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Identification and Mapping of Groundwater Dependent Ecosystems in the AZORES Volcanic Archipelago (Portugal)

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Abstract: Groundwater contributes to the maintenance of the functioning of ecosystems, through aspects related to hydrodynamics and chemical composition. Groundwater-dependent ecosystems (GDE) also offer a wide spectrum of ecosystem services to populations; therefore, their identification and mapping, which is the focus of the present paper, is of high value to environmental policies; for example, WFD envisages protecting both water bodies and GDE. An ecosystem dependence index was applied to proceed with this task in the Azores archipelago, being estimated by adding the values of three partial variables (spring density; wetlands/lakes; river baseflow) over a 10 by 10 m^2 grid; with this methodology avoiding pitfalls due to lack of data. The results enabled the identification and mapping of five GDE, in Flores and São Miguel islands, supported by only three of the 28 groundwater bodies delimited in the Azores RBD. Those groundwater bodies are considered to have a good status according to the WFD requirements; thus, GDE, regardless of their typology, are not at risk of deterioration as a result of the interaction with groundwater. Nevertheless, other studies have shown that some GDE are in conflicting ecological areas and require specific management and protection measures, coupling land use and water resource planning.

Keywords: groundwater; groundwater-dependent ecosystems; volcanic aquifers; Azores

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1. Introduction

Ecosystems associated with freshwater aqueous bodies account for only about 1% of the area of planet Earth [1]. However, in contrast to this reduced territorial expression, these ecosystems correspond to a very high faunal fraction, comprising about 12% of all animal species and 40% of all fish species (WRI-UNEP 1998, in [1]).

Ecosystems whose composition, structure, and/or functioning depend on the supply of groundwater can be considered as groundwater-dependent ecosystems (GDE), depending on the fulfilment of a series of criteria [2]. GDE can have various natural expressions, such as springs, wetlands, lakes, and rivers, and this dependence can be seasonal or continuous, or even merely sporadic [3].

Groundwater contributes to the maintenance of the functioning of aquatic ecosystems, either through aspects related to hydrodynamics or through aspects associated with their respective chemical composition [1]. On the other hand, GDE offer a wide spectrum of ecosystem services to populations [3].

Often, as in the general context of ecosystems associated with freshwater water resources, GDE are of high value; thus, justifying the need to promote measures aimed at their protection [4]. This need has been recognized institutionally and legally in recent decades, a process dynamized by the European Union. Indeed, the legislation emanating from the European Union has multiple interactions with GDE, among which is the Water Framework Directive (WFD; Directive 2000/60/CE, from the European Parliament and the Council, of the 23 October). The WFD established a framework for joint action in the field of water policy for the European Union and, in this context, embodies a set of guidelines reflecting on GDE. In fact, in article 1 of the WFD, one of the objectives mentioned refers to the reversal of the degradation of aquatic ecosystems, as well as terrestrial ecosystems and wetlands directly dependent on groundwater.

The so-called groundwater directive (GD; Directive 2006/118/EC), from the European Parliament and of the Council, of 12 December, specified some aspects of the WFD, namely those arising from article 17 (associated to the prevention and control of groundwater pollution). An essential aspect of the GD corresponds to the assessment of the chemical status of groundwater bodies, to be carried out in relation to the thresholds defined for pollutants, groups of pollutants, and pollution indicators, for which the relationship between the groundwater body and surface water, terrestrial ecosystems, and associated wetlands is instrumental. On the other hand, GD establishes that for a groundwater body or a group of groundwater bodies, which are considered to be in a good chemical state, measures should be considered in order to protect aquatic and terrestrial ecosystems.

The Azores archipelago is made up of nine volcanic islands spread along a 600-km-long NW-SE trending lineament (Figure 1a). The archipelago is located near the triple junction between the North American, African, and Eurasian plates, according to a complex geodynamic setting [5]; and since the discovery and settlement of the archipelago in the early 15th century a total of 28 volcanic eruptions have taken place, both submarine and subaerial in nature [6], the last one being a submarine event in 1998–2000 [7]. In the Azores, groundwater is a key resource for human water supply, which relies almost entirely on abstraction in springs and drilled wells [8–10], and thus groundwater quality is an important subject of study.

The Azores archipelago was designated as the ninth River Basin District (RBD; so-called RH 9) in Portugal. The Azores RBD has a total of 10,045 km^2, of which 76.6% correspond to coastal waters (7693 km^2) and 23.4% to inland area. In the Azores RBD, a total of 63 surface water bodies (10 rivers; 23 lakes; 3 transitional; 27 coastal) and 54 groundwater bodies were delimited [8]. In the 1st and 2nd planning cycles of the RBMP of the RH9, 54 groundwater bodies were delimited, and no GDE were identified, even in cases where some groundwater bodies were classified as being in poor chemical status on the islands of Graciosa and Pico. In the actual RBMP, currently in approval, the number of groundwater bodies was reduced to 28, but, again, no groundwater dependent ecosystems were identified [11].

The objectives of the present paper were to proceed, for the first time, to the identification and mapping of GDE throughout the Azores archipelago; thus, fulfilling the aforementioned gap. These findings are of societal interest and are essential for water management in the archipelago and other volcanic regions worldwide.

