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Natural and anthropogenic factors driving groundwater resources salinization for agriculture use in the Campania plains (Southern Italy)

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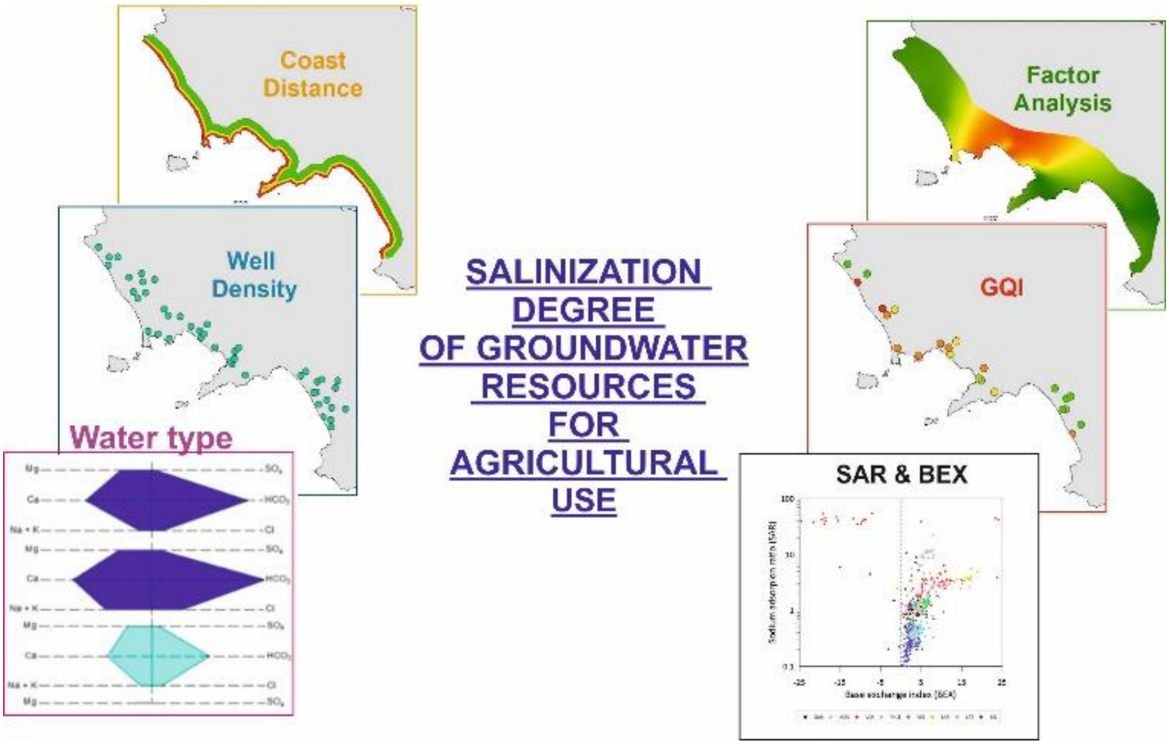
Highlights

Mechanisms of groundwater salinization are studied at the coastal aquifer scale

Withdrawals in greenhouses areas near the coast led to groundwater salinization

BEX and SAR temporal-spatial trends discriminate natural Vs. anthropic salinization

Graphical abstract



ABSTRACT

The Mediterranean region is under pressure for a more sustainable use of water resources in view of the actual and future climate change. Under this pressure, the need to better assess the links between groundwater availability and quality and irrigated agriculture, is becoming urgent. Through the hydrogeologic and hydrochemical characterization of the coastal aquifers of a representative Mediterranean study area (the Campania Region in southern Italy), this study strengthened the analysis of basic components of the groundwater cycle and their temporal variability, including hydrologic, environmental and socio-economic aspects. Selected physiochemical properties of groundwater in 52 monitoring wells were considered from the Campania Environmental Protection Agency database. A total of 626 samples were collected from 2004 to 2018 to capture the water quality variability. Factor analysis and a specific groundwater quality index were also applied on 23 samples in two different timelines (2006, 2016) to capture the hydro-chemistry evolution through year. Moreover, land use and active pumping wells locations were used in the analysis. Spatial and temporal trends of base exchange indices (BEX) and sodium adsorption ratio (SAR) were computed along with Pearson coefficient among different variables, like well densities and distance from the coast. The variation in the distribution of salinity between 2006 and 2016, along with highly positive and highly negative BEX and groundwater quality index values, indicate unstable conditions for the future. In the greenhouse's areas, where groundwater exploitation is elevated, an increase of salinity was recorded due to seawater intrusion. In volcanic districts water rock interaction is the main driver of groundwater salinization, while mixing processes with carbonate freshwaters diminish groundwater salinities in the alluvial plains. This study demonstrates that groundwater over pumping can have a major impact on groundwater quality used for irrigation, despite the dominant influence that local geological and morphological features exert on the area.

Keywords

Regional hydrology; salinization; irrigation and drainage; water-rock interaction; freshwater-seawater mixing, GQI, factor analysis.

1. INTRODUCTION

The Mediterranean region is undergoing intensive demographic, social, economic, and environmental changes. Almost a third of the Mediterranean basin's population (about 170 million in 2020) actually lives within coastal plains covering less than 12% of the surface area of the Mediterranean countries (https://ec.europa.eu/eurostat). In addition to the widespread ongoing urbanization, the Mediterranean coastal areas are also intensively exploited for agriculture purpose. Cereals, vegetables, and citrus fruits account for over 85% of the Mediterranean's total agricultural production. Moreover, cultivation of other products, such as olives and grapes, also occupies a significant amount of agricultural land (Leff et al., 2004). In this context, water resources play a crucial role, so that in the Mediterranean basin, agriculture accounts for 70% of total water use. So, crop irrigation represents the main water utilization, reaching the higher intensity especially in summer (80% of total water use), when crops grow, precipitation decreases, and evapotranspiration consequently increases. As a main consequence, the Water Exploitation Index (WEI) shows that many Mediterranean regions are currently classified as water-stressed, with several countries showing a WEI higher than 40% (https://www.eea.europa.eu/data-and-maps). Almost the 30% of Mediterranean regions are classified as water stressed with a WEI ≥ 20% (Turkey, Belgium, Italy, Cyprus, and Malta) that is widely considered as a warming threshold (Alcamo et al., 2010). The increasing need of freshwater for irrigation has progressively put more pressure onto groundwater resources, also because of the loss of surface water resources due to contamination (Arnell, 1999; Priyantha Ranjan et al., 2006). In the next years, the phenomenon of Climate Change (CC) will most probably exacerbate this issue. For the Mediterranean Region, recent studies predicted sea level rise (SLR), an increase in temperature, especially in summer, a probable decrease in precipitation and a change in the in-year recharge and evapotranspiration patterns (Cramer et al., 2018). So far, most of the studies have been done on the above ground components of the hydrologic cycle, both on historical and projected changes. On the other hand, for the subsurface components (recharge, groundwater levels, aquifer fluxes and groundwater quality), the scientific knowledge is still incomplete. In lowland coastal area, a small rate of sea-level rise will cause an inland shift of saline groundwater (Colombani et al., 2016; Yechieli et al., 2010). In addition, changing precipitation regimes and groundwater recharge rates may cause a similar landward shift of the saltwater-freshwater interface (Chang and Yeh, 2010; Werner et al., 2013). Under this pressure, the need to better assess the links between groundwater availability and quality and irrigated agriculture, especially on a regional scale, is becoming urgent (Romanelli et al., 2012). The concept of groundwater "quality" is strongly related to its chemical composition and destination of use. Generally, a water classified as excellent in chemical and biological quality is mainly retained for human consumption, while agricultural needs can be usually met by water of lesser quality. So, it is important to properly evaluate the water (superficial or groundwater) quality in accordance with its main use. To achieve this target several methodologies have been developed, and a brief description is available in Machiwal et al. (2018). Among these, groundwater quality indices (GQIs) and Fit for purpose (FFT) evaluations have been the more widely applied methods due to their relative ease of use (Bui et al., 2020; Rufino et al., 2019; Karim et al 2020; Jha et al., 2020). These methodologies involve the evaluation of all those variables responsible of groundwater quality (i.e. chemical, physical, and microbial) finally summarizing them in an lumped numerical index in relation to the various water quality thresholds such as the i) World Health Organization (WHO) standards, ii) FAO guidelines or iii) regional standards. The concept of water quality is moreover directly linked with the sustainability of irrigated agriculture that is questioned in many coastal areas for a combination of factors, but above all for the risk of salinization. In fact, salinization affects almost 10% of irrigated land (Tanji and Kielen, 2002). The salt accumulation in

