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*Review*

# The Issue of Groundwater Salinization in Coastal Areas of the Mediterranean Region: A Review

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**Abstract:** The Mediterranean area is undergoing intensive demographic, social, cultural, economic, and environmental changes. This generates multiple environmental pressures such as increased demand for water resources, generation of pollution related to wastewater discharge, and land consumption. In the Mediterranean area, recent climate change studies forecast large impacts on the hydrologic cycle. Thus, in the next years, surface and ground-water resources will be gradually more stressed, especially in coastal areas. In this review paper, the historical and geographical distribution of peer-review studies and the main mechanisms that promote aquifer salinization in the Mediterranean area are critically discussed, providing the state of the art on topics such as actual saltwater wedge characterization, paleo-salinities in coastal areas, water-rock interactions, geophysical techniques aimed at delineating the areal and vertical extent of saltwater intrusion, management of groundwater overexploitation using numerical models and GIS mapping techniques for aquifer vulnerability to salinization. Each of the above-mentioned approaches has potential advantages and drawbacks; thus, the best tactic to tackle coastal aquifer management is to employ a combination of approaches. Finally, the number of studies focusing on predictions of climate change effects on coastal aquifers are growing but are still very limited and surely need further research.

**Keywords:** coastal aquifer; climate change impacts; characterization methods; salinization origin; prediction scenarios



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## 1. Introduction

The climate has changed in the past, is changing now, and will change in the future. The main concern raised by climate change (CC) is that it alters the global hydrological cycle (GHC) around the world, even under the most stringent emissions mitigation scenarios [1–3]. To date, most research has been conducted on the above ground components of the GHC, both on historical and projected changes [4,5]. Conversely, for the sub-surface components of the GHC, the picture is still fragmentary [6,7]. In the next years, arid and semi-arid lands are forecast to become the largest terrestrial biome on Earth [8,9] with a progressive loss of surface water (SW) resources due to contamination and increasing demand for intensive agriculture and demographic and economic growth. Consequently, groundwater (GW) resources will be gradually more stressed, with the likely result of accelerating GW depletion both quantitatively and qualitatively. These impacts will especially hit coastal areas where large socio-economic and environmental stresses are already acting and will rise due to CC [10]. More specifically, these effects will be emphasized in the semi-arid zones and delta areas along which many human activities are concentrated and where sustainable water resources management is essential for ensuring the integration of social, economic, and environmental issues [11].

One of the most widespread and alarming phenomena affecting coastal areas is the progressive salinization of water resources, from both natural and anthropogenic sources [12]. The increasing demand of freshwater, already registered and expect to increase due to CC and the consequent land use changes, has intensified the research on GW salinization, as GW has gained increasing attention as a source of water supply owing to its relatively low vulnerability to pollution in comparison to SW, and its large storage capacity [12]. Even though some comprehensive reviews focusing on the definition, recognition, and monitoring strategies of seawater intrusion (SWI) were already available at the end of the 1990s [13,14], it is above all in the last decade that research on this topic has made enormous strides by deepening not only the understanding of the mechanisms that govern salinization processes [15–18] but also investigating the effects of salinization of water resources on the surrounding environment [19,20] and recognizing its interaction with human activities [21], thus defining possible adaptive measures and solutions to deal with the actual issues and to face future scenarios [22,23]. In particular, these last studies have emphasized that in the absence of a sustainable water resources management, uncontrolled land-use activities and over exploitation can lead to a relevant and long-lasting deterioration of coastal water resources and ecosystems. Thus, long-term monitoring schemes are needed to detect and understand climate-related spatiotemporal trends in groundwater quality. However, understanding the interactions between the coastal zone and global changes cannot be achieved by observational studies alone. Modelling of key environmental processes is a vital tool that must be used if coastal management has to achieve its overall goal of protecting natural resources (soil, water, and biodiversity) [24].

*A Snapshot in the Mediterranean Basin*

In the light of what has been said so far, it is considered superfluous to carry out an extensive methodological review on the techniques for characterizing freshwater/saltwater interaction both in laboratory and field conditions in terms of identifying the various sources of salinization (natural and anthropic), the various hydrogeological and geochemical mechanisms involved, the impacts on the environment and human activities, the vast processing approaches used to handle data, and the many solutions proposed to mitigate the phenomenon of GW salinization. For all these aspects, the authors refer the reader to the comprehensive and recent reviews cited in the introduction.