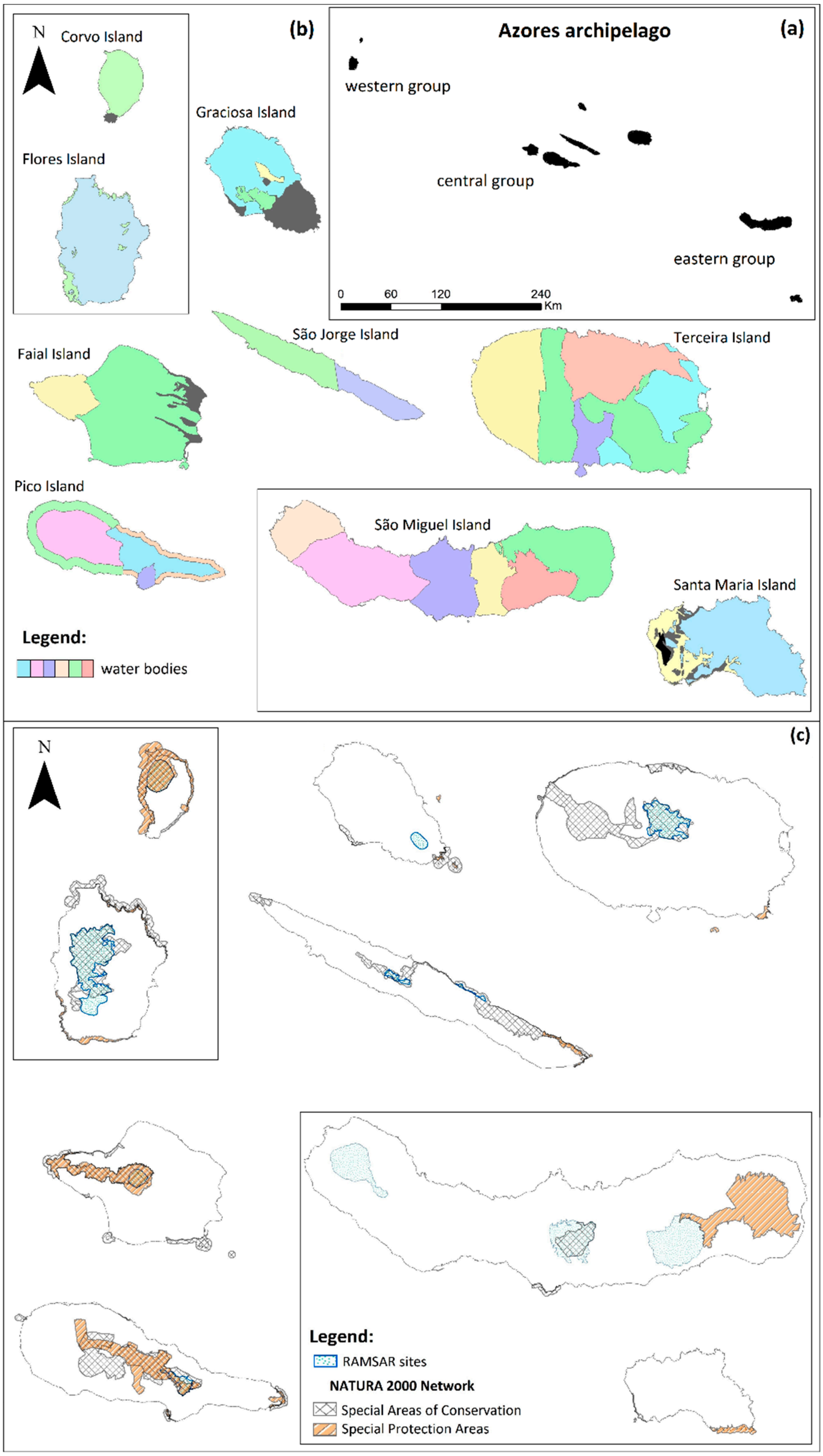

Figure 1. Mapping of the study area: (**a**) Azores archipelago vie; (**b**) groundwater bodies delimited in the Azores River Basin District; (**c**) Special Areas of Conservation and Special Protection Areas included in the Natura 2000 network.

2. Materials and Methods

2.1. Study Area

2.1.1. Geological and Hydrogeological Setting

All the islands in the Azores archipelago are of volcanic nature, the oldest island dating from the late Miocene, with subaerial lava flows dated from 5.7 Ma [12] to 8.12 Ma [13]. The islands are spread over a complex geodynamic setting, near the triple junction between North American, African, and Eurasian lithospheric plates, this context being reflected by intense seismic and volcanic activities [14].

The dominant volcanic activity responsible for the island's formation was highly variable, ranging from effusive to highly explosive eruptions, resulting in diverse geological features within the islands. In islands such as Santa Maria, Pico, and São Jorge, Hawaiian and Strombolian-type eruptions were dominant, with extensive areas dominated by basaltic lava flows and pyroclastic deposits of the same nature, while on other islands, such as São Miguel, Terceira, Faial, and Graciosa, more explosive eruptions took place. On these latter islands, more evolved rocks and volcanic forms are also observed, such as trachytic domes, pumice fall deposits, ignimbrites, and other pyroclastic flow deposits.

Despite being highly variable in the archipelago, mean annual precipitation in the Azores averages 1930 mm/yr, exceeding by far the mean annual actual evapotranspiration (581 mm/yr) [15]. Values are in the range of 966 mm/yr (Graciosa Island) to 2647 mm/yr (Flores Island) and 502 mm/yr (São Jorge Island) to 632 mm/yr (Flores Island), respectively, for mean annual precipitation and evapotranspiration ranges [15].