Mediterranean soils and aquifers is a natural process favoured by the region's ecological conditions, which can however be modified by human activities, especially in flat arable lands. In fact, once groundwater become saline, its fate within the aquifers is most of the times long lasting (Foster and Chilton, 2003). Moreover, when groundwater resources with high salinity content are used for irrigation, they can cause water stress leading to yield reduction, especially for crops with limited salt tolerance. Thus, understanding the salinization processes within coastal aquifers at regional and long-term scales among with groundwater quality evolution is a prerequisite to evaluate the sustainability of irrigated agriculture. The recognition of groundwater salinization origin in coastal aquifers is not a straightforward task; in fact, beside actual seawater intrusion (SWI), groundwater salinization can result from other natural salt sources or from human activities. The most relevant salt sources/processes are: i) water rock interaction, ii) the mobilization of salts stored in the unsaturated zone (Walter et al., 2017), iii) evapoconcentration (Colombani et al., 2018), iv) slow-moving saline/saltwater of marine origin (Meyer et al., 2019), v) highly mineralised waters from geothermal fields (Regenspurg et al., 2010), and finally vi) the agricultural practices mainly as return flow (Foster et al., 2018). The salt sources may have different geochemical imprints, thus an approach by multiple natural tracers is required for their recognition (de Montety et al., 2008). Whatever the salt source, its recognition is often masked by mixing of fresh and saline waters and by water-rock interactions due to increase in water ionic strength (Belkhiri et al., 2010). On one hand, the mixing processes are normally enhanced by human actions as over-exploitation (causing lateral SWI and/or upconing) and presence of drainage systems for land reclamation (Barlow and Reichard, 2010; Custodio, 2010). On the other hand, the main processes that might occur during water-rock interactions are cation exchange, redox reactions, dissolution/precipitation, evapoconcentration, and leakage/seepage of saltwater (de Montety et al., 2008; Mollema et al., 2013). Accordingly, to define the ongoing hydrogeochemical processes within an aquifer system can be a difficult task, and sometimes the analyses of large data sets among with the utilization of advanced statistical methodologies is required. In this scenario multivariate statistical analysis such as factor analysis (FA) and principal component analysis (PCA) has proven to be a useful and a worldwide applied tool that allow to properly explain the main hydrogeochemical factors responsible for the chemical groundwater composition (Hynds et al., 2014; Kazakis et al., 2017: Zanotti et al., 2019). For example, Busico et al. (2018, 2020) successfully utilized the FA to identify all the hydrochemical factors in two coastal plains within the Campania plain, stating how this methodology can be useful in discriminate and identify the different mineralization processes. Through the hydrogeologic and hydrochemical characterization of the coastal aquifers of a representative Mediterranean study area (the Campania Region in southern Italy), this study aims at strengthening the understanding of the analysis of basic components of the groundwater cycle and their temporal variability, including hydrologic, environmental and socio-economic aspects. This was achieved identifying the origin and the mechanism of groundwater salinization, taking into account the main drivers (e.g. subsidence, coastal erosion, sea level rise, meteo-climate variability, lowering of the water table) and verifying whether the current irrigation strategies have created imbalances to the fresh/salt water interface and assess their sustainability in the future, also in view of possible climate and land use changes. Multivariate statistical analysis along with a Specific Groundwater Quality Index (SGQI) has been utilized to identify the main hydrochemical processes that characterize the study area and to define the groundwater salinization degree for the irrigation water utilization for cereals (corn, wheat and oath) production. Moreover, a time series analysis has been conducted to describe the intensification/lessening of the salinization process and the corresponding changes in water quality accordingly with the climate, land cover, and management variation that has interested the last twenty years.

2. MATERIAL AND METHODS

2.1. Study Area

The Campania Region (southern Italy) with its nearly 6 million of inhabitants, of whom 50% live in coastal plains, with 15% of urban areas and more than 50% of agricultural land, could be considered a representative study area to address the issues previously described (Minolfi et al., 2016). The Campania region, surrounded by the Apennine to the west and the Tyrrhenian Sea to the east (Fig. 1), has a Mediterranean climate with cold winters and dry summers. The minimum average temperature is 10.2 °C and the maximum average temperature is 19.6 °C.

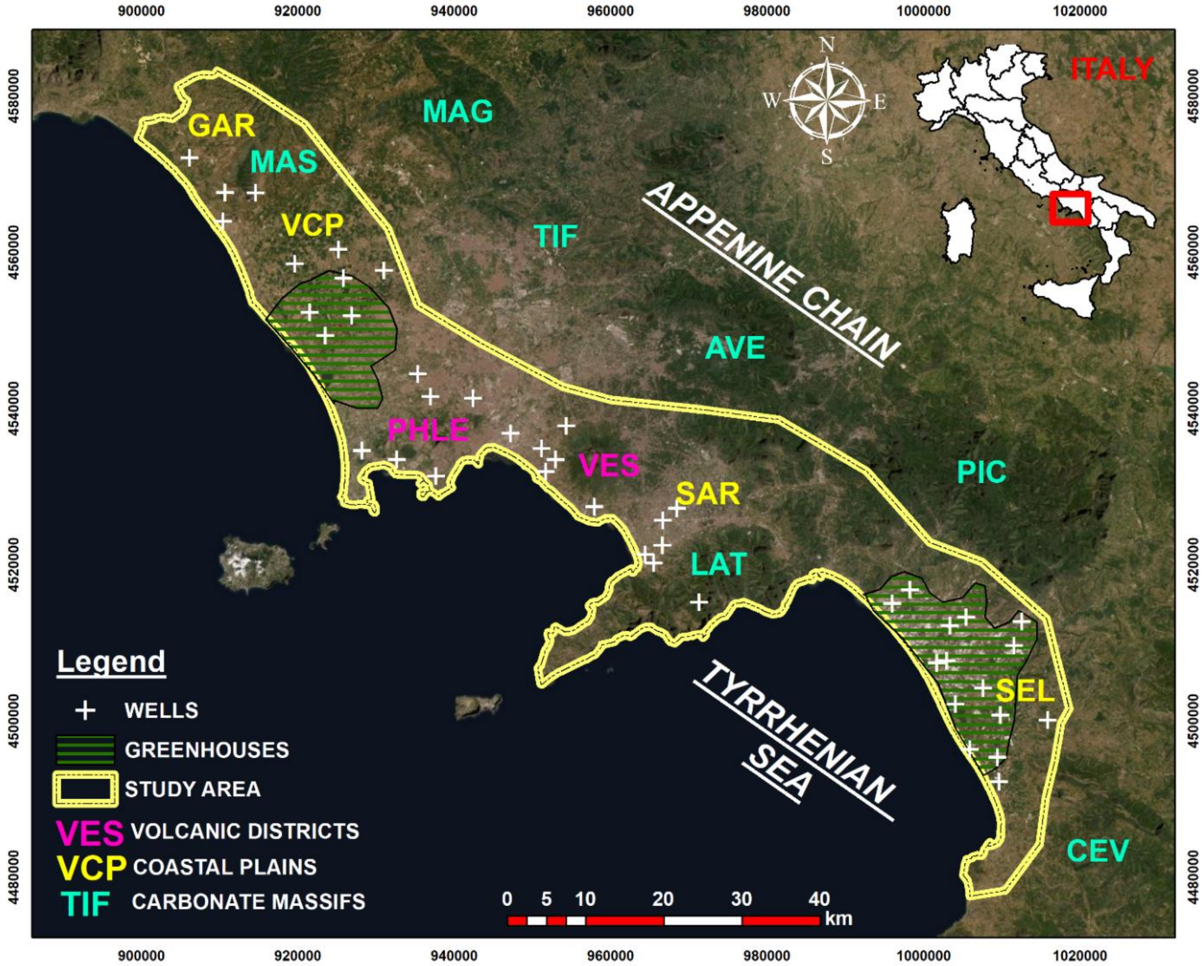


Figure 1: Geographical setting of the Campania Region and location of the monitoring wells and of the greenhouse areas in the VCP and SEL coastal plains.

Precipitations happen primarily in the period between October and May, showing strong patterns in terms of elevation and proximity to the sea (Ducci and Tranfaglia, 2008). The highest precipitation occurs in the Apennine, with values up to 2000 mm/y, while in the coastal plains values around 800 mm/y are registered (Busico et al., 2017). From a geological point of view, the Apennine is characterized by sedimentary rocks like limestones, dolomites and terrigenous sediments of Mesozoic age, buried under variable thicknesses of Neogene units, mainly made of volcanoclastic materials coming from the Roccamonfina Volcano, the Somma-Vesuvio and Campi Flegrei districts; the plains are characterized by Quaternary sediments (alluvial and lacustrine deposits). The Campania region includes many hydrogeological systems: quaternary alluvial deposits, pyroclastic deposits, carbonate karstified systems and silico-clastic systems (Ducci et al., 2019).

Since the present study was intended to address the salinization of water resources only in coastal plains, the Campania Region was not entirely considered but a coastal strip of 2300 km^2 (approximately 150 km along the coast x 15 km inland, highlighted with the yellow bold line in Fig. 1) was selected, where the pressure of agricultural activities and urbanization are particularly high (see Table 1). From NW to SE the Campanian coastal area presents the graben of the Garigliano Plain (GAR), the horst of Monte Massico (MAS), the graben of the Campana Plain, the horst of Monti Lattari (LAT), the graben of the Sele plain (SEL). The Campana Plain is further divided, by two topographic highs of the Phlegraean Fields (PHLE) and the Vesuvius volcanoes (VES), into the Volturno coastal plain (VCP), the Sebeto coastal plain (here discussed together with the VES group) and the Sarno River coastal plain (SAR) (Fig. 1).