The main purpose of this work is to provide the reader with a snapshot on the issue of the salinization of GW resources in the Mediterranean basin, which is considered a hot spot for CC, and to elucidate the various approaches so far employed to disentangle various sources of salinization in coastal aquifers of this area. The Mediterranean region has shown large climate shifts in the past [25], and evidence from model projections indicates that the Mediterranean might be one of the most significant "Hot-Spots" in future CC [26,27]. In the Mediterranean region, recent studies forecast an increase in temperature, especially in summer [28], a probable decrease in precipitation and a change in the in-year precipitation pattern [28,29]. This, along with the potential of pronounced sea level rise under global warming [30,31], could have devastating effects on water resources, natural ecosystems (both terrestrial and marine), human activities (e.g., agriculture, recreation, tourism), and health. About 450 million people live along the 46,000 km of the Mediterranean basin, belonging to as many as 20 different nationalities, and are concentrated above all in the fertile coastal plains, where the density of inhabitants can reach up to 1300 in/km$^2$. This strong demographic pressure, which is also expected to rapidly increase, especially along the coasts in the next decade, places evident stresses on both SW and GW resources. Moreover, in the Mediterranean, the GW resources are not distributed in a homogeneous fashion both at a regional scale and within each country. Thus, the increase in GW exploitation poses a severe risk for the availability of water resources, and the resulting scarcity is a major concern in most countries of the Mediterranean region [32]. If the lack of resources is compounded by the qualitative impact on GW resources induced by CC, the prospects can be troubling. This vision is exemplified by the following discussion, which highlights how the approach to the issue of GW salinization has prompted many Mediterranean countries to intensify their efforts not only to characterize and understand the processes in place but above all, in recent years, to the definition of strategies that allow minimizing their effects in the near future.

## 2. Materials and Methods

This work takes into consideration 304 studies focusing on the salinization issue along the Mediterranean coastline (Figure 1). In order to select the studies considered in this work, we conducted a search in the Scopus database (Elsevier) was conducted using various combinations of the following keywords to perform the research: groundwater; salinization; seawater; coastal aquifer; saltwater wedge. The search was repeated for each country using the "affiliation country" as an additional search term. Moreover, to spatially cover the whole Mediterranean area, we performed a selection of the papers to be explicitly cited by this review, following the criteria of both journal ranking (excluding low ranked journals) and number of citations where a high density of studies was available. No time limits were attributed to the search, while from a spatial point of view, only studies at a maximum distance from the coast of about 100 km were considered. Apart from the peer review papers in the Scopus database, it must be acknowledged that the most important conference on this topic is The Salt Water Intrusion Meetings (SWIMs), which have been held since 1968 every two years. From 2000, also the Salt Water Intrusion in Coastal Aquifers (SWICA) was also added to SWIM and formed an initiative to address salt water intrusion at the global scale. Given the large number of studies in this area, only the contributions published in peer-reviewed international journals were retained for the data analysis. The studies were distinguished into three main categories: (i) methodological studies in which new techniques have been proposed; (ii) studies on the origins and mechanisms of aquifer salinization where the main objective was to discover and quantify the main sources of aquifer salinization; and (iii) predictive studies on the possible evolution of groundwater quality in coastal aquifer due to different stresses. It must be pointed out that the categorization was performed with the simple aim of constructing a logic pathway to analyze the literature in this specific field, but since this choice is inherently subjective, a large overlap is possible between categories.

