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Studies on water resources salinization along the Italian coast: 30 years of work

Studi sulla salinizzazione delle risorse idriche lungo le coste italiane: 30 anni di lavoro

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Riassunto

La densità della popolazione lungo le coste italiane è doppia rispetto alla media nazionale. Lungo la costa si trovano numerosi insediamenti urbani, economici e produttivi, che in molte zone hanno alterato le caratteristiche naturali del territorio. Inoltre, recenti studi sui cambiamenti climatici prevedono grandi impatti sul ciclo idrologico nel Mediterraneo. Pertanto, nei prossimi anni, le risorse idriche in aree costiere saranno sottoposte ad una pressione crescete. Questo a sua volta può tradursi in una progressiva salinizzazione, un fenomeno diffuso e preoccupante in tutto il mondo. In questo articolo verrà discussa in maniera critica la distribuzione storica e geografica degli studi peer-review incentrati sulla salinizzazione delle risorse idriche lungo le coste italiane.

Abstract

The population density on the Italian coasts is twice the national average. Numerous urban, economic, and productive settlements lie along the coast, which in many areas have altered the natural characteristics of the territory. Moreover, recent climate change studies forecast large impacts on the hydrologic cycle in the Mediterranean. Thus, in the next years, coastal water resources will be gradually more stressed. This in turn may result in a progressive salinization, which is a widespread and worrying phenomenon worldwide. In this paper, the historical and geographical distribution of peer-review studies focusing on the salinization of water resources along the Italian coasts will be critically discussed.

Inroduction

The Mediterranean basin showed large climate change (CC) in the past (Luterbacher et al. 2006) and model projections suggest that it will be a “Hot-Spot” in future CC (Giorgi and Lionello 2008). Given its geographical position, there is no doubt that Italy will be affected by these changes. The forecasted CC impacts could have adverse effects on water resources (Ketabchi et al. 2016), terrestrial and marine ecosystems (Walther et al. 2002), human activities (McMichael et al. 2007), and health (Patz et al. 2005). In particular, a gradual depletion of surface water (SW) and groundwater (GW) due to pollution and increasing demand for intensive agriculture, demographic and economic growth is expected (Foster and Chilton 2003). This will be particularly noticeable in coastal areas, already prone to large environmental, economic, and social stresses. About 30% of the Italian population lives along the coast, with an uneven distribution since most of it is concentrated in the fertile coastal plains, where the density of inhabitants can reach peaks of 10.000 in/km^2, like in the metropolitan area of Naples (ISTAT 2020). Additionally, over the Italian peninsula, SW and GW resources are not homogeneously distributed, so that the eventual increase in their exploitation may result in water scarcity (ISPRA 2020). This vision urges the research on water salinization, and the definition of strategies to minimize its impacts in the near future. The main purpose of this paper is to present the knowledge achieved by the research studies concerning the salinization of water resources in Italy, discussing what has been done and what still remains to do to better manage this valuable resource.

Materials and Methods

To select the studies considered in this work, a search in the Scopus database (Elsevier) was conducted using various combinations of the following keywords: water resources, salinization, seawater intrusion (SWI), coastal aquifer, saltwater wedge. From a spatial point of view, only studies at a maximum distance from the coast of about 50 km were considered, while no time limits were attributed to the search. Of the 179 studies analysed (Fig. 1A), only some will be explicitly mentioned in the paper not to burden the discussion and because they were considered more representative. The 179 studies have been classified according to seven different information: the location of the field sites (Fig. 1B), the main topic addressed (Fig. 1C), the type of substrate (Fig. 1D), the data acquisition techniques (Fig. 1E), the data handling methodologies (Fig. 1F), the areal extension of the study (Fig. 1G), and the time of publication (Fig. 1H). It must be pointed out that the categorization was done with the simple aim of constructing a logic pathway to analyse the literature in this specific field, but since this choice is inherently subjective a large overlap is possible between categories.

Results and Discussion

Spatio-Temporal Distribution of the Studies

The 179 studies analysed spread over a period of 30 years, from 1992 to 2021 (Fig. 1H). In the first decade only 4% of the studies were published and they mainly focused on the simple recognition of the salinization of water resources in a given area, addressing only the occurrence of water salinization without identifying the source that induced salinization (e.g., SWI, water rock interaction, up coning of paleo seawater, etc.) and without investigating the mechanisms that induce an increase in the salt content (e.g., transport of dissolved species, dissolution, evapoconcentration, etc.). In the second decade 25% of the studies were published, mainly focusing on the origin of salinization and on the mechanisms governing the phenomenon. The last decade involved the publication of 71% of the studies, which also addressed for the first time the quantification of the impact of salinization on different assets, the estimation of future projections, and the search for possible solutions to the problem.