Table 1. Extension, elevation, and population density of coastal plains (GAR, VCP, SAR, SEL), volcanic districts (PHLE and VES) and carbonate massifs (MAS and LAT) with the relative percentage of land for agricultural use. To locate each morphological unit, refer to Figure 1.

	Area ***(Km^2)***	***Agric. Area*** ***(%)***	**Median Elev. (min./max.)** **(m a.s.l.)**	***Pop. Dens.*** ***(inhabitants/Km^2)***
GAR	137	87	18 (-1/486)	176
VCP	1068	81.8	7 (-2/528)	776
SAR	198	67.7	22 (0/652)	2232
SEL	430	87	31 (0/312)	363
PHLE	203	43.2	139 (0/460)	4458
VES	430	66.3	289 (0/655)	2704
MAS	29	18.1	370 (29/812)	25
LAT	260	25	713 (2/1428)	583

The plains result from the aggradation of structural depressions (Pappone et al., 2011): the Campana Plain (VCP, VES and SAR) comes from volcano-sedimentary aggradation of the peri-Tyrrhenian graben from the Lower Pleistocene (Milia and Torrente, 2003), when most of the Plain was occupied by transitional and shallow marine environments; the Sele Plain (SEL) derives from the sedimentary aggradation of a Plio-Quaternary depression along the western margin of the southern Apennine extending about 400 km^2.

The studied sector of the VCP is characterized by a flat morphology (slope <5°) with a wide lowland area reclaimed starting in the XVI century, which allowed for the development of agriculture and farming as well as severe urbanization along the coastal zone (Ruberti and Vigliotti, 2017).

Recently, the VCP plain, experienced a retreat of hundreds of metres of the Volturno delta due to the reduction of sediment discharge and to coastal erosion. VCP is also affected by a long-term subsidence that nowadays occurs at up to 10 mm/y (where lacustrine deposits are found) due to natural processes, locally accelerated by urbanization, water pumping and drainage for the intense agricultural activities (Matano et al., 2018). Even in the SAR, subsidence appears to have continued until the historical period. SEL has experienced an erosional phase, with a maximum erosion of 4.8 m/y close to the river mouth (Pappone et al., 2011).

From NW to SE the prevailing soil types according to the Soil Map of the Campania Region 1:250.000 (http://agricoltura.regione.campania.it/pedologia/suoli.html), are reported in Table 2.

Table 2. Main and secondary (according to their extension) soil types found in coastal plains (GAR, VCP, SAR, SEL), volcanic districts (PHLE and VES) and carbonate massifs (MAS and LAT). The cation exchange capacity (CEC) and the drainage capacity of soil types are also reported.

	Main soil type	**CEC**	**Drainage capacity**	**Secondary soil type**	**CEC**	**Drainage capacity**
GAR	Deep Vertic & Fluvic Cambisols	high	moderate - good	Eutric Vertisols & Calcic Vertisols	high	moderate - good
VCP	Deep Eutric & Calcic Vertisols, Fluvic Cambisols	high	moderate-good	Deep Vertic & Fluvic Cambisols, Mollic Gleyisols	high-medium	good-low

SAR	Deep Fluvic Cambisols	low	good-high	Deep Vitric Cambisols & Gleyic Andosols	medium-low	good-low
SEL	Shallow Calcaric Fluvisols & Fluvic Cambisols	medium	good-high	Shallow Eutric Fluvisols	medium	moderate
PHLE	Deep Haplic & Mollic Andosols	medium-high	good-high			
VES	Deep Vitric Cambisols & Humic Andosols	medium	good			
MAS	Shallow Epileptic Andosols, Regosols & Mollic Leptosols	high	good-high	Deep Eutric Andosols	high	good
LAT	Shallow Vitric Andosols	medium	good	Eutric & Luvic Andosols	medium	good

In the coastal area, the mean annual precipitation (2004–2018) is 870 mm and the mean annual evapotranspiration is 968 mm. From 2004 to 2018 the average precipitation diminished of about 20-25% for all the coastal plains considered in this study. Nevertheless, Campania is not a highly water stressed region, but irrigation of agricultural land is essential since this is one of the more productive agricultural areas in Italy, valuable crops such as vegetables, fruits, olives and grapes. Irrigated land is between 58% and 67%, with an input of 160-190 mm over the growing season. Water allocation is managed by water districts for irrigation and drainage. Most of the irrigation water comes from large diversions from the rivers crossing the coastal plains (see Table 3). For the Volturno river, withdrawals for irrigation (up to 35% of the river discharge) induced a decrease in river discharge during summer, with minimum values sometimes lower than the historical minimums recorded in the last decades. This induced a lowering of the piezometric heads, leading to sporadic saltwater intrusion events, which have already occurred in some coastal areas of VCP. Also, the Sele river, especially in recent years, is negatively affected by withdrawals granted for irrigation (up to 25% of the river discharge), with frequent imbalances between the summer river discharge and the active withdrawal concessions. Groundwater flow direction in the coastal aquifers of Campania is roughly oriented NE-SW towards the Tyrrhenian Sea. The water table generally lies close to the land surface, facilitating losses via evapotranspiration (see Table 3).

Table 3. Average Precipitation (P), Potential Evapotranspiration (PET), Water Table (WT) depth and River Discharge (RD) during the monitoring period (2004-2018), in coastal plains (GAR, VCP, SAR, SEL), volcanic districts (PHLE and VES) and carbonate massifs (MAS and LAT).

	Mean P (mm)	**Mean PET (mm)**	**Mean WT depth (m b.g.l.)**	**Mean RD (Mm^3/y)**
GAR	1011	1095	6-12	3784 (Garigliano)
VCP	937	922	1-6	2586 (Volturno)
SAR	1084	1116	3-18	410 (Sarno)
SEL	1215	1268	5-40	2185 (Sele +Tusciano)
PHLE	847	956	50-250	-
VES	985	1007	10-23	-
MAS	985	973	-	-
LAT	1236	1175	-	-

2.2. Sampling and analytical methods

2.2.1 Database selection

For this study, selected physiochemical properties of groundwater in 52 monitoring wells (see Fig. 1 for location) from the online available dataset of ARPAC (Agenzia Regionale per la Protezione Ambientale in Campania) [ARPAC, 2019] were considered. A total of 626 samples were collected in wet and dry seasons from 2004 to 2018 to capture the water quality variability (see Table 4). Water samples were grouped with respect to their sampling environment into coastal plains (GAR, VCP, VES, SAR and SEL), volcanic districts (PHLE and VES) and carbonate massifs (MAS and LAT) (Fig. 1).

Among the large ARPAC database, temperature, electrical conductivity (EC), pH, chloride (Cl), bicarbonate (HCO_3), sulphate (SO_4), calcium (Ca), magnesium (Mg), sodium (Na), potassium (K) and boron (B), were selected to carry out this study. Temperature, EC, and pH were measured in situ, while samples intended for major ions analyses were collected in HDPE bottles and analysed in a laboratory following the international standards guidelines (APHA, 2017). The ionic balance was calculated for all samples and samples with an ionic balance exceeding ±5% were not included in the water type analysis.

Table 4. Summary of the groundwater physiochemical parameters database. N° refers to the number of observations available for the selected parameter; M. is the median value for the selected parameter for each year.

	HCO_3 (mg/l)		B (µg/l)		Ca (mg/l)		Cl (mg/l)		EC (µS/cm)		Mg (mg/l)		K (mg/l)		Na (mg/l)		SO_4 (mg/l)	
	N°	M.	N°	M.	N°	M.	N°	M.	N°	M.	N°	M.	N°	M.	N°	M.	N°	M.
2004	52	415	26	218	52	104	47	72	46	947	47	31	47	15	47	49	47	46
2005	62	364	42	159	62	108	62	87	62	947	62	30	62	31	62	57	62	37
2006	62	415	56	45	62	110	56	74	56	1033	56	33	56	29	52	54	56	49
2007	63	4151	56	126	63	104	57	85	57	1086	57	36	57	35	57	52	57	55
2008	43	274	37	46	43	110	40	80	40	1093	40	36	40	30	40	43	40	34
2009	71	410	58	150	71	84	64	86	64	1024	64	34	63	31	64	56	64	51
2010	44	488	42	207	44	107	42	95	42	1110	42	35	42	46	42	78	42	58
2011	24	455	20	17	24	117	20	23	20	751	20	32	20	6	20	18	20	24
2012	69	439	62	67	70	113	62	52	62	1028	62	35	62	13	62	50	62	44
2013	59	366	63	44	71	94	63	55	62	998	63	30	63	26	63	50	63	54
2014	64	468	54	69	65	104	67	81	67	1120	55	34	55	30	55	58	67	76
2015	47	463	47	97	47	114	42	67	41	1100	42	33	42	27	42	53	42	61
2016	28	439	24	63	28	166	26	37	24	805	24	42	24	21	24	47	33	38
2017	37	427	36	77	37	135	42	45	40	845	37	35	37	15	37	57	46	22
2018	37	488	33	66	89	37	43	40	42	885	37	30	37	13	37	32	43	23

2.2.2. Data Analyses

Groundwater samples were assigned to a given hydro-chemical class considering the major dissolved cations and anions, by using Stiff diagrams via the Excel macro PiperStiff-QW-2019.v5, freely available on-line (https://halfordhydrology.com/piper-and-stiff/). Salinity was subdivided into four classes according to Rhoades et al. (1992) (Fig. 4). The long-term effect of irrigation water on physical and chemical properties of soil and crop productivity depends on several factors, like Na and alkaline earth elements (Ca and Mg) content, electrical conductivity, and initial physical properties of soil. In this study, to assess the degree of salinization for irrigation groundwater of Campania Plains, the following parameters were used: Sodium Adsorption Ration (SAR), electrical conductivity (EC) and Base Exchange index (BEX).