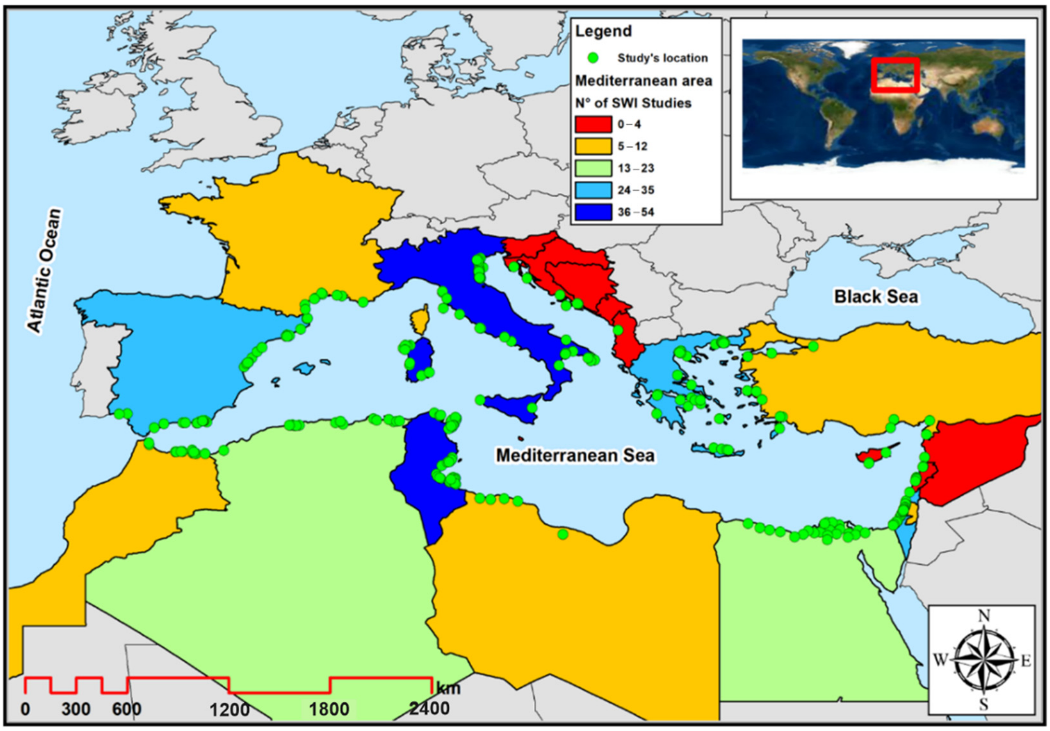


**Figure 1.** Distribution of the studies focusing on groundwater (GW) salinization along the Mediterranean coast.

## 3. Results and Discussion

### *3.1. Spatio-Temporal Distribution of the Studies*

The 304 studies analyzed are spread over a period of 35 years, from 1985 to present (Figure 2, left panel). Up to 2005, no more than 10 contributions per year were ever exceeded, and afterwards the number of studies per year increased up to 32 studies in 2017. In general, the number of studies increased from 2013 onward, due to the greater availability of economic resources made available by public and private bodies to tackle the increasingly pressing problem of GW salinization. The countries that have contributed most to the publication of studies on GW salinization are Italy, Tunisia, Greece, Spain, and Israel (Figure 2, right panel), but even for them, the temporal trend is completely different from country to country. In fact, while Israel, Spain, and Greece show a linear increase in studies starting from the 1990s, for Italy and Tunisia, the increase in recent years is much more marked and the first studies on the subject date back only to 2000. The increase is particularly evident after 2010, the year in which the number of studies that acknowledge a funding entity in the Scopus database is nearly doubled.

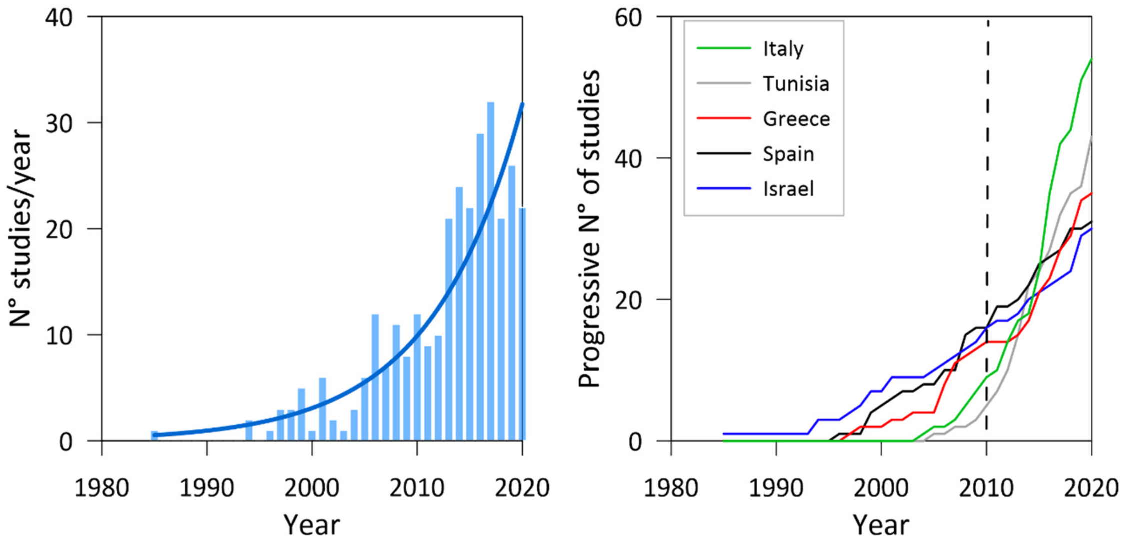


**Figure 2.** Studies focusing on GW salinization from 1980 to present for all the Mediterranean countries (**left panel**) with the blue line showing their exponential growth, and trend for the most productive countries over the same period (**right panel**) with the dashed black line indicating the year in which the number of studies that acknowledge a funding entity is nearly doubled.