Concerning the geographical distribution of the studies (Fig. 1B), most of them (43%) were performed in the Po delta (considered as its maximum extension in the Holocene) and among them the majority was published in the last decade. A large number of studies were performed in Sicily and Sardinia (12%), in the Upper Thyrrenian (11%) and in the Murge-Salento (10%). An interesting aspect to underline concerns the extension of the areas covered by these studies and again the geographical distribution of the more extensive studies (Fig. 1G). Most of the studies extend over 10 to 100 km^2 and are equally distributed throughout the Italian peninsula. Studies covering small areas are quite common (32% considering both 0.1-1 km^2 and 1-10 km^2 classes) and are mostly located in the Po delta, specifically in the Emilia-Romagna region where hot spots of salinization were detected and where the studies have been often performed in order to find solutions to protect or restore specific sites. In the same area, most of the studies extending over 100 to 1000 km^2 were also performed. Regional studies extending more than 1000 km^2 are only 10% and they are almost entirely located in the Murge-Salento region, where salinization of water resources is an urgent issue already posing a serious threat to human activities.

Finally, considering the type of aquifer investigated (Fig. 1D), 81% of studies were performed on porous aquifers and only 19% on fractured aquifers. For the porous aquifers, the largest number of studies concerns the main deltas of the Italian peninsula (47%), while in the fractured aquifers most of the studies investigate karst aquifers and once again most of them are in the Murge-Salento region. The smaller number of studies on karst massifs respect to the alluvial aquifers is probably due to the inherent technical complexities and high costs that characterize the field activities.

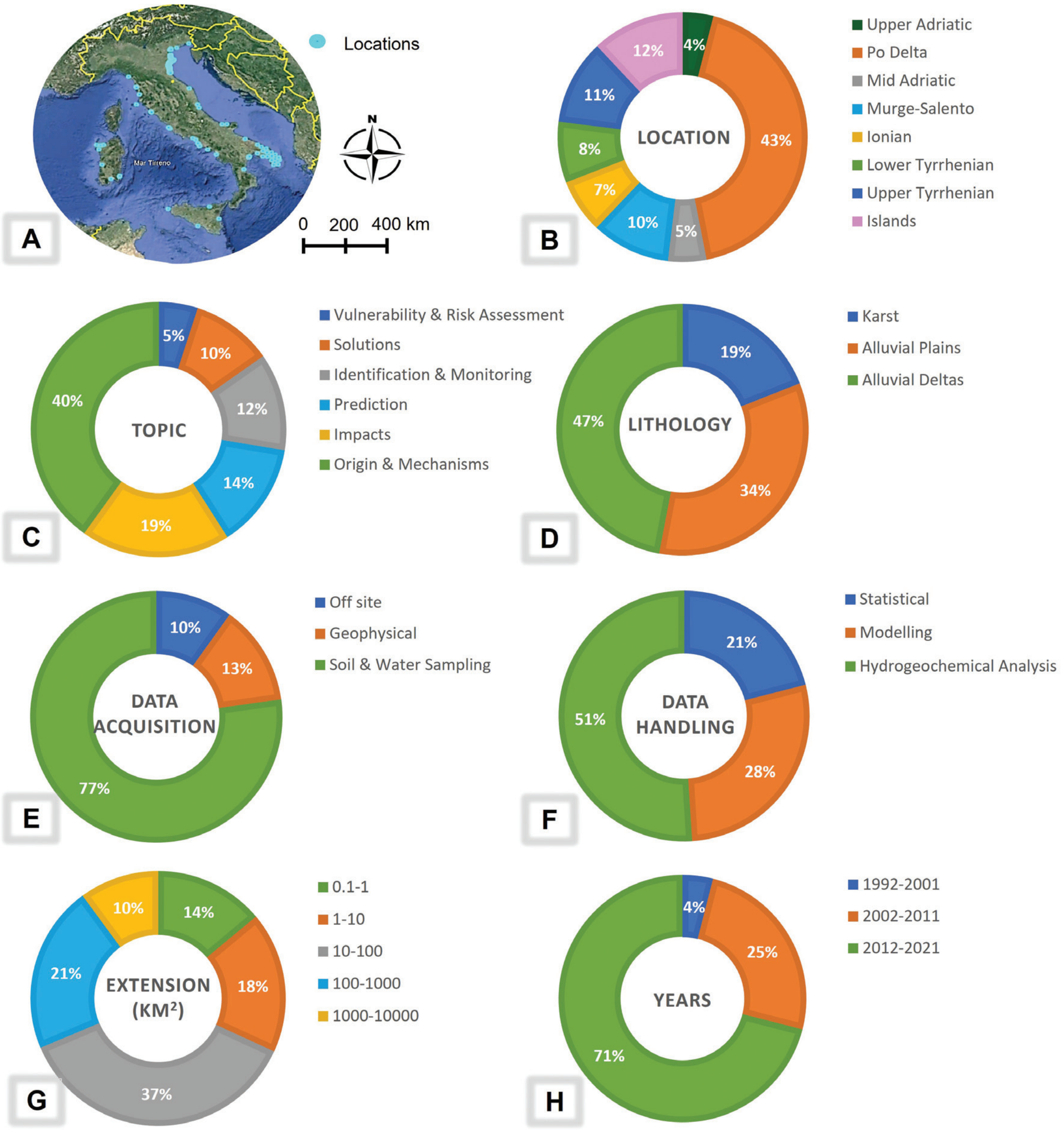

Fig. 1 - Distribution and analysis of the studies on water resources salinization in Italy.