Recharge rates are in the range of 8.5% to 62.1% of the average precipitation, the higher values occurring in areas characterized by a sparse soil cover over young basaltic lava flows that are also frequently fractured [9,16]. The estimated groundwater resources in the Azores are about 1580 $\times$ 10^6 m^3/yr, in the range of 8.3 $\times$ 10^6 (Corvo island) to 582 $\times$ 10^6 m^3/yr (Pico Island; [9,16]). Values above the median (101.3 $\times$ 10^6 m^3/yr) are observed in islands such as São Miguel, São Jorge, Terceira, and Flores.

Surface runoff is usually of torrential nature and is estimated to be in the range of 1.30 $\times$ 10^7 m^3/yr (Corvo island) to 2.77 $\times$ 10^8 m^3/yr (Pico Island). Permanent rivers are only observed in the islands of Santa Maria, São Miguel, Faial, and Flores, and river discharge is strongly dependent of baseflow contribution, which can account for up to 87% of the total river flow [17].

Groundwater in the Azores occurs in two main types of aquifers, namely perched-water bodies, corresponding to confined or leaky altitude aquifers, which explain the existence of numerous springs spread over the flanks of volcanic edifices, and basal aquifers, which mainly occur in the coastal zone, characterized by a very low hydraulic gradient [16,18]. Specific well capacity in wells drilled in basal aquifers range from 1.40 $\times$ 10^{-2} to 266.67 L/s.m (median = 32.29 L/s.m), the higher values being in fresh and fractured young basaltic lava flows, frequently interbedded with clinker levels [16]. The median value for transmissivity is equal to 3.7 $\times$ 10^{-2} m^2/s [16].

Water supply in the Azores is based on groundwater-fed systems, in seven of the nine islands being totally dependent on aquifers, and groundwater abstraction sums up a total of 4.67 $\times$ 10^7 m^3/yr; a much higher value when compared to surface water abstraction (7.94 $\times$ 10^5 m^3/yr). This abstraction mainly occurs in perched-water body springs, as well as in drilled wells in seven of the nine islands, except for Flores and Corvo islands, with the latter in basal aquifers.

Nowadays, a total of 28 groundwater bodies are delimited in the RH9, according to the requirements of the WFD (Figure 1b), from which 10.7% are in poor chemical status, due to coastal aquifer salinization, namely in Graciosa and Pico [11]. Salinization is one of the main concerns regarding groundwater quality in the Azores [19–21].

Besides salinization, other groundwater quality problems are of concern, presenting a local impact in some areas, such as nutrient and microorganism fecal pollution, due to agricultural activity and untreated wastewater discharges [10,22,23], or high fluoride content in São Miguel [24] and Terceira [25], associated with volcanic influences. The interaction between groundwater and volcanic activity is also shown by numerous mineral water discharges, spread in seven of the nine islands, except for Corvo and Santa Maria islands, from cold CO_2-rich mineral springs, to boiling pools [26,27].

2.1.2. Nature Conservation Setting

The Natura 2000 Network consists of an ecological structure that resulted from the implementation of the 'Birds' and 'Habitats' EU Directives of the Council Directive 79/409/EEC, of 2 April (and subsequent amendments) and Council Directive 92/43/EEC, issued in 21 May (and subsequent amendments), respectively. It is a European ecological network whose objectives are to ensure biodiversity, through the conservation or restoration of natural habitats and wild fauna and flora to a favorable state of conservation, as well as the protection, management, and control of species. The Natura 2000 Network comprises areas classified as Special Protection Areas (SPAs), under the Bird Directive, and Sites of Community Importance, under the Habitats Directive; meanwhile, they are classified as Special Areas of Conservation (SACs) after formal adoption.

In the Azores, the Natura 2000 Network comprises 41 areas (~80,418 ha), of which 3 are Sites of Community Importance (30,660 ha), 23 are SACs (33,569 ha), and 15 are SPAs (16,190 ha), covering marine and terrestrial areas (Figure 1c).

Under the Ramsar Convention (Convention on Wetlands of International Importance) a total of 13 areas were designated as Ramsar Sites (13,000 ha) (Figure 1c). According to the convention, the classification of these sites should enhance the sustainable use of wetlands through land use planning, the development of policies, and the publication of legislation aimed at protecting wetlands and the species that inhabit them and carrying out management and education actions for populations in these zones.

2.2. Methodology

Within the scope of the technical studies to define the common strategy for the implementation of the WFD, the European Commission produced some guidance documents regarding GDE, both for groundwater associated aquatic ecosystems (GWAAE) [28] and for terrestrial ecosystems dependent on groundwater (GWTDE) [29,30]. Henceforth, in the present study, this dichotomy between GWAAE and GWTDE is followed, assuming the basic definitions deriving from the aforementioned reports. Thus, an GWAAE corresponds to an ecosystem comprising one or more bodies of surface water (rivers, lakes, transitional, and coastal waters), whose ecological or chemical status may suffer negative impacts resulting from changes in the groundwater level or due to the introduction of pollutants carried by groundwater [28]. As a result, deterioration of GWAAE may result in the designation of the associated groundwater body as in poor status. Instead, an GWTDE corresponds to ecosystems directly dependent on a body of groundwater, the latter of which must provide groundwater in quantity, either by flow or by maintaining the water table, and quality, to maintain the ecosystem [29]. It should be noted that the delimitation of GWTDE is a very difficult task, because, due to the ecological continuum, the boundary between ecosystems dependent on groundwater and those dependent on other sources of water is not always clear [29].

During the elaboration of the 1st generation of RBMP, it was found that in most EU member states the starting point for the identification of ecosystems dependent on groundwater was the delimitation of areas considered within the scope of the Natura 2000 Network and subsequently formed based on the opinion of experts and on the hierarchy of wetlands that could be designated as GWTDE [30].