An interesting subdivision of the published studies can be deduced if the coastal extension of each country bordering the Mediterranean basin is taken into consideration (Figure 3). In this case it is evident that the contribution of the countries of the southern Mediterranean shore is much more intense, with Palestine showing the highest number of works published every 100 km of coastline. Since the graph is in logarithmic scale, the following countries can be grouped together starting from: (i) Palestine and Israel; (ii) Tunisia, Lebanon, Egypt, Morocco, Spain, Algeria, and France; (iii) Italy, Syria, Turkey, Cyprus; (iv) Libya Albania, Greece and Croatia have much less studies respect to their coastal extension. This emphasizes a greater interest in the problem of GW salinization precisely in countries where the issues relating to water scarcity are yet more pressing. An exception is Greece, even if is highly affected by water scarcity, since its coastal extension is huge with respect to its area. While Libya and Syria have low values despite their extremely high water scarcity because military conflicts have played a role.

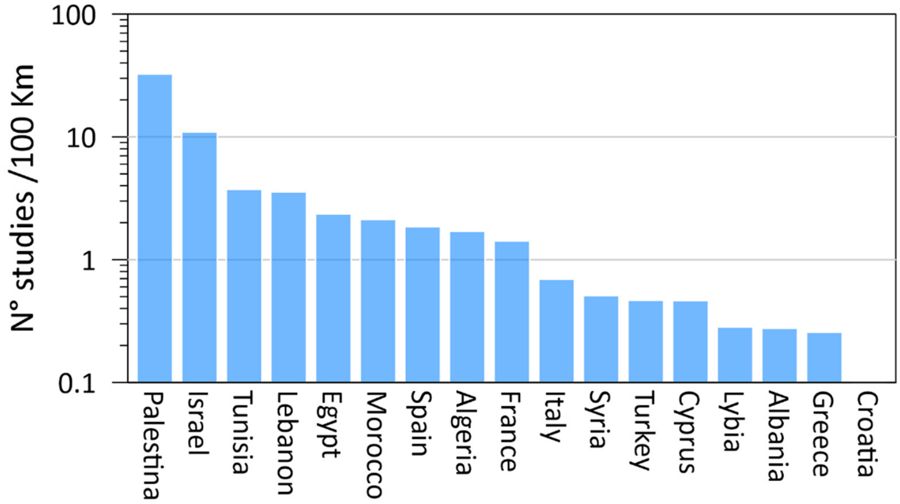


**Figure 3.** Number of studies focusing on GW salinization with respect to the coastal extension of each country along the Mediterranean.

As regards the extension of the studies focusing on GW salinization in the Mediterranean, the vast majority have an extension between $10^2$ and $10^3$ $Km^2$ (Figure 4a); a fair number of studies have been carried out on more limited areas, extended between 10 and $10^2$ $km^2$, while regional studies are far more scarce. Only very few studies on the entire Nile delta cover an area greater than $10^6$ $km^2$, while some studies in Egypt, Israel, and Tunisia cover areas between $10^4$ and $10^5$ $km^2$. The scarcity of studies at the regional level does not only depend on the frequent need to solve specific local problems that increase the number of pilot and small-scale studies, but also, and perhaps above all, on the lack of extensive and homogeneous monitoring networks that can allow a consistent characterization of a large portion of the coast.