There is a significant relationship between SAR values and the effect on soils: at high SAR, the cation exchange complex may become saturated with Na, leading to a loss of soil structure due to the dispersion of clay particles. SAR is computed from the following equation (Oster and Sposito, 1980):

$$SAR = \frac{Na^{+}}{\sqrt{\frac{1}{2}(Ca^{2+}+Mg^{2+})}} \qquad (1)$$

where Na^{+}, Ca^{2+} and Mg^{2+} concentrations are expressed in meq/L.

The identification of spatial and temporal changes in the position of the freshwater/saltwater interface may be obtained applying the BEX, which defines cation exchange reactions due to water–rock interactions when saline water enters a freshwater aquifer and vice versa (Vandenbohede and Lebbe, 2012). For instance, during salinization sea water (with high Cl, Na, K and Mg) displaces fresh water with high Ca and HCO_3 and Na is adsorbed, conversely during freshening Ca is adsorbed. BEX was calculated according to the following formulas, for Ca and Mg rich aquifers, respectively (Stuyfzand, 2008):

$$BEX = Na + K + Mg - 1.0716\,Cl \qquad (2)$$

$$BEXD = Na + K - 0.8768\,Cl \qquad (3)$$

where 1.0716 and 0.8768 equal to [Na+K+Mg]/Cl and [Na+K]/Cl for mean ocean water in meq/L, respectively (Riley and Skirrow, 1975). The BEX application subdivided groundwater samples into three classes: positive during freshening, negative during salinization and zero when there is no base exchange, and the situation is stable. Saturation indices (SI) for various mineral phases and ionic balances were calculated with PHREEQC-3 (Parkhurst and Appelo, 2013). When SI of a given mineral is negative the solution is undersaturated and the mineral (if present in the aquifer) may dissolve, while if SI is positive the mineral may precipitate. Finally, the groundwater dataset together with some representative drivers of groundwater salinization (e.g. distance from the coastline, well density) were analysed using Pearson correlation via Excel 2016 (Microsoft, Redmond, WA, USA) without data normalization. Linear mixing lines were created for freshwater/seawater and for freshwater/geothermal waters; using for the freshwater end-member the less saline groundwater present in the database, for the seawater end-member the mean Tyrrhenian seawater composition (Pennisi et al., 2006) and for the geothermal end-member the composition found by Cuoco et al. (2017b).

2.2.3. Multivariate statiscal analyis and GQI.

For this study, a multivariate statistical approach through the application of FA has been applied to: i) discriminate all the hydrogeochemical processes occurring in the studied aquifer in two different time period (2006 and 2016) and ii) to evaluate the evolution intensity of the main salinization process through time. A 10-years interval has been chosen i) to involve at least a decadal climate variability in the analysis which is considered the minimum time laps to appreciate a variation in the climate regime and its effect (Kim et al., 2012, Dono et al., 2013), and ii) to obtain a proper evaluation considereing the same sampling wells accordingly to the data availabiltiy, as the monitoring database suffer of several missing analysis and only few years allow a comparative assessment. The FA has become a robust approach worldwide applied in all the geoscience fields allowing to highlight the relationships between observed variables creating a list of few significant factors which include them. The number of factors are chosen following the Kaiser criterion (Kaiser, 1960) hence considering significant those factors with an eigenvalue higher than 1, while the overall meaningfulness are considered significant with the Kaiser-Meyer-Olkin (KMO) coefficient higher than 0.5 (Kumar, 2014). The average values of HCO_3^-, Cl^-, B^+, SO_4^{2-}, Na^+, K^+, Mg^{2+}, EC and SAR within the same twenty-three sample for the 2006 and the 2016 has been utilized as variables. The GQI evaluation instead, has been calculated following the methodology proposed by Babiker et al. (2007). The SGQI fot this study, has been created utilizing the thershold values suggested from Food and Agricultural Organization (Ayers and Westcot, 1994.) and reported in Table 5 for the optimal cereals grow. Accodingly, a salinization assessment has been carried out based ong GQI structure for 24 monitoring wells. Similarly for FA, the GQI has been calculated for 2006, 2016 and its decadel evolution.

Table 5: Water Quality Criteria for GSIQ

Parameters	*Units*	*Cereals*
Boron (B)	mg/L	2
Chloride (Cl)	mg/L	300
Electrical Conductivity (EC)	µS/cm	1100
Sodium (Na)	mg/L	300
Sodium Absorption Ratio (SAR)	-	10
Total Dissolved Solid (TDS)	mg/L	704

3. RESULTS

3.1 General hydro-geochemistry.

Water-rock interaction processes dominate the composition of most of groundwater samples (Buondonno et al., 2007; Cuoco et al., 2017a). From the chemical results of the 626 water samples, 4 main water types were identified (Fig. 2). In summary, 57% are of the Ca-Mg-HCO_3 type (where Ca is largely prevailing on Mg), 23% are Na+K-HCO_3-SO_4 type (where HCO_3 is largely prevailing on SO_4), 1% are Na-Cl type and 19% are a mixing between the two dominant types and the Na-Cl type. Among the Ca-Mg-HCO_3 type that is found in correspondence of the carbonate massifs and the plains delimited by them (Fig. 2), two groups are evident: on one hand LAT and MAS show a saturation index (SI) of Calcite of 3.6 and a SI of Dolomite of 6.1, on the other hand SEL and GAR have a SI of Calcite of 2.4 and a SI of Dolomite of 3.7. The Na+K-HCO_3-SO_4 type which includes the volcanic districts of PHLE and VES is characterize by a SI of Gypsum of 0.81. Finally, the alluvial systems of VCP and SAR are a variable mix of the previous water types with some samples showing a large interaction with Na-Cl water type. The pH values of all the aquifers considered in this study ranges between 6.5 and 8.3. Spatial and temporal variations of pH are controlled by the quality and the infiltration rate of recharge water, the replenishing water rate and water-rock interaction in the aquifer. These pH values are all in the desirable limits set by the World Health Organization (WHO). The temperature values of groundwater varied from 12.2°C to 22.6°C.

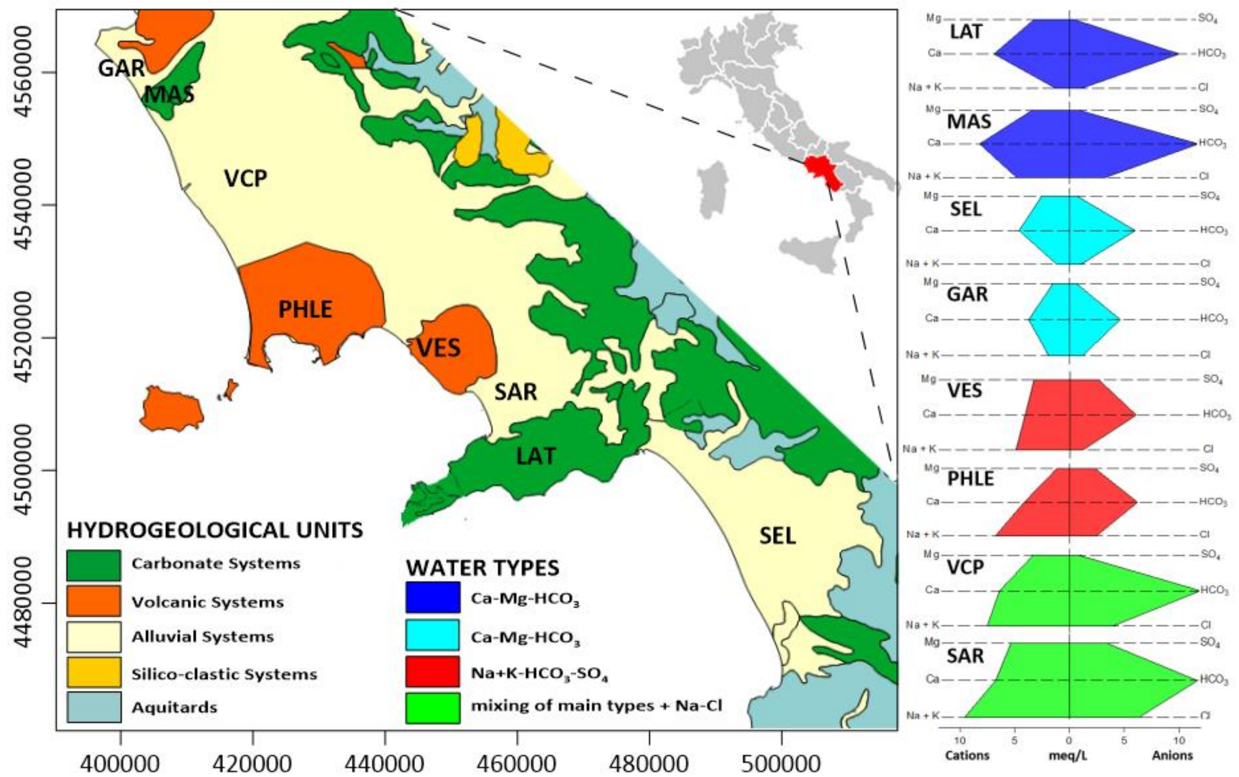


Figure 2: Hydrogeological units and water types of the coastal zone of the Campania region.