Within the scope of the 2nd planning cycle of the RBMP for mainland Portugal, the methodology used to identify GDE was homogenized. The approximation carried out was based on the sites designated by the Natura 2000 Network (SPAs and SACs, respectively listed under the Birds Directive and the Habitats Directives) and by the Ramsar Convention, as well as the establishment of hydrogeological and ecological criteria. The weighted hydrogeological criteria were the slope, the climatology, the water balance (P-ETR), the hydrogeological environment, and the depth of the water level; while in the case of the ecological values, the stygofauna, the priority flora, and the habitats were evaluated. However, it should be noted that, in the case of the Azores River Basin District, some of the hydrogeological criteria mentioned have not been mapped so far, such as the water level of groundwater bodies; therefore, this methodology has proven impossible to apply, without having to apply exaggerated simplifications.

In recent years, some approaches to the identification of GDE have been published in the national and international technical-scientific literature, at different scales, from the adoption of automatic GIS mapping criteria of hydrogeological and ecological variables [31–33], to the development of groundwater flow models [34] or remote sensing techniques [35,36].

Considering the various methodological approaches applied worldwide and considering the scarce basic information available on some hydrogeological variables, in particular the quantitative status of groundwater bodies, which is severely limited by the lack of monitoring data on groundwater levels or spring discharge, which in turn limits the application of numerical models, it was decided in the present study to adapt and implement the solution proposed by [32]. This methodology, developed in a study concerning the state of California (USA), is based on the processing of georeferenced data in GIS, and has proven to be particularly useful for territories where the monitoring of groundwater resources is insufficient.

The adaptation of the methodology proposed by [32] was carried out in the present study based on the consideration of three distinct variables (spring density; wetlands/lakes; river baseflow) over a 10 by 10 m^2 grid, classified according to five successive categories that correspond to classes with a similar interval (Table 1). The ecosystem dependence index was computed through the sum of the values of the three partial variables, following the categorization into five classes (0—not applicable; 1—very low; 2—low; 3—moderate; 4—high), the first of which with a smaller interval compared to the distribution of values by quartiles (Table 2). Within the scope of the present work, it is considered that only ecosystems corresponding to the moderate and high index categories should be designated as GDE.

The variable spring density, which measures the occurrence of natural groundwater discharges, is analyzed according to the respective spatial density. A spring is any point at which groundwater emerges from the surface of the ground, or in the vicinity of the land–atmosphere or land–water interface, and, thus, corresponds to a place where a given aquifer discharges giving rise to a visible flow [37,38]. The geomorphological framework of some springs allows these emergencies to support numerous microhabitats and a wide variety of aquatic, riparian, and wetland animal and plant species [37].

The existence of wetlands and lagoons (regardless of the hydrological regime) are potential areas of interaction between surface water and groundwater, which can give rise to dependent ecosystems.

The connection between surface water and groundwater is common in most wetlands and lakes [39], and the interaction between wetlands and groundwater determines water quality and the geochemical balances that are established [40], and, thus, even if indirectly, it is crucial for the maintenance of ecosystems. In this variable, the occurrence of coastal lagoon systems was also considered, as they correspond to ecosystems dependent on brackish water, resulting from the mixing of seawater with groundwater inputs [41]. In this context, within the scope of this variable, the occurrence of the coastal Lagoas dos Cubres and Santo Cristo (São Jorge Island), which are classified as transitional water bodies, and the lagoon systems in the municipality of Praia da Vitória (Terceira Island), in particular the Paul da Praia da Vitória, were accounted for.

The third variable corresponds to the contribution of groundwater to the total flow of permanent rivers in the RH9 and is analyzed as a function of the fraction of the total flow that corresponds to the base flow; thus, contributing to maintaining ecosystem status.

Table 1. Variables considered for the determination of groundwater dependent ecosystems in RH9, data source and respective categorization into five classes (0—not applicable; 1—very low; 2—low; 3—moderate; 4—high). All the variables correspond to GIS layers, the one associated to Wetland/Lakes being derived from satellite imagery, as described in the original source.

Variables	Description/Source	Classes
Spring density	RBMP—Azores [9].	0: 0 springs/100 m^2 1: (0.001–0.05 springs/100 m^2) 2: (0.05–0.10 springs/100 m^2) 3: (0.10–0.15 springs/100 m^2) 4: (0.15–0.20 springs/100 m^2)
Wetland/Lakes	Classes 411 (wetlands) and 512 (lakes) from the satellite Azores land use map [42]; the lake located inside the so-called Furna do Enxofre volcanic cave (Graciosa Island) was added according to the mapping by [43]	0: 0 m^2/100 m^2 1: (0.001–25 m^2/100 m^2) 2: (25–50 m^2/100 m^2) 3: (50–75 m^2/100 m^2) 4: (75–100 m^2/100 m^2)
Baseflow	Base flow was estimated through the application of the software BFI+ v.s 3.0 [44] on the average daily flow data recorded in the various hydrometric stations that make up the Hydrometeorological Network of the Azores	0: 0%/100 m^2 1: (0.001–20%/100 m^2) 2: (20–40%/100 m^2) 3: (40–60%/100 m^2) 4: (60–80%/100 m^2)

Results obtained by classes, and in particular the respective spatial distribution, were latter combined with the sites of the Natura 2000 and the Ramsar Network, to access their potential correspondence to GDE, also enabling a further description of the ecosystems.

Table 2. Classes adopted for the ecosystem dependence index.

