decision-making for groundwater management, particularly in desalination planning. Identifying zones of moderate salinity helps optimize reverse osmosis (RO) feedwater extraction, minimizing pre-treatment requirements and antiscalant dosing, which reduces operational costs and environmental impact. Furthermore, this approach allows optimizing the siting of boreholes, reducing the total number of wells required to ensure water supply and consequently lowering drilling and maintenance costs. In this volcanic island context, where the exploitation of freshwater lenses is restricted to prevent overextraction, targeting brackish rather than fully saline or fresh groundwater offers a sustainable and technically feasible alternative for desalination. Additionally, this information aligns with the regional regulatory framework that prioritizes sustainable freshwater abstraction in coastal aquifers of the Canary Islands.

4.4. Optimization of Drilling in Touristic Contexts

One of the main practical contributions of this study is the identification of optimal drilling zones within conductive domains. These zones ensure the presence of aquifers with sufficient permeability and, at the same time, connection to saline water as required by regulations.

From an economic perspective, this result is particularly relevant in touristic areas such as Los Cristianos, where the hotel sector demands large volumes of water and already has reverse osmosis infrastructure for treatment [3,18]. The ability to precisely locate boreholes and to reach the appropriate depth reduces exploration costs and increases the viability of projects.

4.5. Transferability of the Methodology

The approach applied in Los Cristianos is replicable in other volcanic environments with similar challenges. In the Azores, ERT has been employed to delimit marine intrusion in coastal aquifers, providing key information for the management of water abstraction [26].

In Cape Verde, the combination of ERT and 3D modelling has made it possible to identify exploitable saline aquifers in islands where EM methods had failed [28].

Likewise, in the Canary archipelago, the methodology can be applied in other coastal sectors where tourist pressure is high (e.g., Playa de las Américas, Puerto de la Cruz, Costa Teguise). Thus, ERT integrated into 3D models consolidates itself as a robust, efficient, and transferable tool, with the potential to become a standard for hydrogeological management in volcanic islands.

5. Conclusions

The case study developed in Los Cristianos (Arona, Tenerife) demonstrates that Electrical Resistivity Tomography (ERT), complemented by three-dimensional modeling, represents a highly valuable tool to address one of the most significant challenges in groundwater management in volcanic islands: the detection and characterization of marine intrusion. Throughout the investigation, it has been shown that in contexts where electromagnetic methods present inherent limitations due to basalt magnetization, electromagnetic noise, high resistivity, and the structural heterogeneity of the terrain [7,19], electrical methods provide a more robust and consistent alternative, capable of clearly discriminating between resistive and conductive domains.

The results obtained not only make it possible to establish the geometry of saline intrusion, but also, when integrated into a three-dimensional geomatic framework, provide a continuous spatial representation that reduces interpretive uncertainty and facilitates strategic decision-making [16,25]. In this sense, the applied methodology does not merely provide geophysical information but constitutes a genuine bridge between scientific knowledge and water management practice in volcanic territories.

The relevance of this approach is particularly significant in the Canarian regulatory context, where the exploitation of groundwater is only viable if it presents high salinity levels, a prerequisite for subsequent desalination through reverse osmosis [2]. The ability to accurately locate saline horizons thus becomes a decisive factor in ensuring the technical and legal feasibility of new abstractions, especially in regions under strong touristic pressure such as southern Tenerife [3,18].

This study also highlights that the selection of drilling points should not be approached solely from a hydraulic perspective, but also from the integration of geophysical criteria that allow the identification of transitions between resistive and conductive domains. The experience developed in Los Cristianos provides a replicable example for other volcanic island environments where water constitutes both a strategic and a vulnerable resource.

Ultimately, the research carried out allows us to affirm that the combination of ERT and 3D modeling not only responds to a local need, but also opens the door to a methodological framework applicable at a global scale. Its versatility and relatively low cost make this approach a competitive option compared to more sophisticated techniques that are difficult to implement in volcanic environments. In the future, integration with hydrochemical data, control boreholes, and temporal monitoring techniques will allow the methodology to be further refined, contributing to a dynamic monitoring of marine intrusion and to an adaptive management of water resources.