3.2. FA applications

Both the results of FAs for 2006 and 2016 well agree with the above discussed geochemistry evaluation. The same three factors have been identified in the two different timelines (2006 and 2016) (Table 6). The results of FA have been spatialized using the Ordinary Kriging (OK). The OK is a geostatistical technique widely utilized to spatial interpolate the values of a certain field in unobserved locations starting from nearby observations points. In this study the factor scores belonging to each groundwater monitoring wells have been considered as input variables to interpolate and consequently display the range and the degree of groundwater salinization influenced by the common factors. This procedure has been commonly worldwide utilized with excellent results (Busico et al., 2018, 2020, Shyu et al.,2011, Wang et al., 2001). The F1 explains the 34% of the total variance and shows a positive correlation between Na^+, SAR, Cl^-, B^+ and EC highlighting the presence of a persistent salinization probably due to phenomena of actual SWI, and to the water rock interaction with shallow marine sediments and reworked volcanic materials (Busico et al., 2018). In F2, the chemical species of HCO_3^-, Mg^{2+}, and Ca^{2+} are strongly correlated, indicating the carbonate water-rock interaction, and describing the 33% of the total variance. Finally, the F3, explaining the 22% of the total variance, strongly correlate K^- and SO_4^{2-}. Both elements are ascribable to intensive feldspar weathering process and magmatic fluid contact (Thivya et al. 2013). Among the three factors, F1 has been chosen as describer of SWI and saline water mixing process. In Figure 3 is shown the spatial distribution of F1 in the two different years (Fig. 3a, b) and its evolution through the decadal timeline (Fig. 3c). The legends of Figure 3a and 3b express the values of factor scores calculated through FA of the F1. Negative and positive values indicate low and strong magnitude of the process respectively, allowing the identification of those areas more prone to SWI. Specifically, for the 2006 (Fig. 3a) the areas more affected are the whole coastal plains of VCP and SAR along with the northern part of SEL and volcanic districts of PHLE and VES. For the 2016, instead, a different situation was portrayed (Fig. 3b): the VCP showed a reduction of the process going far from the coastline accompanied by a slightly increase along the coastline. The SEL plain, instead, suffered of a general magnitude increase, especially in the southern sector of the plain. In Figure 3c is possible to appreciate the F1 evolution from 2006 to 2016. This map has been created realizing a spatial difference among 2016 and 2006 F1's maps, processing both the raster files in ArcGIS environment using raster calculator tool. The result highlighted where the process' s magnitude has increased, decreased, or remained constant through the decadal timeline. Summarizing, those areas that have registered a SWI increase are the PHLE field along with GAR and SEL plains while no significative differences are verifiable near the main carbonate massifs (LAT and MAS). The spatial distribution of F2 and F3, responsible of carbonate influx and volcanic water rock interaction respectively, are shown in Figure S1 and S2. These two factors are further contributing to the salinization degree of the local groundwater resources. The F2 characterized the whole VCP in the 2006 (Fig. S1a) due to the later influx from MAS carbonate relief, while in the 2016 it will be also more evident in the LAT reliefs and SAR plain (Fig. S1b). F3 instead, is perfectly localized within PHLE and VES volcanic centres (Fig. S1) with a lower lateral influence also within SAR and VCP plain. The main differences among 2006 and 2016 distribution is only related to the PHLE area where the magnitude of F3 slightly decrease (Fig. 3b) concurrently with the increase of F1 in the same area (Fig. 3c). The spatial distribution of FA's results further confirmed how each specific area is characterized by multiple processes of salinization aside of SWI, responsible of the main groundwater chemistry.

Table 6. Factors score for the applied FAs.

	FACTORS - 2006			FACTORS - 2016		
	F1	F2	F3	F1	F2	F3
HCO_3	0.445	0.846	-0.181	0.163	0.771	-0.084
Na	0.908	0.354	0.158	0.900	0.290	0.258
SAR	0.936	-0.204	0.176	0.949	-0.226	0.107
Cl	0.669	0.542	0.297	0.643	0.531	0.408
K	0.267	0.106	0.928	0.234	0.270	0.821
Mg	-0.040	0.862	0.096	-0.076	0.907	0.180
B	0.761	0.410	0.410	0.644	0.515	0.258
SO_4	0.179	-0.076	0.960	0.167	-0.201	0.831
Ca	0.108	0.893	-0.025	0.017	0.903	-0.122
EC	0.684	0.575	0.318	0.736	0.449	0.402
KMO		0.657			0.653	

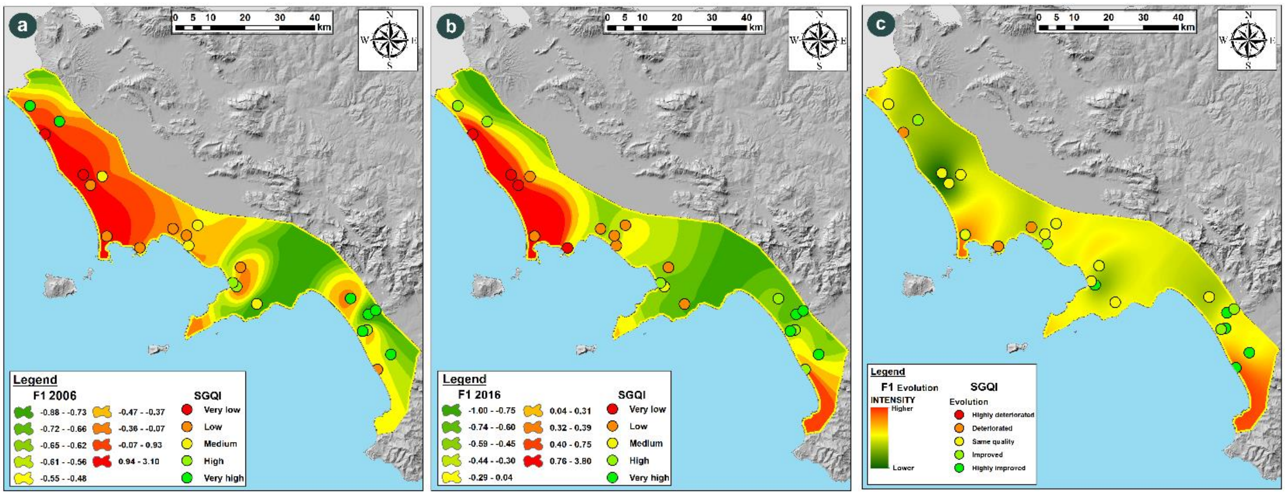


Figure 3: Spatial distribution of F1 for 2006 (a) and 2016 (b) along with correspondent SGQI. The figure 3 (c) shows the F1 and SGQI evolution trough time.

Similar results to F1 are represented in Figure 4, using the previous described salinity indices (BEX and SAR), where the increasing salinity is magnified for the two coastal areas further confirming the phenomena. In VCP an area that in 2006 was characterized by slightly saline waters, in 2016 become moderately saline. Furthermore, in the southernmost part of SEL a large area shifted from freshwater to slightly saline.