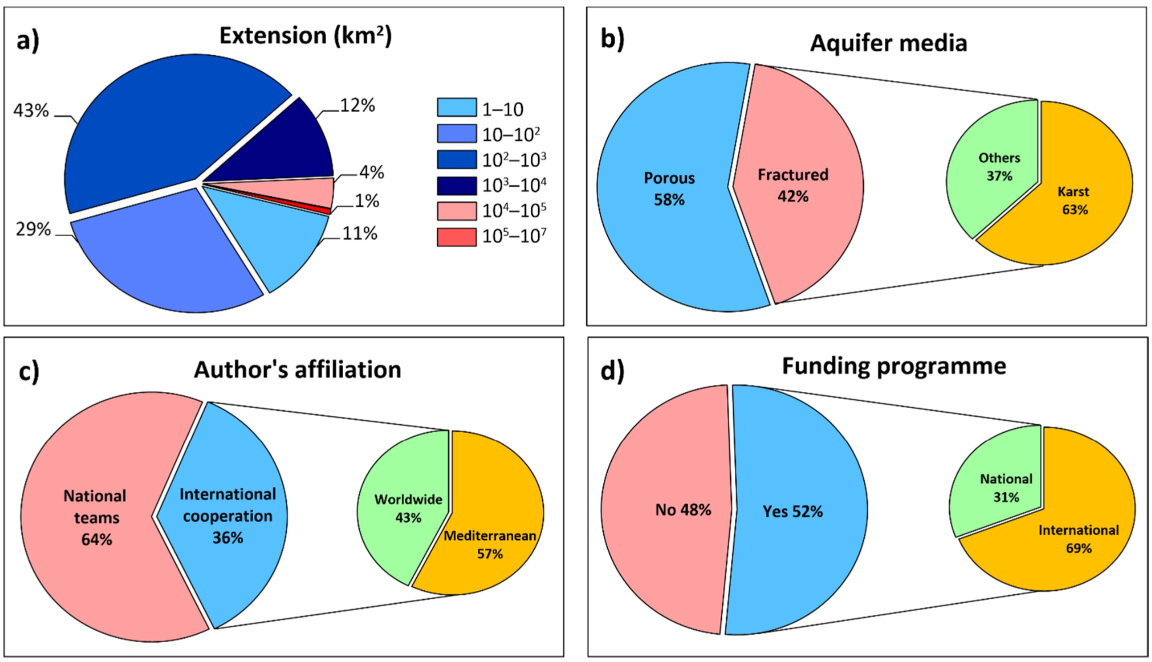


**Figure 4.** Geographical extension (**a**) and type of aquifer (**b**) of the studies focusing on GW salinization; relevance of international cooperation (**c**) and funding programmes (**d**) within the selected studies.

Considering the type of aquifer investigated, Figure 4b shows that there is a slight prevalence of studies on porous aquifers compared to those on fractured aquifers. In the porous aquifers, the largest number of studies concerns the main deltas of the Mediterranean (Nile, Po, Rhône, Ebro, and Llobregat), while in the fractured aquifers, most of the studies investigate karst aquifers, especially along the southeastern coast of the Mediterranean basin. In this case, it is believed that the smaller number of studies on karst massifs with respect to the alluvial aquifers—even though karst massifs are among the largest GW reserves on earth—is due to the technical difficulties and high costs that characterize the field activities.

One aspect that is worth investigating is the weight of international collaborations in the studies considered and the availability of funds. As can be seen from Figure 4c, most of the studies on GW salinization have been conducted by national teams, and only a third of the studies involve international collaborations, most of which involve neighboring countries, or at least countries belonging to the Mediterranean area. As regards the availability of funds to conduct the research (Figure 4d), in general, about half of the studies report some type of funding (mostly from international bodies). However, it should be specified that the distribution of funds is not homogeneous neither from a geographical point of view (with the Balkan countries and Greece behind other countries), nor from a temporal point of view; in fact, starting from 2010, there has been a very strong increase in the availability of funds, which has contributed to boost the research on this topic (see also Figure 2, right panel), together with the intensification of the issues related to water resources deterioration and to the recurrent droughts experienced in the Mediterranean countries.

### 3.2. Detailed Analysis of the Topics Covered in the Studies

The results have been summarized in three main categories in which the studies developed in the Mediterranean area have been subdivided, namely, methodological studies, origin and mechanisms studies on aquifer salinization, and predictive studies (Figure 5).

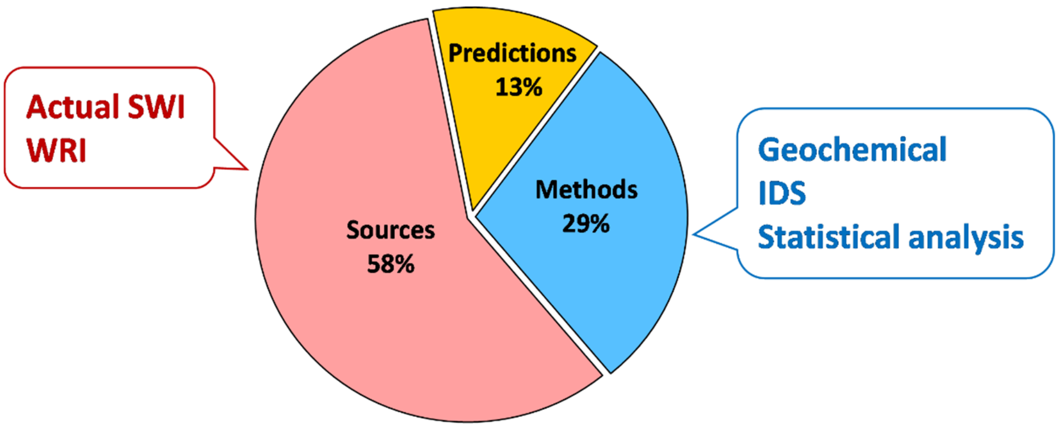


**Figure 5.** Main topics covered by the studies focusing on GW salinization along the Mediterranean coast. The most common methodologies applied in data acquisition and handling are reported in the blue call out while the most common sources of GW salinization are reported in the red call out.

#### 3.2.1. Methodological Approaches for Groundwater Salinization Delineation

Data Acquisition Techniques

Many studies have used indirect techniques to monitor the spatial extent of saline groundwater in coastal aquifers, such as geophysical methods. For example, the electrical resistivity tomography (ERT) and geological data have been largely used [33–36] to map zones characterized by high salinities, while ERT coupled with hydrochemical data was less commonly employed [37–43], although it provides more robust information in comparison to former. Moreover, the time domain electromagnetic method (TDEM) has been widely employed as a characterization method to delineate the salinization of coastal aquifers with good results at large-scale areas [44–48], while only an example of airborne electromagnetics methods (AEM) has been present [49] due to the high cost of instrumentation and survey. Finally, a new downhole probe subsurface monitoring device (SMD) has been developed to monitor in real time the resistivity variations along a monitoring well profile via a cable loaded with electrodes [50] or via coupled fiber optics and ERT techniques [51].