In conclusion, the Los Cristianos case study illustrates how applied geophysics, supported by geomatic tools, can become a central pillar of water sustainability in volcanic islands. The combination of science, regulation, and social demand reinforces the idea that electrical methods are not merely a technical resource, but a fundamental component in building a more balanced and resilient future in territories where water is both the greatest challenge and the key to development.

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References

1. Custodio, E. Groundwater in Volcanic Hard Rocks. In *Groundwater in Fractured Rocks*; Krásný, J., Sharp, J.M., Eds.; Taylor & Francis: London, UK, 2007; pp. 95–110. [CrossRef]
2. Gobierno de Canarias. *Normativa Sobre Aprovechamiento de Aguas Subterráneas en Canarias*; Boletín Oficial de Canarias: Tenerife, Spain, 2010.
3. Instituto Canario de Estadística (ISTAC). *Estadísticas de Turismo en Canarias 2023*; Gobierno de Canarias: Tenerife, Spain, 2024; Available online: https://www.gobiernodecanarias.org/istac (accessed on 25 September 2025).
4. Sheriff, R.E. *Geophysical Methods*; Prentice Hall: Englewood Cliffs, NJ, USA, 1989. Available online: https://archive.org/details/geophysicalmetho0000sher (accessed on 25 September 2025).
5. Fitterman, D.V.; Stewart, M.T. Transient Electromagnetic Sounding for Groundwater. *Geophysics* **1986**, *51*, 995–1005. [CrossRef]
6. Auken, E.; Christiansen, A.V.; Jacobsen, B.H.; Foged, N.; Sørensen, K.I. Piecewise 1D laterally constrained inversion of resistivity data. *Geophys. Prospect.* **2005**, *53*, 497–506. [CrossRef]
7. Spies, B.R. Depth of Investigation in Electromagnetic Sounding Methods. *Geophysics* **1989**, *54*, 872–888. [CrossRef]
8. Loke, M.H.; Barker, R.D. Rapid Least-Squares Inversion of Apparent Resistivity Pseudosections by a Quasi-Newton Method. *Geophys. Prospect.* **1996**, *44*, 131–152. [CrossRef]
9. Oldenburg, D.W.; Li, Y. Inversion of induced polarization data. *Geophysics* **1994**, *59*, 1327–1341. [CrossRef]
10. IGME. *Mapa Geológico de España, Hoja 110–Arona*; Instituto Geológico y Minero de España: Madrid, Spain, 1983.
11. Custodio, E.; Cabrera, M.C. Coastal Aquifers in Volcanic Islands: Hydrogeological and Hydrochemical Aspects. *Hydrogeol. J.* **2002**, *10*, 493–502. [CrossRef]
12. Flores, C.; Avilés-Esquivel, T.; Arango, C.; Salas, J.L. Seal Cap Resistivity Structure of Los Humeros Geothermal Field from DC and TDEM Soundings. *Geofís. Int.* **2022**, *61*, 351–371. [CrossRef]
13. Herckenrath, D.; Fiandaca, G.; Auken, E. Sequential and Joint Hydrogeophysical Inversion Using Coupled TDEM and Flow. Hydrol. *Earth Syst. Sci.* **2013**, *17*, 4043–4060. [CrossRef]
14. Behroozmand, A.A.; Auken, E.; Fiandaca, G.; Christiansen, A.V. Improvement in MRS Parameter Estimation by Joint and Laterally Constrained Inversion of MRS and TEM Data. *Geophysics* **2012**, *77*, WB191–WB200. [CrossRef]
15. Macnae, J.C. On Transient Electromagnetic Depth Sounding. *Geophysics* **1984**, *49*, 934–948. [CrossRef]
16. Constable, S.C.; Parker, R.L.; Constable, C.G. Occam's Inversion: A Practical Algorithm for Generating Smooth Models from Electromagnetic Sounding Data. *Geophysics* **1987**, *52*, 289–300. [CrossRef]
17. Geosoft. *Oasis Montaj: Geophysical Mapping and Modeling Software, Version 9.0*; Seequent: Toronto, ON, Canada, 2021.
18. Stumm, F.; Como, M.D.; Zuck, M.A. *Use of Time Domain Electromagnetic Soundings and Borehole Electromagnetic Induction Logs to Delineate the Freshwater/Saltwater Interface on Southwestern Long Island, New York, 2015–17*; U.S. Geological Survey Open-File Report 2020-1093; U.S. Geological Survey: Reston, VA, USA, 2020; 27p. [CrossRef]
19. Nabighian, M.N. *Electromagnetic Methods in Applied Geophysics*; Society of Exploration Geophysicists: Tulsa, OK, USA, 1988. [CrossRef]