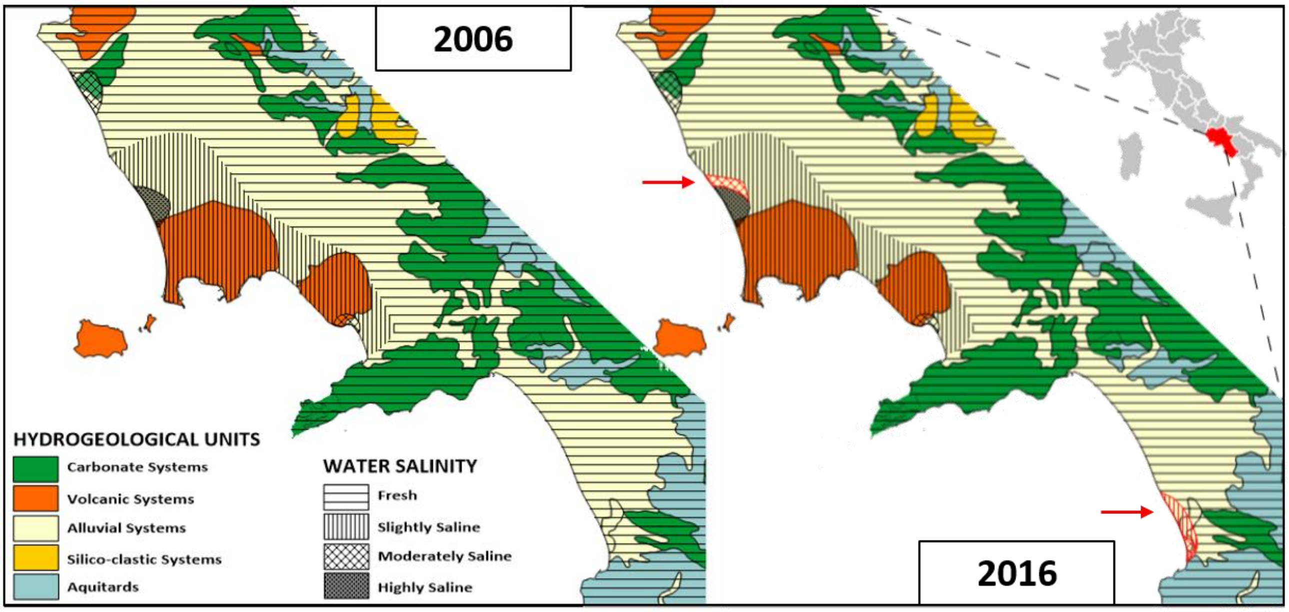


Figure 4: Hydrogeological units and water salinity classes (according to Rhoades et al., 1992) of the coastal zone of the Campania region, for 2006 (left plot) and 2016 (right plot), where the expansion of areas with high salinity are highlighted by red arrows.

3.2.1 Water quality evaluation.

Many water quality parameters affect the suitability of groundwater for irrigation, but in this study, the most concerning parameter is salinity. Salinization eventually makes groundwaters inadequate for the growth and productivity of many crops (Moujabber et al., 2006). For example, for an appropriate growth and productivity of most crops, EC levels should be less than 2,250 µS/cm. But 10% of the coastal groundwater exceeded the recommended EC value, and 3% of EC values were greater than 15,000 µS/cm, above which growth is impossible or crop yield seriously compromised (Katerji et al., 2003). Accordingly, the 50% of groundwaters investigated with the realization of a SGQI are subjected to a high salinization degree which made them unsuitable for cereals irrigation (dots in Figure 3). The lower quality waters, and consequently the higher salinization degree, are located within VCP and VES districts in agreement with previous investigation done by Rufino et al. (2019) while the higher quality waters and lower salinization are found in correspondence of

MAS, LAT, and SEL. As major and minor components of salinity from seawater, B and SO_4 concentrations were moreover further studied. The maximum concentration for SO_4 for agricultural water is designated at 50 mg/l (Lee and Song, 2007) and 45% of groundwater samples exceeded this threshold. Irrigation procedure with high-sulphate groundwater concentration may result in an increasing salinity in the soil profile, governed by the solubility of gypsum (Methochis, 1989). The maximum concentration for B in agricultural water is designated at 1000-2000 μg/l (Regulation EC 2003/2003) and 6% of groundwater samples exceeded this threshold. Specifically a groundwater B concentration less than 500 μg/l can be satisfactory for all kind of crops while yet value higher than 1000 μg/l could generate several negative effect such as leaf burning in some sensitive species (Zaman et al., 2018).The diagrams showing the relationship between the seawater markers B, Cl and SO_4 (Fig. 5) shows that not all samples follow a simple mixing line between freshwater and seawater. In fact, water rock interaction (e.g. cation exchange and precipitation/dissolution) and migration of saline water are also important chemical and physical processes determining the water quality. VCP samples are characterized by both paleo and actual SWI close to the shoreline and by freshwater recharge inland (Busico et al., 2018). Some of the SAR samples show an enrichment in B and SO_4, due to the interaction with the volcanic lithofacies and/or to the circulation of geothermal fluids (like in the MAS, PHLE and VES samples showing high B concentrations). The remaining samples show a large interaction with fresh water from regional and local recharge.

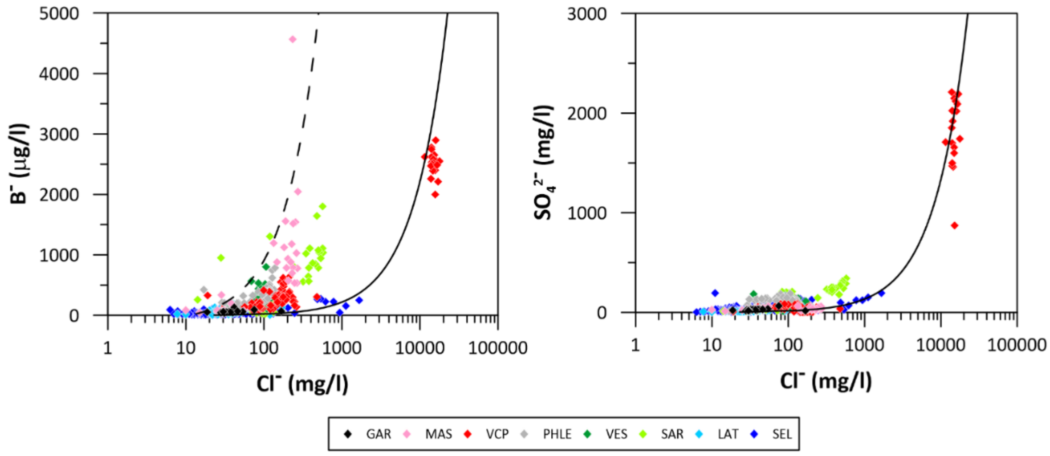


Figure 5: The diagrams show the relationship between the groundwater tracers B-Cl (left plot) and between SO_4-Cl (right plot). The black line shows the mixing trend between fresh water and sea water, the dashed line shows the mixing trend between geothermal water and fresh water.

The sodium hazard of the irrigation water can be evaluated using SAR from Ca, Mg and Na contents. The SAR values in the study area range between 0.1 and 54.1. A SAR greater than 10 represents a high sodium hazard (Hem, 1985); 9% of groundwater samples exceeded this threshold. The combination of EC and SAR is generally used to determine the degree of salinization of water used for irrigation and consequently its suitability. The Fig. 6 illustrates that most groundwater samples fall into C2S1 (34%) and C3S1 (26%), indicating water with medium-to-high salinity and low SAR, which is suitable for irrigation. In this group fall all GAR and LAT samples, almost all SEL samples and a part of MAS and VES samples accordingly with SGQI spatial distribution (Fig. 3). The remaining VES samples plot into C3S2, together with part of the PHLE, SAR and VCP samples. The latter group shows very high salinities and medium alkalinity hazards. The C3S3 and C4S3 categories are represented by MAS and BVR samples, indicating strongly mineralized groundwater presenting important risk of soil salinization and alkalization. Finally, C3S4 and C4S4 (7% and 9%, respectively) indicate very high salinity waters pertaining to VCP, PHLE, SAR and SEL. This type of waters is completely unsuitable for irrigation, regardless of the type of plant and soil and especially for cereal production. To sum up, approximately 16% of the groundwater samples are unsuitable for irrigation, 8% are suitable only with specific crops (salt tolerant species like cauliflower, sorghum and sunflower), 17% is usable with special caution (e.g. limited to well drained soils with low CEC) and the remaining 60% is good quality water accordingly wit SAR classification.

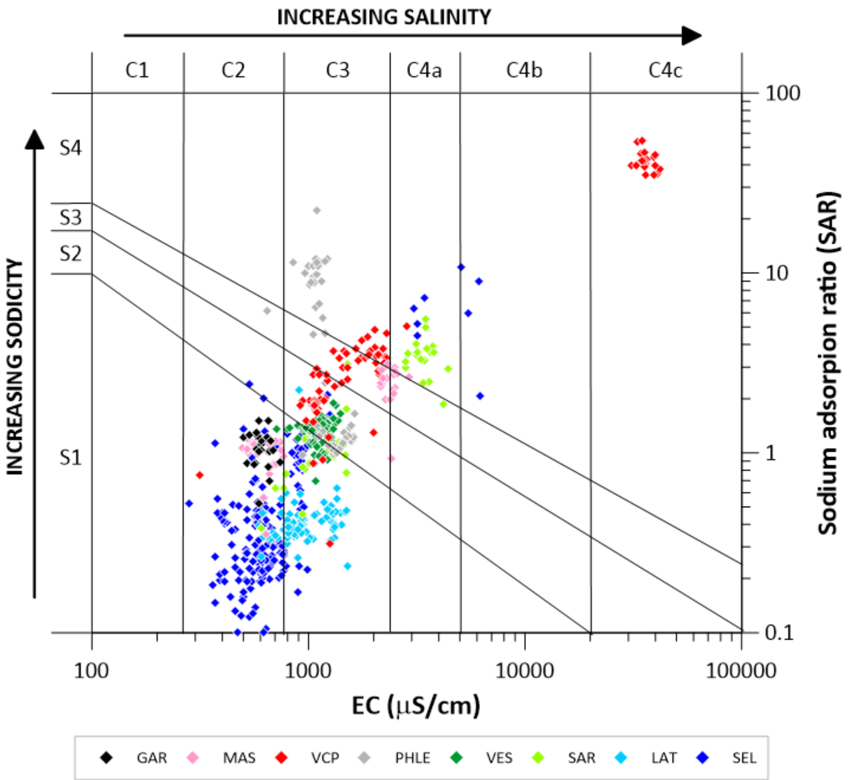


Figure 6: US Salinity Laboratory diagram for classifying irrigation waters on the basis of SAR and EC as described by Richards (1968).