Fig. 1 - Distribuzione e analisi degli studi incentrati sulla salinizzazione delle risorse idriche in Italia.

Data acquisition and handling

Among the 179 papers considered, few studies were performed via off site data acquisition (10%) (Fig. 1E). Barbarella et al. (2015) used satellite ASTER data to assess the effects of SWI on coastal pinewood vegetation, while airborne electromagnetics methods (AEM) were employed to identify SW-GW exchange in the Venice Lagoon (Viezzoli et al. 2010). On the other hand, few studies were performed in laboratory conditions to understand specific mechanism influencing saltwater distribution in the field, like the complex biogeochemical processes that occur between buried peaty lenses and the flowing through GW (Colombani et al. 2016a).

Moving to field-based monitoring strategies, the direct acquisition of water and/or soil samples (77%) is by far more employed than the indirect acquisition via geophysical techniques (13%). Whitin this last group, the Vertical Electrical Sounding (VES) (Balia et al. 2008), the electrical resistivity tomography (Greggio et al. 2018), and the time-lapse electrical resistivity tomography (De Franco et al. 2009) have been largely used together with geological and hydrogeological data to map zones characterized by high salinities and their dynamics. Often geophysical methods have been coupled with geochemical data (Cimino et al. 2008) to calibrate indirect acquisitions and to provide more robust information. When a direct collection of water and/or soil samples was planned, in most cases the sampling was carried out in pre-existing wells by means of standard integrated depth sampling, while the studies carried out via dedicated

Multi-Level Samplers (MLSs) were far less numerous, though they allow a correct vertical discretization which is essential in complex transitional coastal areas (Mastrocicco et al. 2012).

Several papers have focused on the origin and distribution of GW salinization by mean of a detailed geochemical study using major ions and selected trace elements, both in porous (Pittalis et al. 2016; Summa et al. 2019) and fractured aquifers (Sappa et al. 2019; Ghiglieri et al. 2009). To further increase the potential in distinguishing the mechanisms of GW salinization, different major ions ratios were employed (Bonamico et al. 2021; Zancanaro et al. 2020). Together with the ion ratios approach, a widely used technique to disentangle the origin of GW salinization is the employment of environmental isotopes (Mongelli et al. 2013; Caschetto et al. 2017).

Even though most papers (51%) rely on the sole analysis of the collected hydrogeochemical information (Fig. 1F), a widely applied approach to evaluate GW salinization is surely the use of geostatistical methodologies (21%) like: i) Monte Carlo approach to evaluate SWI (Lecca and Cau 2009); ii) drought indices to qualitatively infer the aquifer salinization trend (Alfio et al. 2020); iii) probabilistic framework to reproduce SWI (Felisa et al. 2015); and iv) risk assessment methods and fuzzy cognitive maps to analyse the impact of agricultural activities on aquifer salinization (Zaccaria et al. 2016).

A more complex and data requiring approach is the one that makes use of numerical models (28%) (Fig. 1F). They have been widely used to quantify the different origins of salinization via density dependent flow and transport models, starting with simple applications in the past (Bixio et al. 1998) to more complex simulation combining numerical models with geophysical methods (Masciopinto et al. 2017), with complex reactive transport software (Campana and Fidelibus 2015), or with both (Vespasiano et al. 2019).

Whatever the methodology used to acquire and handle the dataset, it can be stressed that there is a net prevalence of the spatial analyses (Polemio 2016) with respect to the temporal trend analyses (Giambastiani et al. 2020), since it is more challenging to obtain consistent hydrochemical information for long time periods.

Detailed Analysis of the Topics Covered in the Studies

The 179 studies have been summarized in seven main categories based on their main topic (Fig. 1A): (i) sole identification of water resources salinization and/or description of monitoring techniques; (ii) origins and mechanisms governing water salinization; (iii) environmental, economic and social impacts of salinization; (iv) predictive studies on water quality in coastal areas; (vi) vulnerability and risk assessment; and (vii) solutions to counteract progressive salinization.

Identification of the phenomenon and monitoring techniques

Most studies focusing on the sole identification of water salinization date back to '90s and most of them make use of geophysical techniques to gain the information needed to map salinity distribution. One of the first studies relying on hydrogeochemical analysis was performed in Tuscany (Giménez et al. 1996). More recently, Masciopinto et al. (2017) address the issue of GW salinity mapping in fractured coastal aquifers, via the aid of numerical simulation, while Mastrocicco et al. (2012) discuss the importance of data acquisition techniques in SWI monitoring.