20. Loke, M.H.; Dahlin, T. A Comparison of the Gauss–Newton and Quasi-Newton Methods in Resistivity Imaging Inversion. *J. Appl. Geophys.* **2002**, *49*, 149–162. [CrossRef]
21. Porras, D.; Carrasco, J.; Carrasco, P.; Herrero-Pacheco, J.L. A Case Study of the Barbastro Saline-Evaporitic Formation Using Deep TDEM. *Appl. Sci.* **2023**, *13*, 6385. [CrossRef]
22. Sasaki, Y. Resolution of resistivity tomography inferred from numerical simulation. *Geophys. Prospect.* **1992**, *40*, 453–464. [CrossRef]
23. Nieto, I.M.; Carrasco García, P.; Sáez Blázquez, C.; Farfán Martín, A.; González-Aguilera, D.; Carrasco García, J. Geophysical Prospecting for Geothermal Resources in the South of the Duero Basin (Spain). *Energies* **2020**, *13*, 5397. [CrossRef]
24. Carrasco-García, J.; Porras-Sanchiz, D.; Carrasco-García, P.; Herrero-Pacheco, J.L.; Martín-Nieto, I.; Benito-Herrero, J.M.; Huerta-Hurtado, P. Time-Domain Electromagnetics as a Geophysical Tool in Hydrogeological Exploitation Projects in Mesozoic Formations. *Appl. Sci.* **2022**, *12*, 8655. [CrossRef]
25. Tarantola, A. *Inverse Problem Theory and Methods for Model Parameter Estimation*; SIAM: Philadelphia, PA, USA, 2005. [CrossRef]
26. Cruz, J.V.; Coutinho, R.M.; Cymbron, R.; Freire, P.; Antunes, P. Groundwater Salinization in Volcanic Islands: The Azores Case Study. *Environ. Earth Sci.* **2010**, *61*, 1531–1541. [CrossRef]
27. Rotzoll, K.; El-Kadi, A.I. Estimating Hydraulic Properties from Head Observations in a Basaltic Aquifer, Oahu, Hawaii. *Hydrogeol. J.* **2008**, *16*, 1057–1069. [CrossRef]
28. Gonçalves, R.; Farzamian, M.; Monteiro Santos, F.A.; Represas, P.; Mota Gomes, A.; Lobo de Pina, A.F.; Almeida, E.P. Application of Time-Domain Electromagnetic Method in Investigating Saltwater Intrusion of Santiago Island (Cape Verde). *Pure Appl. Geophys.* **2017**, *174*, 4171–4182. [CrossRef]
29. Ward, S.H.; Hohmann, G.W. Electromagnetic Theory for Geophysical Applications. In *Electromagnetic Methods in Applied Geophysics*; Nabighian, M.N., Ed.; SEG: Tulsa, OK, USA, 1988; pp. 131–311. [CrossRef]
30. Huerta, P.; Carrasco-García, P.; Armenteros, I.; Recio, C.; Carrasco-García, J.; Rodríguez-Jiménez, E. TDEM Soundings as a Tool to Determine Seasonal Variations of Groundwater Salinity (Villafáfila Lakes, Spain). *Water* **2022**, *14*, 1452. [CrossRef]

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