The BEX index classification resulted in 82% of all samples showing a positive BEX, 13% a zero BEX, and 5% a negative BEX (Fig. 7). Negative BEX, indicating a worsening of the groundwater quality, are located in VCP and SEL plains and to a lesser extent in GAR and SAR; most samples plots close to the zero BEX value (dashed line in Fig. 7), indicating stable conditions; a clear positive BEX, indicating a freshening trend, is shown by some SAR, MAS and VCP samples.

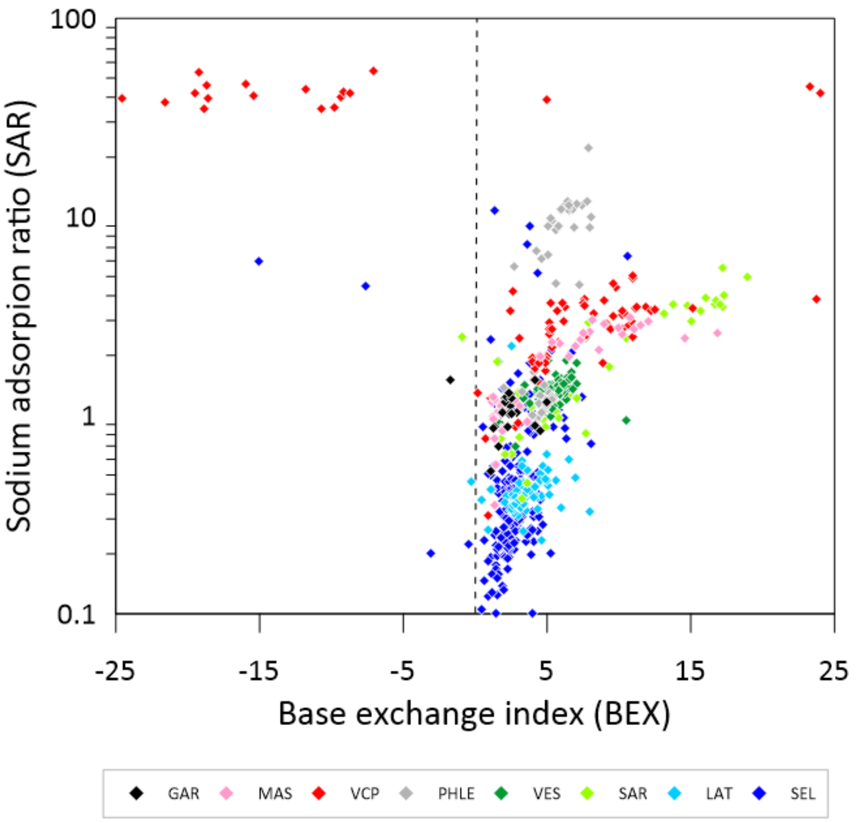


Figure 7: SAR versus BEX distribution for the morphological units of the Campania coastal area. The dashed line indicates stable conditions.

Considering the temporal trend of the BEX for selected monitoring wells in the VCP, SEL, PHLE and LAT morphological units (Fig. 8), even within the same unit, wells located in different area may have dissimilar behaviour. In VCP, the monitoring wells 28 and 6, both located in the greenhouses area where groundwater abstraction is particularly intense, show acceptable SAR values during the whole monitoring period, conversely BEX remains positive in well 6 (located 8500 m from the shoreline) with values around 5, but in well 28 (located 4250 m from the shoreline) BEX shows a progressive decrease from 9 in 2016 to almost 0 in 2018. In SEL, the monitoring well 24, located in the greenhouse area at 820 m from the shoreline, shows low SAR values but with an increasing trend from 2013 to 2018; its BEX values are often close to zero and a negative BEX was recorded in 2013. The monitoring well 22, located at the edge the greenhouses area at 6410 m from the shoreline and right downstream to the Cervati carbonate massif (see Fig. 1), shows low values of SAR, and BEX values are always positive around 3. For the PHLE 1a monitoring well (located 2350 m from the shoreline) it is interesting to note that SAR and BEX have concordant trends, meaning that they are not governed by variable boundary conditions (like SWI, groundwater fluctuation and/or local recharge) but rather by strong local drivers (like water rock interactions and/or geogenic factors). In PHLE 1a SAR values are greater than 10 (high sodium hazard according to Hem, 1985) for most of the monitoring period with a peak of 22.3 in 2009; BEX values, though showing large oscillations, remain always positive. In the monitoring well LAT 4 (located 2300 m from the shoreline within the Lattari carbonate massif) SAR and BEX have nearly constant values of 0.5 and 3, respectively, for the whole monitoring period.

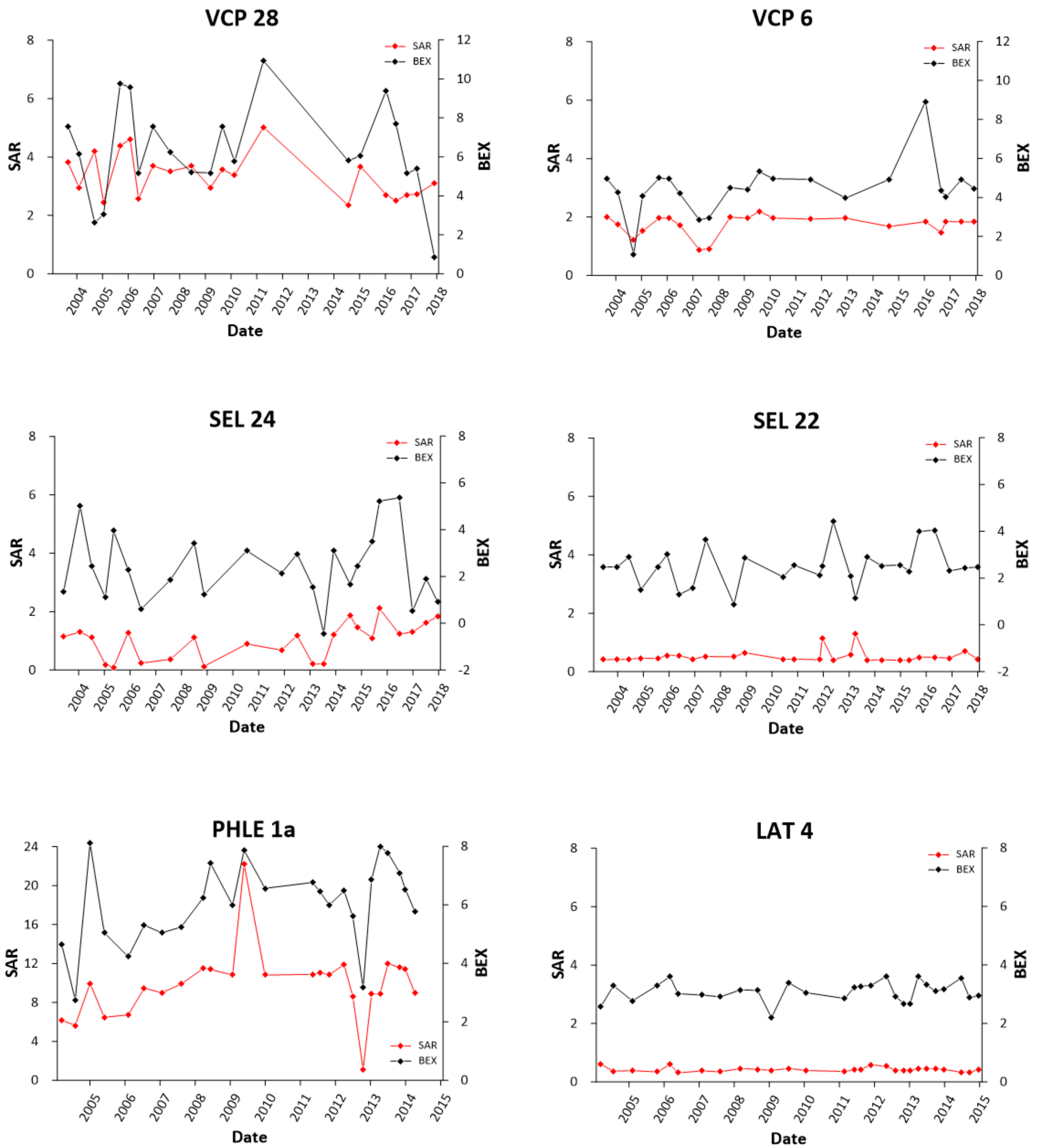


Figure 8: SAR and BEX trend during the monitoring period (2004-2018) for select monitoring wells of the study area.