Origin and mechanisms governing water salinization processes

Studies that have addressed the origin and mechanisms of salinization are the largest group (40%; Fig. 1A) and have been published from 2008 onwards. In most studies several concomitant causes have been identified (Mastrorillo et al. 2016; Mongelli et al. 2013), showing the complexity of this phenomenon. A large number recognize water rock interactions (Campana and Fidelibus 2015; Sappa et al. 2019) and actual SWI both from underground (Gattacceca et al. 2009; Vespasiano et al. 2019) and surficial flows via rivers and canals (Franceschini and Signorini 2016) as the major salinization mechanisms, usually employing hydrogeochemical characterizations. Less studies have pointed other processes like: paleo-seawaters up coning (Colombani et al. 2017), geo-thermal sources (D'Alessandro et al. 2017), sea salt aerosol (Manca et al. 2015), and recurrent drought (Alfio et al. 2020). In many studies, over-pumping or excessive artificial drainage (Barazzuoli et al. 2008; Grassi et al. 2007), if not identified as the main cause of salinization, are however always considered as an extremely detrimental factor for water quality, as the lowering of the water table favours both SWI and the upwelling of waters with high relict salinity.

Impacts of water resources salinization on natural systems

Along the Italian coast, a variety of impacts induced by increasing salinization of SW and GW were reported in the most disparate environments. The best documented impacts refer to: i) soil salinization promoted by SWI and irrigation with unsuitable waters (Vittori Antisari et al. 2020; Castrignanò et al. 2008), which in some cases are explicitly correlated with a decrease in crop yield (Leogrande et al. 2016); ii) the stress and mortality in pinewood coastal vegetation induced by high salinity levels in shallow GW (Barbarella et al. 2015), and the decrease in vegetation species richness (Antonellini and Mollema 2010; Gerdol et al. 2018); and iii) the increase mobility of trace elements which can even lead to exceeding the permitted limits (Pezzetta et al. 2011; Protano et al. 2000). Studies on the impact on microbial and macroinvertebrate communities are rarer and usually focus on SW salinity (Muresan et al. 2020). Finally, an interesting and innovative branch discusses the impact of SWI on valuable or ancient artifacts (Di Sipio et al. 2011; Stellato et al. 2020) pointing out that sea-salt damages on different building materials may be widespread and need to be kept under control to preserve cultural heritage in coastal areas.

Prediction of salinization trends and vulnerability assessment

Most studies employed numerical flow and transport models to simulate future salinization trends induced by CC in SW (Bellafiore et al. 2021) and GW (Masciopinto and Liso 2016), or by changes in land use (Mastrocicco et al. 2019) and GW exploitation (De Filippis et al. 2016). A different approach has been followed by Parisi et al. (2018) where climatic drivers like meteorological droughts are proposed as cascading events that trigger aquifer salinization. Similarly, Benini et al. (2015) used climatic balances from predicted CC scenarios to derive a vulnerability index to salinization. The assessment of the vulnerability to salinization via GIS weighting and rating methods was further implemented for low lying areas accounting for the role of SW bodies (Kazakis et al. 2019) and subsidence rate (Da Lio et al. 2015). The main advantage of these methods, with respect to numerical simulations, is the relative easiness to handle high amount of data in a GIS environment, even thou they are highly user dependent and cannot reproduce temporal evolution. Finally, a study from Colombani et al. (2016b) predicts salinization trends according to forecasted CC in the Po delta, and the trend of heavy metal release triggered by the increased salinity.

All approaches used to predict future trends in water quality in the abovementioned studies are affected by uncertainties due to: (i) variation of the surficial and underground morphology and flow regime (e.g., subsidence, coastal erosion, lack of recharge), (ii) poorly known stresses (e.g., future pumping rates and land use changes), (iii) inherent uncertainties of CC projections. Nevertheless, these studies often quantify the uncertainties linked with the unknown variables (sensitivity analysis) and account for different scenarios considering the most probable conditions, thus providing information on future hydrodynamic and biogeochemical behaviours which are essential for planning countermeasures to address in advance future adverse impacts related to the salinization of coastal water resources.

Possible solutions to the salinization issue

The studies that present strategies and/or technologies to prevent or mitigate water salinization are not numerous (10%). A study from Antonellini et al. (2015) reports GW freshening following coastal progradation and land reclamation and highlights that this trend could be strengthened by appropriate management of the drainage network. An interesting study on farmed coastal plains at risk of salinization proposes changes of irrigation deliveries by the water users' organization to counter farmers' propensity to pump GW, rather than rely on rotational deliveries (Zaccaria et al. 2016). For fractured aquifers, the identification of critical threshold for GW exploitation (Cherubini et al. 2011; Nocchi and Salleolini, 2013) and the definition of effective MAR strategies (Polemio and Zuffianò 2020; De Filippis et al. 2019) has been proposed.