Moving to field-based monitoring strategies where a direct acquisition of GW samples in the field is planned, was can see that in the vast majority of cases, the acquisition of the GW sample is carried out in pre-existing wells, which were not explicitly designed for research purposes, and by means of standard integrated depth sampling (IDS). On the other hand, the studies carried out via dedicated multi-level samplers (MLSs) to determine the heads and groundwater quality variations induced by saltwater intrusion [52] or to quantify the salinization impact of pumping wells used to feed desalination plants [53] are far less numerous. In all the cases, the use of MLSs enabled the clear recognition of the transition zone variations due to change in vertical shift of the fresh-saline interface and to clearly identify the different sources of salinity that could be present in coastal environments and that are hardly identifiable by using standard integrated depth borehole data [54,55]. In fact, the key issue to understand salinization processes and to properly manage groundwater resources is to correctly characterize the vertical variability of groundwater quality. An inexpensive and fast method to obtain depth dependent groundwater quality data is the open borehole logging. Despite the apparent simplicity, the open borehole logging technique has some limitations, especially in coastal zones where the measured values (salinity or any other water property) may be representative of the stratified water column accumulated in the piezometer but not of the processes occurring within the porous media [56]. Mastrocicco et al. [57] have shown that the use of open borehole logging may lead to substantial bias when geochemical interaction between groundwater and sediments are studied or when wide tidal variations are present [56]. On the contrary, MLSs are routinely applied in contaminated sites to map contaminant spreading and to quantify biogeochemical reaction pathways, but less frequently in monitoring the saltwater intrusion in coastal areas because of their high installation and monitoring costs [33,54].

Analytical Techniques

One of the first papers using major ions and trace elements for a geochemical assessment of GW salinization in the Mediterranean area is the paper by Mercado [58] that analyzed the chromatographic effect of Israel coastal aquifers during salinization and freshening due to their cation exchange capacity as a preliminary tool to delineate whether the aquifer is salinizing or freshening. A decade later, another simple approach was proposed by Melloul and Azmon [59], where groundwater quality trends of selected species were proposed as a qualitative indicator of aquifer salinization and aquifer pollution by anthropogenic sources. More recently, several papers have focused on the origin and distribution of GW salinization either in porous aquifers [60–66], especially in arid and semiarid regions of the Mediterranean basin [67–73], or in fractured aquifers [74–79], by means of a detailed geochemical study. Together with major ions trend, selected trace elements were used to better characterize GW flow and thus salt transport [80].

To further increase the potential in distinguishing the various processes of GW salinization, researchers also employed different major ions ratios were also employed [13,81]. One of the first studies dated back to 1994 [82], in which major ions ratios were used to infer the influence of groundwater overexploitation in the increased aquifer salinization due to actual seawater encroachment. With similar approaches, there are a large number of studies even in recent years that identified actual SWI as the major salinization mechanism [83–91].

Together with the ion ratios approach, a widely used techniques to disentangle the origin of GW salinization is the employment of environmental isotopes. Early studies in the Mediterranean area were developed in Israel [92,93], while since the year 2005, there has been a growing legacy of studies employing these techniques. Most of the studies used stable isotopes to distinguish between different GW origins [94–113], while some of them used radioactive isotopes to determine the residence time of GW [114–116], that is, one of the very few pieces of information allowing researchers to distinguish between actual and paleo SWI. These last elements have also been used to study surface water/groundwater interaction; for example, in a recent paper from Mayer et al. [117], short-lived radioactive isotopes, such as radon-222, allowed not only for the determination of the amount of exchange between different water bodies, but also for the ability to precisely derive GW flow velocities and saturated hydraulic conductivities, which are vital parameters to constrain numerical simulations.

Data Handling Techniques

A widely applied approach to evaluate GW salinization, is surely the one that employed geostatistical methodologies such as multivariate statistical analysis [118–126]. In a recent study, Slama and Bouhlila have strengthened this approach by adding hydrogeochemical modelling to further constrain seawater-freshwater mixing [127].

Other interesting methods consist of using drought indices to qualitatively infer the aquifer salinization trend [128] or using simplified risk assessment methods and fuzzy cognitive maps from the farmer perspective to analyze the impact of agricultural activities on aquifer salinization [129].