Value	Designation
0	Not applicable
1–2	Very low
3–4	Low
5–8	Moderate
9–12	High

3. Results and Discussion

Mapping for the three variables that make up the ecosystem dependence index is shown in Figures 2–4. The histograms shown in Figure S1 depict the reduced spatial representation of the three partial variables. Regarding the spring density variable and considering the classification shown in Table 1, in most of the islands the spatial representativeness is very low, as class 1 represents less than 0.01% of the islands area. Only in São Miguel Island, does the area occupied by class 1 correspond to 0.01% (0.04 km^2), the values for classes 2 to 4 being lower than 0.01%. These results reflect the spring distribution pattern depicted in Figure 2.

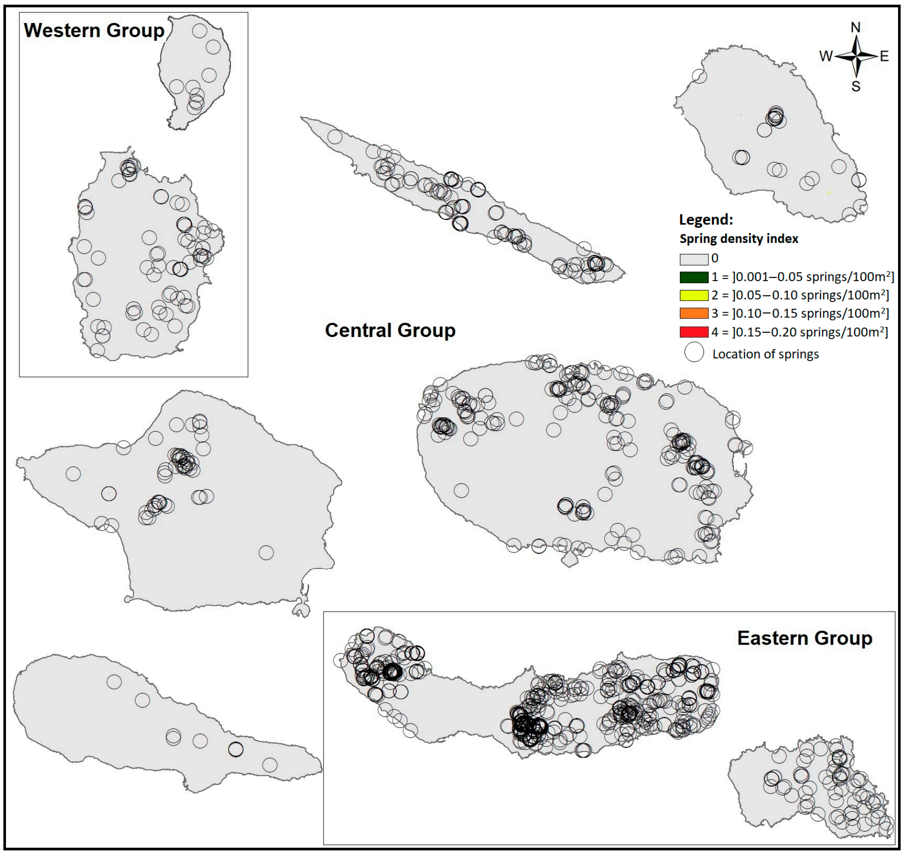

Figure 2. Mapping of the variables that compose the ecosystem dependence index: spring density.

Considering the baseflow variable spatial representativeness, the class with the highest values was only observed in São Miguel and Flores, with fractions of the total area of the islands equal to 5.75% (42.72 km^2) and 3.16% (4.46 km^2), respectively. Class 3 is also observed in Flores (5.46%; 7.70 km^2), Santa Maria (2.89%; 2.80 km^2), and São Miguel (1.96%; 14.62 km^2) islands. In the remaining islands, which are characterized by a surface runoff of torrential nature, this variable has no spatial representativeness (Figure 3).

The third variable is the most widely represented in the territory of the various islands (Figure 4), the highest areal fractions for class 4 being observed in Flores (17.28%; 24.36 km^2) and Corvo (8.04%; 1.38 km^2) islands, despite values in the range from 2.62% to 3.48% for São Miguel, Terceira, Pico, and São Jorge islands. In islands such as Santa Maria, Graciosa, and Faial this variable presents a rather low spatial representativeness.

The ecosystem dependence index, computed through the sum of the values of the three partial variables, and the final mapping is provided in Figure 5. The fraction of the island area occupied by each of the classes considered is shown in Table S1 (electronic supplementary material). The results obtained show that only on the islands of São Miguel and Flores are there values of the dependency index classified as moderate, corresponding to a fraction of the surface area of the island equal to 0.57% (4.26 km^2) and 3.41% (4.81 km^2), respectively (Table S1 and Figure 6). It should be noted that in the case of the island of São Miguel, there are index values that are occasionally classified as high, essentially when there are groundwater springs in the vicinity, corresponding to an overall fraction of the area of the island lower than 0.01%. Index values classified as low occupy an area of the islands of Flores, São Miguel, and Corvo equal to, respectively, 19.24% (27.12 km^2), 9.21% (68.63 km^2), and 8.13% (1.39 km^2), while on Graciosa Island, the value is as high as 0.02% (0.01 km^2).