Discussion

The number of studies on water resources salinization has grown fast in the last decade in Italy but there is a large inequality in their spatial distribution, with areas that have not yet received the appropriate attention and areas investigated in detail (Po delta and Murge-Salento). Moreover, there is still a lack of studies addressing the temporal variations in GW quality. Most papers emphasize the role of human perturbation on coastal system, in fact even where salinization processes are occurring naturally the human activities tend to accelerate these processes. For instance, many papers reported strong signals that some aquifers, especially karst ones, are critically overexploited and that corrective actions must be undertaken, eventually at the whole watershed scale. Studies addressing the impacts of water salinization on GW dependent ecosystems (coastal wetlands, forests, lagoons, and their fauna) and social dimensions (agricultural, industrial, and urban) are just a few, thus there is the urgent need to build conceptual (and possibly numerical) models that include these assets to better manage coastal water resources. Accordingly, more studies focusing on predictions of CC impacts on coastal SW and GW are needed to give direction to future prevention and mitigation interventions.

Conclusions

The integrated coastal aquifer management is a key issue that must be tackled in the near future to defend freshwater resources in presence of CC and the related land use changes along the Italian coast. The major goal for the coming research will be to provide studies that widen the local perspective towards the regional one and to obtain long-term series of off-site and on-site data. To tackle this challenge, a common monitoring strategy should be started aiming to gain publicly shared database that could be used by both the academic and professional communities to manage coastal aquifers.

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Competing interest
The authors declare no competing interest.

Author contributions
Micòl Mastrocicco: Conceptualization, Methodology, Writing and Editing.

Additional information
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REFERENCES

Alfio MR, Balacco G, Parisi A, Totaro V, Fidelibus MD (2020) Drought Index as Indicator of Salinization of the Salento Aquifer (Southern Italy). Water. doi:10.3390/w12071927

Antonellini M, Allen DM, Mollema PN, Capo D, Greggio N (2015) Groundwater freshening following coastal progradation and land reclamation of the Po Plain, Italy. Hydrogeol J. doi:10.1007/s10040-015-1263-0

Antonellini M, Mollema PN (2010) Impact of groundwater salinity on vegetation species richness in the coastal pine forests and wetlands of Ravenna, Italy. Ecol Eng. doi:10.1016/j.ecoleng.2009.12.007

Barazzuoli P, Nocchi M, Rigati R, Salleolini M (2008) A conceptual and numerical model for groundwater management: a case study on a coastal aquifer in southern Tuscany, Italy. Hydrogeol J. doi:10.1007/s10040-008-0324-z

Barbarella M, De Giglio M, Greggio N (2015) Effects of saltwater intrusion on pinewood vegetation using satellite ASTER data: the case study of Ravenna (Italy). Environ. Monit. Assess. doi:10.1007/s10661-015-4375-z

Bellafiore D, Ferrarin C, Maicu F, Manfè G, Lorenzetti G, Umgiesser G, Zaggia L, Valle Levinson A (2021) Saltwater Intrusion in a Mediterranean Delta Under a Changing Climate. JGR Oceans. doi:10.1029/2020JC016437

Benini L, Antonellini M, Laghi M, Mollema PN (2016) Assessment of Water Resources Availability and Groundwater Salinization in Future Climate and Land use Change Scenarios: A Case Study from a Coastal Drainage Basin in Italy. Water Resour. Manag. doi:10.1007/s11269-015-1187-4

Bixio A, Putti M, Tosi L, Carbognin L, Gambolati G (1998) Finite Element Modeling of Saltwater Intrusion in the Venice Aquifer System. In: Computational Methods in Surface and Ground Water Transport 2:193-200. Burganos VN et al. (Eds.), Suthampton, UK.

Bonamico M, Tuccimei P, Mastrorillo L, Mazza R (2021) Freshwater–Saltwater Interactions in a Multilayer Coastal Aquifer (Ostia Antica Archaeological Park, Central ITALY). Water. doi:10.3390/w13131866

Campana C, Fidelibus MD (2015) Reactive-transport modelling of gypsum dissolution in a coastal karst aquifer in Puglia, southern Italy. Hydrogeol. J. doi:10.1007/s10040-015-1290-x

Caschetto M, Colombani N, Mastrocicco M, Petitta M, Aravena R (2016) Estimating groundwater residence time and recharge patterns in a saline coastal aquifer. Hydrol. Process. doi:10.1002/hyp.10942

Castrignanò A, Buttafuoco G, Puddu R (2008) Multi-scale assessment of the risk of soil salinization in an area of south-eastern Sardinia (Italy). Precis. Agric. doi:10.1007/s11119-008-9054-4