Another cluster of papers pertaining to this group tackled the saltwater intrusion delineation by using GIS weighting and rating methods, in which simple overlay maps methods are employed to estimate the vulnerability of a given coastal aquifer to salinization such as the GALDIT method (GALDIT is the acronym formed from the highlighted letters of the parameters used) [130–135], even with modifications to account for surface-groundwater interactions [136], or by using GIS and water quality index interpolation methods to propose maps of vulnerability to salinization [137–143]. The main advantage of these methods is the relative easiness to handle high amount of data (i.e., spatially continuous precipitation and evapotranspiration data, land use maps, etc.), although GIS weighting and rating methods are often highly user dependent and thus more subjective than numerical models. This because the attribution of the different classes of the rating method is selected by the user and may vary considerably among different users; moreover, the GIS weighting and rating methods are usually static, while numerical models account for the temporal evolution of the aquifer salinization [15].

A more complex and data requiring approach is the one that make use of numerical models to deploy new characterization methods, for example, describing the linear and non-linear optimization approaches to manage seawater intrusion via numerical scenarios [144–150], or determining the long-term effects induced by pumping saline groundwater to feed desalination plants [151]. In addition, the employment of geophysical methods coupled with numerical models to quantify the aquifer salinization extension has been explored only in few studies [152–155], and only one reported the socio-economic aspects of SWI in the modeling procedure [156]. Finally, two studies have employed complex reactive transport models to quantify biogeochemical reactions induced by SWI [157–159]. Besides the physically based density dependent numerical models that need a large number of field data to be calibrated, there has recently been a growing number of papers that have employed the surrogate models, such as non-linear regressive techniques, to describe the SWI phenomenon [160–164], or using simple spreadsheet macros to plot the hydrochemical facies evolution [165]. In general, numerical models have been widely used to quantify the different origins of salinization via density dependent flow and transport models [166–175]. Finally, only a few papers have been conducted involving the coupling major ions, isotope data, or geophysical investigations to achieve a multidisciplinary model construction [176,177].

From the analysis of the previously mentioned literature, we have been found that the number of studies employing numerical models that account for the effects of fluid density on groundwater flow have been steadily increasing in the last decade. Since such numerical models are specifically suited to address scientific, engineering, and water resource management problems in coastal aquifer where a unique combination of factors (mixed irrigation/drainage canal networks, tidal fluctuations, coastal wetlands, lagoons, etc.) leads to complicated hydrodynamic conditions. However, three-dimensional modelling is usually computationally time consuming when multi species variable density flow and transport problems are simulated. In addition, the field data required for the implementation and calibration of three-dimensional variable density models are usually more complex than the ones needed for simple flow models, and thus their use is actually still limited with respect to classical hydrogeochemical studies.

#### 3.2.2. Groundwater Salinization Origins and Mechanisms

The studies that have addressed the salinization origins and their mechanisms in the Mediterranean area are the largest group of papers published in peer-reviewed journals. A large sub-group is constituted by papers that recognize the actual SWI as major salinization mechanism [178–185]; these papers usually employed major ions and trace element geochemical characterizations.

A large number of studies have established that the main source of salinity is coming from water-rock interactions [186–189], and to better establish such relationships in those papers, the researchers largely used stable and radioactive isotopes in groundwater were largely used. Less studies have pointed out paleo-seawaters as the main mechanism of aquifer salinization [190–199], although in many cases this distinction was possible by using high resolution MLSs. Only a few papers distinguished as the main salinization mechanism the return flow from agricultural lands [200–202]. Again, only two papers recognized the geothermal sources as the main salinization mechanism in coastal aquifers [203,204]. Finally, some studies encompass the recognition of multiple sources of salinity such as geothermal fluids, actual and paleo-seawaters, evaporitic rocks dissolution, and anthropogenic sources [205–210]. It is worth remembering here that these latter processes are much more relevant in inland areas.

Another point that can be stressed from the reported literature, is that there is a net prevalence of the spatial analyses [211–216], with respect to the temporal trend analyses [217–223]. This is due to the fact that it is much more challenging to obtain consistent hydrochemical information for long time periods, because the monitoring network must have been sampled and analyzed for the major and minor water constituents without important gaps.

#### 3.2.3. Predictive Studies of Coastal Aquifers' Salinization

The studies that have addressed the prediction on near or distant future salinization of aquifers in the Mediterranean area are the smallest group of papers published in peer-reviewed journals, with only 18 of the 304 analyzed documents. This small group is mainly constituted of papers that employed density dependent numerical flow and transport models used to predict the evolution of aquifer salinization induced by CC [224–229] or by changes in land use and/or groundwater use, such as increased pumping rates [230,231]. Other authors have used simplified sharp interface models [232] or surrogate models [233] to quantify the effect of several pumping scenarios in the near future, but these approaches suffer for simplified assumptions that may hamper their validity at later stages.