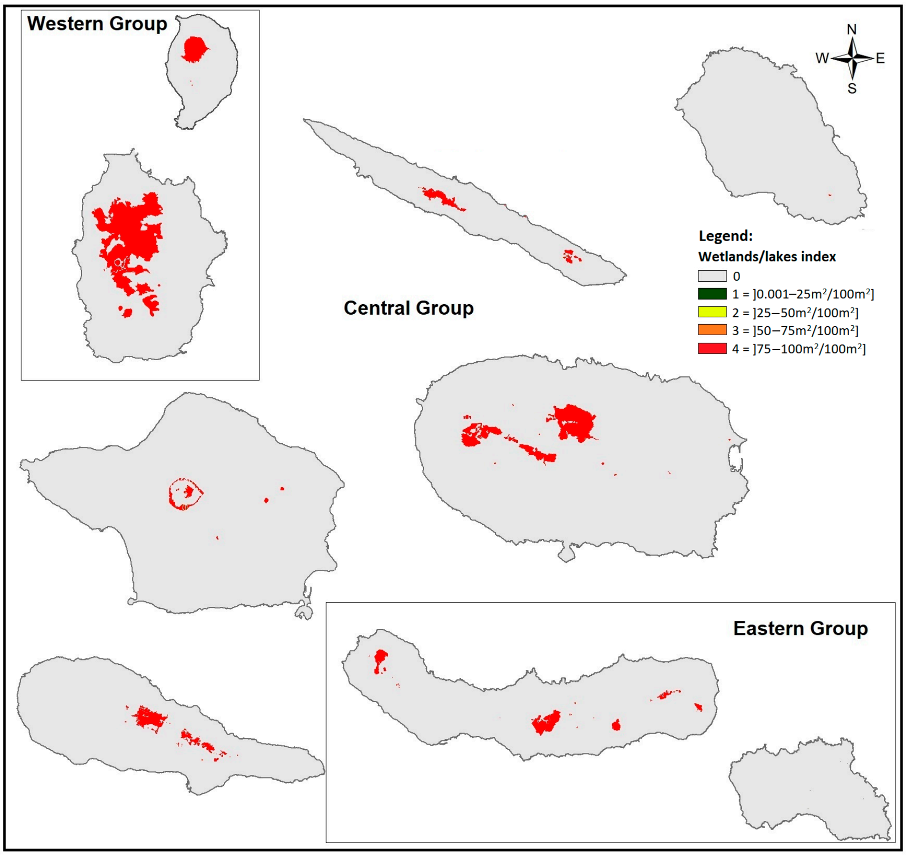

Figure 3. Mapping of the variables that compose the ecosystem dependence index: wetlands/lakes.

In most islands, excluding the null values, the predominant class is the reduced index, which occupies a fraction of the area between a minimum of 0.02% (Graciosa) and a maximum of 19.24% (Table S1 and Figure 6). On the other hand, on the island of Santa Maria, the predominant class, once again excluding values equal to zero, corresponds to a reduced dependence index, which corresponds to a percentage of the total area equal to 8.64% (Table S1 and Figure 6).

The combination of the results of the dependency index with the sites of the Natura 2000 and Ramsar Network allows, not only refining the analysis undertaken, which led to the computation of the dependency index and the identification of potential ecosystems, but also to proceed with their characterization, including the legal figures that promote their protection. Thus, according to the respective typologies, and considering all the information compiled, it is proposed that within the scope of the RH9 planning and management work, five GDE should to be listed; comprising two GWAAE, associated with the upstream sections of the rivers Grande and Badanela (respectively GDE1 and GDE2 on Figure 5), both on Flores island; and three GWTDE, all located on the island of São Miguel and corresponding to wetlands (GDE3—Pico da Vela; GDE4—Planalto dos Graminhais; GDE5—Serra da Tronqueira (V.G. Bartolomeu; Figure 5)).

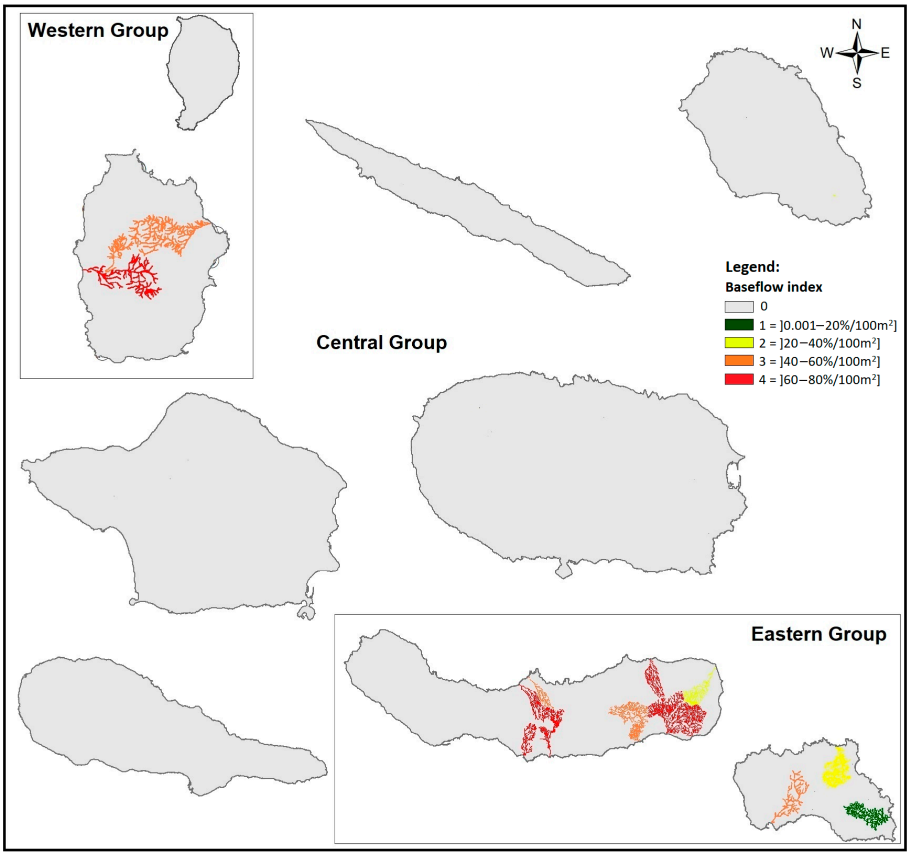

Figure 4. Mapping of the variables that compose the ecosystem dependence index: river baseflow.