Cherubini C, Pastore N (2011) Critical stress scenarios for a coastal aquifer in southeastern Italy. Nat. Hazards Earth Syst. Sci. doi:10.5194/nhess-11-1381-2011

Cimino A, Cosentino C, Oieni A, Tranchina L (2008) A geophysical and geochemical approach for seawater intrusion assessment in the Acquedolci coastal aquifer (Northern Sicily). Environ. Geol. doi:10.1007/s00254-007-1097-8

Colombani N, Cuoco E, Mastrocicco M (2017) Origin and pattern of salinization in the Holocene aquifer of the southern Po Delta (NE Italy). J Geochemical Explor. doi:10.1016/j.gexplo.2017.01.011

Colombani N, Mastrocicco M (2016a) Geochemical evolution and salinization of a coastal aquifer via seepage through peaty lenses. Environ. Earth. Sci. doi:10.1007/s12665-016-5642-1

Colombani N, Dinelli E, Mastrocicco M (2016b) Trend of Heavy Metal Release According to Forecasted Climate Change in the Po Delta. Environ. Process. doi:10.1007/s40710-016-0146-2

D'Alessandro, W.; Bellomo, S.; Brusca, L.; Kyriakopoulos, K.; Calabrese, S.; Daskalopoulou, K. (2017) The impact of natural and anthropogenic factors on groundwater quality in an active volcanic/geothermal system under semi-arid climatic conditions: The case study of Methana peninsula (Greece). J. Geochem. Explor. doi:10.1016/j.gexplo.2017.01.003

Da Lio C, Carol E, Kruse E, Teatini P, Tosi L (2015) Saltwater contamination in the managed low-lying farmland of the Venice coast, Italy: An assessment of vulnerability. Sci Total Environ. doi:10.1016/j.scitotenv.2015.07.013

De Filippis G, Foglia L, Giudici M, Mehl S, Margiotta S, Negri SL (2016) Seawater intrusion in karstic, coastal aquifers: Current challenges and future scenarios in the Taranto area (southern Italy). Sci. Total Environ. doi:10.1016/j.scitotenv.2016.07.005

De Filippis G, Margiotta S, Branca C, Negri SL (2019) A Modelling Approach for Assessing the Hydrogeological Equilibrium of the Karst, Coastal Aquifer of the Salento Peninsula (Southeastern Italy): Evaluating the Effects of a MAR Facility for Wastewater Reuse. Geofluids. doi:10.1155/2019/5714535

De Franco R, Biella G, Tosi L, Teatini P, Lozej A, Chiozzotto B,Giada M, Rizzetto F,Claude C, Mayer A, Bassan V, Gasparetto-Stori G (2009) Monitoring the saltwater intrusion by time lapse electrical resistivity tomography: The Chioggia test site (Venice Lagoon, Italy). J Appl. Geophys. doi:10.1016/j.jappgeo.2009.08.004

Di Sipio E, Zezza F (2011) Present and future challenges of urban systems affected by seawater and its intrusion: the case of Venice, Italy. Hydrogeol J. doi:10.1007/s10040-011-0784-4

Felisa G, Ciriello V, Antonellini M, Di Federico V, Tartakovsky DM (2015) Data-driven models of groundwater salinization in coastal plains. J Hydrol. doi:10.1016/j.jhydrol.2015.07.045

Foster S, Chilton PJ (2003) Groundwater: The processes and global significance of aquifer degradation. Philos. Trans. R. Soc. B Biol. Sci. doi:10.1098/rstb.2003.1380.

Franceschini F, Signorini R (2016) Seawater intrusion via surface water vs. deep shoreline salt-wedge: A case history from the Pisa coastal plain (Italy). Groundw Sustain Dev. doi:10.1016/j.gsd.2016.05.003

Gattacceca JC, Vallet-Coulomb C, Mayer A, et al (2009) Isotopic and geochemical characterization of salinization in the shallow aquifers of a reclaimed subsiding zone: The southern Venice Lagoon coastland. J Hydrol. doi:10.1016/j.jhydrol.2009.09.005

Gerdol R, Brancaleoni L, Lastrucci L, Nobili G, Pellizzari M, Ravaglioli M, Viciani D (2018) Wetland Plant Diversity in a Coastal Nature Reserve in Italy: Relationships with Salinization and Eutrophication and Implications for Nature Conservation. Estuaries and Coasts. doi:10.1007/s12237-018-0396-5

Ghiglieri G, Oggiano G, Fidelibus MD, Alemayehu T, Barbieri G, Vernier A (2009) Hydrogeology of the Nurra Region, Sardinia (Italy): basement-cover influences on groundwater occurrence and hydrogeochemistry. Hydrogeol. J. 17:447–466. doi:10.1007/s10040-008-0369-z

Giambastiani BMS, Macciocca VR, Molducci M, Antonellini M (2020) Factors affecting water drainage long-time series in the salinized low-lying coastal area of Ravenna (Italy). Water. doi:10.3390/w12010256

Giménez E, Bencini A, Pranzini G (1996) Indagine idrogeochimica sulla salinizzazione della falda di Pian di Rocca (GR). Mineralogica et Petrographica Acta. 39:25-37.