A different approach has been followed by Parisi et al. [234], in which climatic drivers such as meteorological droughts are proposed as cascading events that trigger aquifer salinization. In addition, in low lying areas, other parameters such as the subsidence rate have also been employed [235]. A similar approach was used by Benini et al. [236] in which climatic balances using predicted climate scenarios were established to derive a vulnerability index to salinization, or by Slama et al. [237], who analyzed the pattern of precipitations and evapotranspiration via an unsaturated model to predict soil and groundwater salinization patterns. While Sušnik et al. [238] used an interdisciplinary approach to assess sea-level rise and CC impacts on the lower Nile delta, Egypt, where CC effects should be studied in light of all the previously available data, as suggested by Mabrouk et al. [226]. All the approaches used are affected by large uncertainties due to the combined effects of: (i) uncertainties linked with the aquifer characterization, e.g., the hydraulic conductivity field reconstruction, (ii) or linked to poorly known stresses, e.g., pumping and recharge rates, (iii) or linked to the climatic projections that are inherently affected by uncertainties. Nevertheless, these studies provide useful insights on the aspects that are actually less understood or less characterized and require further studies to better assess the near future development of aquifer salinization in coastal regions. For example, predictive modelling of key environmental processes (coupled reactive transport and density dependent flow) could be used if a holistic coastal management must be achieved, e.g., with the main goal of protecting natural resources. In order to investigate and model a particular coastal aquifer system, there are two types of information required: (i) assessment of the relevant biogeochemical reactions in the system, and (ii) dynamic simulation of reactive processes in the coastal system, which can be used to explore the consequences of environmental change, and produce forecasts of future fluxes (scenarios). The scenario modelling process must incorporate the evaluation of methods and techniques that can be applied to improve the management of coastal zones and should also provide the uncertainties linked with the unknown variables such as the hydrodynamic and biogeochemical parameters.

#### 3.2.4. Future Perspective of Coastal Aquifers' Salinization in the Mediterranean Area

The integrated coastal aquifer management in the whole Mediterranean area is a key issue that must be tackled in the near future to defend freshwater resources in presence of CC and the related sea level rise. The number of peer review studies has grown fast in the last decade, but despite this increase, there are many areas of the Mediterranean coastal aquifers that have not yet received the appropriate attention. This is a stringent requirement to reach the target of optimizing water management strategies in coastal areas. Moreover, there is still a lack of studies addressing the temporal variations in groundwater quality in coastal aquifers. This information is pivotal to obtain a long-term view of aquifer salinization processes to permit to adapt and modulate the monitoring strategies to better capture salinization and freshening trends. Thus, it is urgent to create network of permanent monitoring wells equipped with MLSs by local authorities to collect time series data of water quality in coastal aquifers. However, it must be pointed out that an efficient coastal aquifer monitoring at the Mediterranean scale is maybe beyond the effective possibilities due to long lasting conflicts and to the wide extension of the coastline. Many papers have reported strong signals that some Mediterranean aquifers are critically overexploited and that corrective actions must be undertaken eventually at the whole watershed scale if a good balance between sink and sources must be obtained. This can be achieved via complex three-dimensional numerical models, but these models need a large amount of data to be considered reliable and robust. Solving the near and mid-term future coastal aquifer management in the whole Mediterranean area is a challenge that extends far beyond the actual studies and requires international cooperation and agencies specifically focused on this highly stressed region working together for a holistic approach to such a multifaceted problem. Thus, the major goal for the coming research will be to provide studies that widen the local perspective towards the regional perspective since many coastal aquifers are also transboundary aquifers. To start tackling this challenge, a common monitoring strategy should be started with the aim of gaining a publicly shared database that could be used by both the academic and professional communities to manage coastal Mediterranean aquifers.

## 4. Concluding Remarks

From the literature review here exposed, it is apparent that some aspects have been covered with much more detail than others in the Mediterranean area, such as the use of IDS in long screen wells to characterize the origin of salinization. This is easily explained by the fact that the construction and maintenance of MLSs networks is expensive and time consuming, while already existing wells are often the only means to access groundwater to be sampled in remote regions. Nevertheless, it has been demonstrated by many authors that the use of IDS may lead to biased results due to artificial mixing within or near the well screen and casing, especially in the presence of saline and freshwater lenses. Geophysical techniques can partially overcome the issue of vertical and spatial characterization, but since they are measuring electrical and magnetic properties, indirectly related to salinization, they must be compelled by control points where direct measurements are available to verify the obtained geophysical results.

The number of studies focusing on predictions of CC effects on coastal aquifers are growing but are still very limited and surely require further research. Another urgent requirement is to create conceptual (and possibly numerical) models that include the groundwater dependent ecosystems components and social dimensions (agricultural, industrial and urban) to better manage these critical environments.

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

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