Both GWAAE in the Flores Island are in the Natura 2000 network ZEC PTFLO0002 (Zona Central—Morro Alto) and in the Ramsar site 1806 (Planalto Central das Flores—Morro Alto), corresponding to a moderate dependence index (Figure 5). In the Flores Island the ecosystem dependence index is particularly dominated by the baseflow, as groundwater can account for about 63% of the total river flow [17], and wetlands/lake variables, and reflects the role of groundwater in the hydrological regime of the island, as already pointed out by [16,45].

The GWTDE on São Miguel are mainly located in the central and the westernmost areas of the island. GDE3 is located in the Natura 2000 network ZEC PTMIG0019 (Lagoa do Fogo) and in the Ramsar site 1803 (Complexo Vulcânico do Fogo), while GDE4 and GDE5 are located in the ZPE PTZPE0033 (Pico da Vara/Ribeira do Guilherme). These GWTDE mainly correspond to an ecosystem dependence index classified as moderate, of which the baseflow and wetlands/lakes variables are by far the largest terms of the final sum. Nevertheless, in the case of GDE3, there are sparse areas with a high dependency ratio, generally resulting from the location of springs. In addition to Flores Island, groundwater plays a crucial role in the hydrological functioning of São Miguel [46]. Besides the referred GDE, it should be noted that, associated to the numerous mineral and thermal water discharges spread along seven of the nine islands in the archipelago [26,27], some other smaller areas may represent GDE due to their microbial characteristics [47].

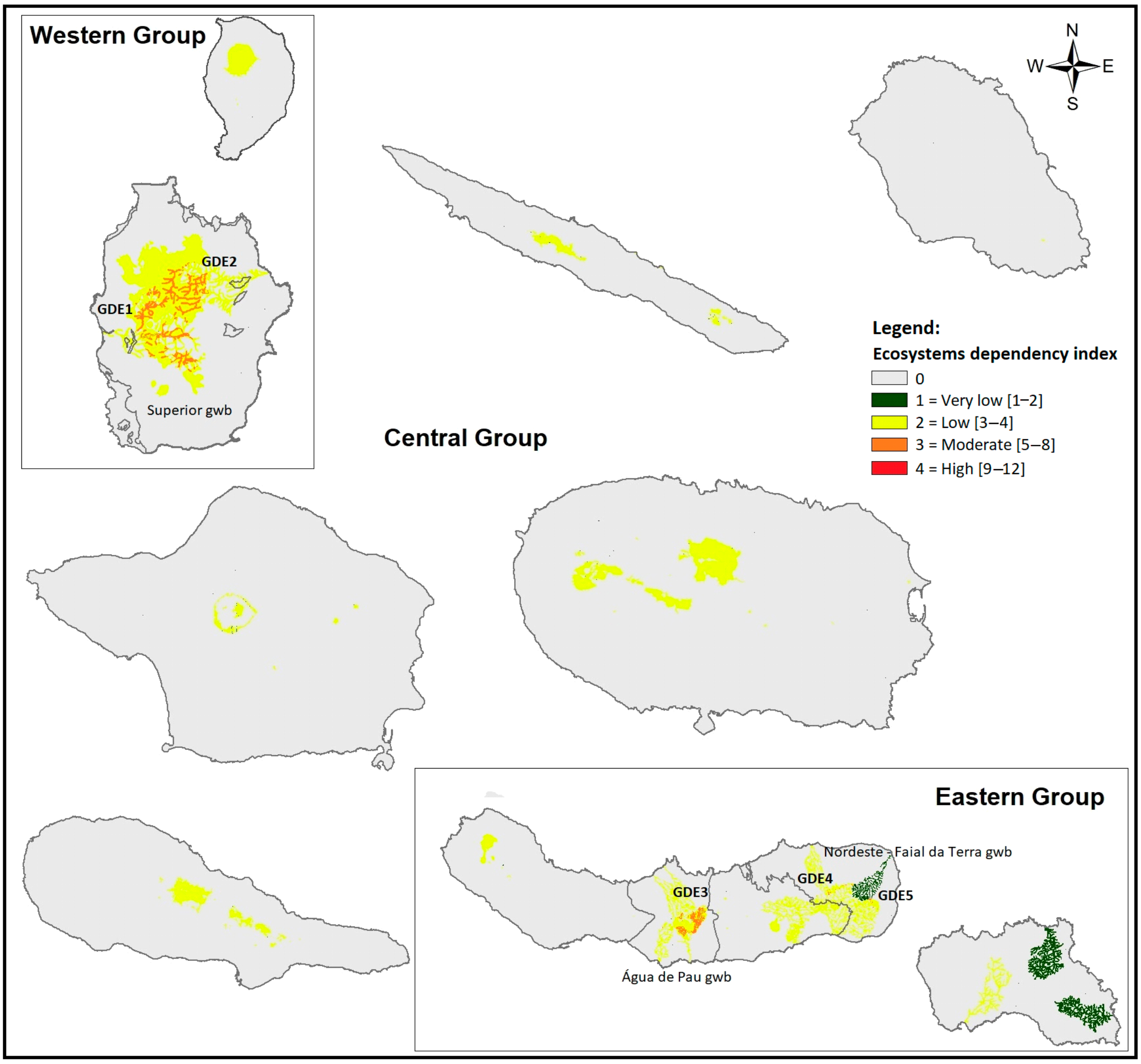

Figure 5. Mapping of the ecosystem dependence index in the Azores River Basin District.