Giorgi F, Lionello P (2008) Climate change projections for the Mediterranean region. Glob. Planet. Chang. doi:10.1016/j.gloplacha.2007.09.005

Grassi S, Cortecci G, Squarci P (2007) Groundwater resource degradation in coastal plains: The example of the Cecina area (Tuscany-Central Italy). Appl Geochemistry. doi:10.1016/j.apgeochem.2007.04.025

Greggio N, Giambastiani BMS, Balugani E, Amaini C, Antonellini M (2018) High-Resolution Electrical Resistivity Tomography (ERT) to Characterize the Spatial Extension of Freshwater Lenses in a Salinized Coastal Aquifer. Water. doi: 10.3390/w10081067

Kazakis N, Busico G, Colombani N, Mastrocicco M, Pavlou A, Voudouris K (2019) GALDIT-SUSI a modified method to account for surface water bodies in the assessment of aquifer vulnerability to seawater intrusion. J Environ Manage. doi:10.1016/j.jenvman.2019.01.069

Ketabchi H, Mahmoodzadeh D, Ataie-Ashtiani B, Simmons CT (2016) Sea-level rise impacts on seawater intrusion in coastal aquifers: Review and integration. J. Hydrol. doi:10.1016/j.jhydrol.2016.01.083.

ISPRA (2020) Le risorse idriche nel contesto geologico del territorio italiano. Disponibilità, grandi dighe, rischi geologici, opportunità. *"Water resources in the geological context of the italian territory. Availability, large dams, geological risks, opportunities".* Dipartimento per il Servizio Geologico d'Italia, Rapporto 323/2020. ISBN 978-88-448-1011-5.

ISTAT (2020) Il Censimento permanente della popolazione e delle abitazioni. Prima diffusione dei dati definitivi 2018 e 2019 *"The permanent census of population and housing. First dissemination of the final data for 2018 and 2019".* https://www.istat.it/it/censimenti/popolazione-e-abitazioni.

Lecca G, Cau P (2009) Using a Monte Carlo approach to evaluate seawater intrusion in the Oristano coastal aquifer: A case study from the AQUAGRID collaborative computing platform. Phys Chem Earth, Parts A/B/C. doi:10.1016/j.pce.2009.03.002

Legrande R, Vitti C, Lopedota O, Ventrella D, Montemurro F (2016) Effects of Irrigation Volume and Saline Water on Maize Yield and Soil in Southern Italy. Irrig Drain. doi:10.1002/ird.1964

Luterbacher J, Xoplaki E, Casty C, Wanner H, Pauling A, Küttel M, Rutishauser T, Brönnimann S, Fischer E, Fleitmann D, et al. (2006) Mediterranean climate variability over the last centuries: A review. Dev. Earth Environ. Sci. doi:10.1016/s1571-9197(06)80004-2.

Manca F, Capelli G, Tuccimei P (2015) Sea salt aerosol groundwater salinization in the Litorale Romano Natural Reserve (Rome, Central Italy). Environ Earth Sci. doi:10.1007/s12665-014-3704-9

Masciopinto C, Liso I, Caputo M, De Carlo L (2017) An Integrated Approach Based on Numerical Modelling and Geophysical Survey to Map Groundwater Salinity in Fractured Coastal Aquifers. Water. doi:10.3390/w9110875

Masciopinto C, Liso IS (2016) Assessment of the impact of sea-level rise due to climate change on coastal groundwater discharge. Sci Total Environ. doi:10.1016/j.scitotenv.2016.06.183

Mastrocicco, Busico, Colombani, Vigliotti M, Ruberti D (2019) Modelling Actual and Future Seawater Intrusion in the Variconi Coastal Wetland (Italy) Due to Climate and Landscape Changes. Water. doi:10.3390/w11071502

Mastrocicco M, Giambastiani BMS, Severi P, Colombani N (2012) The Importance of Data Acquisition Techniques in Saltwater Intrusion Monitoring. Water Resour. Manage. doi: 10.1007/s11269-012-0052-y.

Mastrorillo L, Mazza R, Manca F, Tuccimei P (2016) Evidences of different salinization sources in the roman coastal aquifer (Central Italy). J Coast Conserv. doi:10.1007/s11852-016-0457-5

McMichael AJ, Powles JW, Butler CD, Uauy R (2007) Food, livestock production, energy, climate change, and health. Lancet. doi:10.1016/S0140-6736(07)61256-2

Mongelli G, Monni S, Oggiano G, Paternoster M, Sinisi R (2013) Tracing groundwater salinization processes in coastal aquifers: a hydrogeochemical and isotopic approach in the Na-Cl brackish waters of northwestern Sardinia, Italy. Hydrol Earth Syst Sci. doi:10.5194/hess-17-2917-2013

Muresan AN, Gaglio M, Aschonitis V, Nobili G, Castaldelli G, Fano EA (2020) Structural and functional responses of macroinvertebrate communities in small wetlands of the Po delta with different and variable salinity levels. Estuar Coast Shelf Sci. doi:10.1016/j.ecss.2020.106726

Nocchi M, Salleolini M (2013) A 3D density-dependent model for assessment and optimization of water management policy in a coastal carbonate aquifer exploited for water supply and fish farming. J Hydrol. doi:10.1016/j.jhydrol.2013.03.048

Parisi A, Monno V, Fidelibus MD (2018) Cascading vulnerability scenarios in the management of groundwater depletion and salinization in semi-arid areas. Int J Disaster Risk Reduct. doi:10.1016/j.ijdrr.2018.03.004

Patz JA, Campbell-Lendrum D, Holloway T, Foley JA (2005) Impact of regional climate change on human health. Nature. doi:10.1038/nature04188

Pezzetta E, Lutman A, Martinuzzi I, Viola C, Bernardis G, Fuccaro V (2011) Iron concentrations in selected groundwater samples from the lower Friulian Plain, northeast Italy: importance of salinity. Environ Earth Sci. doi:10.1007/s12665-010-0533-3

Pittalis D, Carletti A, Ghiglieri G, Celico F (2016) The influence of hydrogeological properties, seawater intrusion and refreshening on the quality of groundwater used for irrigation in an agricultural coastal plain in North Sardinia, Italy. Environ Earth Sci. doi:10.1007/s12665-016-5770-7

Polemio M (2016) Monitoring and Management of Karstic Coastal Groundwater in a Changing Environment (Southern Italy): A Review of a Regional Experience. Water. doi:10.3390/w8040148

Polemio M, Zuffianò LE (2020) Review of Utilization Management of Groundwater at Risk of Salinization. J Water Resour Plan Manag. doi:10.1061/(ASCE)WR.1943-5452.0001278

Protano G, Riccobono F, Sabatini G (2000) Does salt water intrusion constitute a mercury contamination risk for coastal fresh water aquifers? Environ Pollut. doi:10.1016/S0269-7491(99)00317-6

Sappa G, Iacurto S, Ferranti F, De Filippi FM (2019) Groundwater Quality Assessment in a Karst Coastal Region of the West Aurunci Mountains (Central Italy). Geofluids. doi:10.1155/2019/3261713

Stellato L, Coda S, Arienzo M, De Vita P, Di Rienzo B, D'Onofrio A, Ferrara L, Marzaioli F, Trifuoggi M, Allocca V (2020) Natural and Anthropogenic Groundwater Contamination in a Coastal Volcanic-Sedimentary Aquifer: The Case of the Archaeological Site of Cumae (Phlegraean Fields, Southern Italy). Water. doi:10.3390/w12123463

Summa V, Margiotta S, Tateo F (2019) Correlation between geochemical, mineralogical and physical characters of sediments and salinization phenomena in a pilot area in the ionian plain (Southern Italy). Geomatics, Nat Hazards Risk. doi:10.1080/19475705.2018.1539039

Vespasiano G, Cianflone G, Romanazzi A, Apollaro C, Dominici R, Polemio M, De Rosa R (2019) A multidisciplinary approach for sustainable management of a complex coastal plain: The case of Sibari Plain (Southern Italy). Mar Pet Geol. doi:10.1016/j.marpetgeo.2019.06.031

Viezzoli A, Tosi L, Teatini P, Silvestri S (2010) Surface water-groundwater exchange in transitional coastal environments by airborne electromagnetics: The Venice Lagoon example. Geophys Res Lett. doi:10.1029/2009GL041572

Vittori Antisari L, Speranza M, Ferronato C, De Feudis M, Vianello G, Falsone G (2020) Assessment of Water Quality and Soil Salinity in the Agricultural Coastal Plain (Ravenna, North Italy). Minerals. doi:10.3390/min10040369

Walther G-R, Post E, Convey P, Menzel A, Parmesan C, Beebee TJC, Fromentin J-M, Hoegh-Guldberg O, Bairlein F (2002) Ecological responses to recent climate change. Nature. doi:10.1038/416389a

Zancanaro E, Teatini P, Scudiero E, Morari F (2020) Identification of the Origins of Vadose-Zone Salinity on an Agricultural Site in the Venice Coastland by Ionic Molar Ratio Analysis. Water. doi:10.3390/w12123363

Zaccaria D, Passarella G, D'Agostino D, Giordano R, Sandoval Solis S (2016) Risk Assessment of Aquifer Salinization in a Large-Scale Coastal Irrigation Scheme, Italy. CLEAN - Soil, Air, Water. doi:10.1002/clen.20140039