Only three groundwater bodies support GDE, namely on Flores Island the upper groundwater (PT09FLOGWSUP1), and on São Miguel Island the Água de Pau (PT09SMGGWAP) and Nordeste—Faial da Terra (PT09SMGGWNFT) bodies (Figure 5). Taking into account that all three groundwater bodies are considered to have a good status according to the WFD requirements, it is considered that the GDE, regardless of their typology, are not at risk of deterioration as a result of the interaction with groundwater, either as a result of possible quantitative or qualitative pressures.

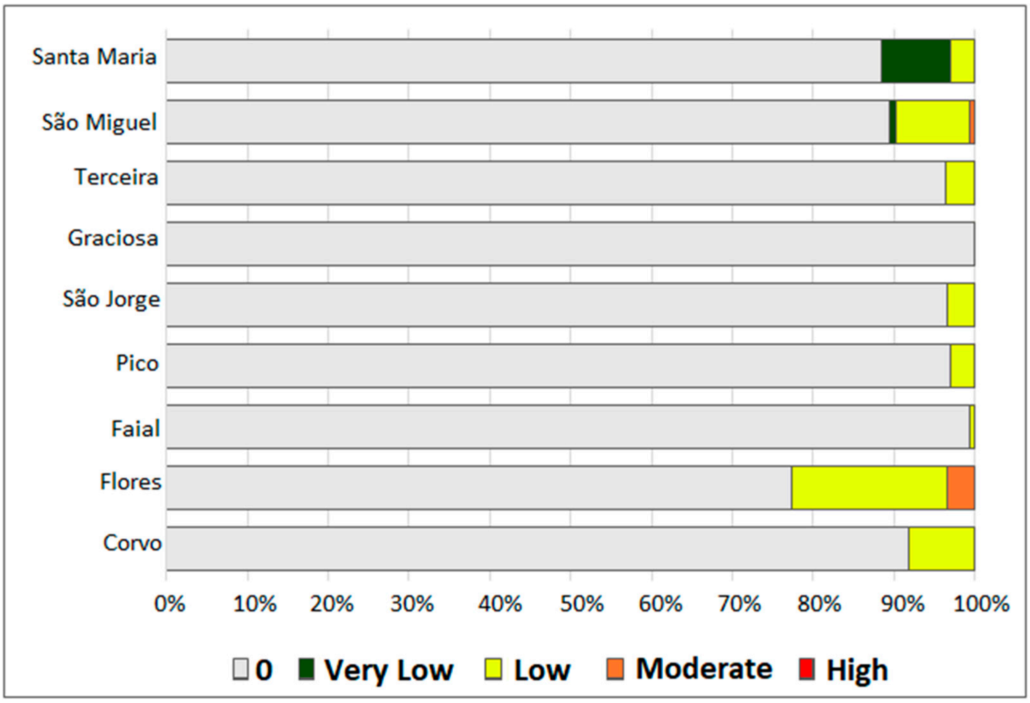

Figure 6. Fraction of the area of each island in the Azores occupied by the various classes of the ecosystem dependence index.

4. Conclusions

A recent survey made in the Azores by 43 specialists has shown the need to, besides the role of groundwater in water supply, increase awareness on groundwater valuing and protection [48]. This need results from the various environmental and socioeconomic impacts that can emerge from groundwater development, among which is degradation of dependent ecosystems [49,50].

In this context, the identification of GDE in two of the nine islands of the Azores archipelago indicates the need for implementing measures to preserve the groundwater bodies that support those dependent ecosystems, despite the fact that currently those units are considered to have a good status according WFD criteria. However, it should be pointed out that GDE diversity implies that management and protection measures have to be adapted to fit specificities, such as ecological water requirements [4]. This latter aspect is stressed, as GDE4 and GDE5, both in São Miguel Island, are in sensitive and conflicting ecological areas; thus, demanding specific land use planning [51], coupled with water resource tools. Further studies should address the biocenosis of the identified GDE, as well as consider adding new variables, such as a layer related to the distribution of vegetation types, when available.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/w14071126/s1, Figure S1: Histograms of the territorial expression of the variables (by classes) that make up the ecosystem dependence index in the Azores archipelago, as a function of the fraction of the area of each island (a—spring density; b—wetlands/lakes; c—baseflow), Table S1: Territorial expression of the ecosystem dependence index (by classes) in the Azores archipelago, as function of the fraction of the area of each island.

Author Contributions: Conceptualization, J.V.C. and C.A.; methodology, J.V.C., C.A. and R.C. (Rui Coutinho); software, C.A.; investigation, J.V.C. and C.A.; validation, J.V.C., C.A., R.C. (Rui Coutinho), D.M. and R.C. (Raquel Cymbron); writing—original draft preparation, J.V.C. and C.A.; writing—review and editing, J.V.C., C.A. and R.C. (Rui Coutinho); visualization, C.A.; supervision, J.V.C. All authors have read and agreed to the published version of the manuscript.

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