4. DISCUSSION

From the analysis of the results, specific water rock interaction is the driver responsible for the salinization of a large coastal area of the Campania Region, especially between the volcanic districts of the Campi Flegrei (PHLE) and the Somma Vesuvio (VES, which also include the Sebeto Plain), where groundwater is slightly saline (Fig. 3-4) due to the combined effect of SWI, specific water rock interaction and geothermal fluids. This result is confirmed both from salinity index, SGQI and FA application. Here the main groundwater type is Na+K-HCO_3-SO_4 (see Fig. 2), with medium to high SAR values and high ECs, indicating strongly mineralized groundwater presenting important risk of soil salinization and alkalization, which makes groundwater unsuitable for irrigation (Fig. 5-6). Also, the SGQI evaluation showed in these zone and high degree of salinization and a low water quality for irrigation use. Accordingly with Factor 3 (Fig. S2) distribution, here the water quality is probably governed by strong local drivers (geogenic factors) and it is almost independent of the variability of phenomena such recharge, SWI and over pumping. It is evident from Figure S3 how within these two volcanic areas the continuous water rock interaction with volcanic materials (mainly tuffs) represents the main salinization factor. This is also witnessed by the statistical analysis (Table. 7) that shows no significant correlations between salinity, SAR and Na, Cl, well density and distance from the coast, for both PHLE and VES samples. Anyway, if these SWI phenomena play a role in defining the quality of the water in this area, they are however largely masked by water rock interactions and this leads to the consideration that even if the latter drivers should change in the near future due to climate and/or land use changes, groundwater quality should not undergo major changes. This assumption is also confirmed by the calculated SGQI evolution from 2006 to 2016 (Fig. 3c). Despite an albeit light increase of F1 in these areas, the water quality will be not subjected to significative changes, showing almost the same SGQI values in the two investigated periods (yellow dots in figure 3c). D'Alessandro et al. (2011) and Paternoster (2019) found similar behaviour for the Etnean and Vulture areas, respectively.

Even in the Lattari carbonate massif (LAT), groundwater quality is mainly driven by water rock interaction, with a Ca-Mg-HCO_3 type (where Ca is largely prevailing on Mg, Fig. 2), but in this case groundwater is fresh

(Fig. 2) with low SAR and EC values (Fig. 5) and nearly constant BEX values close to zero (Figs. 6 and 7), indicating a stable situation. Also in this case, the statistical analysis (Table 5) show no relevant correlations. The good quality and the large amount of groundwater reserves hosted within this massif have ensured that it is used for drinking purposes. The exploitation of this coastal aquifer did not show any worsening between the monitoring campaigns of 2006 and 2016 and it is believed that, given the large regional recharge feeding this aquifer, there will be no considerable variations in the near future. Likewise, the Garigliano Plain (GAR) shows Ca-Mg-HCO_3 groundwater type with good quality as regards salinity, EC, SAR, BEX and SGQI. This is mostly due to the positive groundwater/surface water interaction which sees the Garigliano River feeding the highly permeable aquifer with a considerable discharge (see Table 3) coming from large springs which drain vast carbonate massifs of the Apennines chain (Saroli et al., 2017). Once again from the statistical analysis (Table 5) no significant correlation was found between salinity, SAR, and the considered parameters. The groundwater of the Garigliano plain is suitable for irrigation and its suitability it is believed to last on the long term, given the massive regional freshwater flux.

Another relevant process affecting the quality of groundwater in the coastal area of the Campania Region, is mixing among different water types, which in some cases lead to salinization.

The groundwater in the Mount Massico (MAS) is Ca-Mg-HCO_3 type but due to the proximity to the volcanic district of the Roccamonfina, a high content of Na+K is also recorded (Fig. 2). Moreover, this area is affected by the circulation of geothermal fluids that rise towards shallow aquifers thanks to the presence of extensive tectonic lines. like the regional fault Ortona-Roccamonfina; (Cuoco et al., 2017b). This geological setting favours the mixing of different water end-members which is responsible for the moderate salinity recorded in this area (Corniello et al., 2018) (Fig. 3), accordingly MAS samples line up along the dashed mixing line of Figure5, showing an enrichment in B, precisely attributable to deep geothermal fluids (Pennisi et al., 2006). Most MAS samples show high SAR and EC, indicating strongly mineralized water presenting important risk of soil salinization and alkalization (Fig. 5). According to the statistical analysis (Table 5), salinity is strongly correlated to Mg, Na and Cl concentration and negatively related to the distance from the coast and the well density, indicating that the origin of the salinization is not imputable to the interaction with seawater (proximity to the coast and over pumping inducing inland migration of the freshwater/saltwater interface) but rather to the mixing with highly mineralized water of geogenic origin. Accordingly, SAR is positively correlated to Cl and negatively to WD. These features make the water unsuitable for irrigation.

Even in the Sarno plain (SAR) mixing is the main driving process of groundwater salinization, as clearly emphasized by the Stiff diagram in Figure 2. The area is characterized by slightly saline groundwater with variable SAR and EC contents. A group of SAR samples shows extremely high SAR and EC values (C4S4 in Fig. 5); these samples are the ones that plot along the freshwater/geothermal mixing line (Fig. 4) indicating the interaction among the regional groundwater flow coming from the Somma-Vesuvio and the one coming from the Lattari Massif. In fact, recently has been pointed out that both feed the aquifer hosted in the Sarno Plain (Lasagna et al., 2020). The remaining SAR samples show much lower SAR and EC values, indicating groundwater that is usable for irrigation at specific conditions, like in well drained soils with low CEC. According to Table 2, the main soil type found in the Sarno plain (Deep Fluvic Cambisols) shows these specific features, so that the groundwater in the inland portion of the plain may be considered suitable for irrigation. The results of the statistical analysis confirm that salinity is not related to actual SWI (negative values of DC and WD), but rather to local mixing processes with highly mineralised waters; in the same way, SAR is positively correlated with Cl and K. It must be admitted that the high values of Na+K and Cl would suggest that saltwater intrusion may play a role in this area, but like for the water rock interaction in PHLE and VES areas, if other phenomena play a role in defining the quality of the groundwater in SAR, they are however largely masked by mixing processes.

In the Volturno Coastal Plain (VCP), the area to the left of the Volturno River is characterized by slightly saline groundwater inland and by highly saline groundwater in proximity to the coast. This latter zone expanded in the 2016 monitoring campaign, compared to the 2006 one (Fig. 3, 4). SAR and EC show medium to extremely high values, making most of the coastal groundwater unsuitable for irrigation (Fig. 5). Moreover, the BEX show negative values for some wells close to the shoreline, indicating that cation exchange with saline water intruding in the aquifer is still in progress in this area (Fig. 6), as confirmed by the BEX trend of VCP monitoring well 28 (Fig.7).

From the statistical analysis (Tab. 5) it is clear that groundwater salinization is this area should be attributed to SWI (positive values for Na, Cl, Mg and SO_4) probably due to overexploitation of resources (positive values for WD) to be attributed to the high irrigation requirements of the intensive agriculture (e.g. see greenhouse extension in Fig. 1). It is clear that in VCP, local geomorphological features, like below sea-level topography, natural subsidence and coastal erosion (Tab. 1), worsen by the anthropogenic impact (land reclamation, urbanization and intensive agriculture) induce a general inland groundwater gradient, which lead to the inland migration of the freshwater/saltwater interface. What it is not possible to assess is whether the worsening of the groundwater quality is only due to actual SWI or if paleoseawater upconing is also contributing to groundwater salinization. The existence of low permeability saline lenses pertaining to the Lower Pleistocene, when most of the Plain was occupied by transitional and shallow marine environments (Amorosi et al., 2012), make it reasonable to speculate that even the latter mechanism may play a role, but the information considered in this study do not make it possible to distinguish between the two processes. A clue of this phenomena can be given observing the result of F1 evolution and its correlation with groundwater quality. In fact, despite a decrease F1 intensity in these areas, the GSIQ did not register appreciable variations.

In this contest it is clear that not only the intensive use of water resources (both surficial and below ground ones) for irrigation has impacted groundwater quality in VCP, but also that it will continue to worsen if alternative strategies to safeguard coastal aquifers are not put in place. The impact of climate and land use changes (variation in precipitation regime, total rainfall reduction, decrease in the Volturno River discharge, expansion of the greenhouse area) have already proved to be harmful in VCP, as in many other Mediterranean coasts (Moutahir et al., 2017; Ertürk et al., 2014), and are believed to show even more negative effects in view of the forecasted increase of the population and of the irrigation needs in this area (Reimann et al., 2018; Malek et al., 2018, von Gunten et al., 2015), as already demonstrated by predictive modelling on a small portion of the VCP coast (Mastrocicco et al., 2019).

Similar issues are also affecting the Sele Plain (SEL), were a shift from fresh to slightly saline groundwater was registered in 2016 (Fig. 3), once again in the greenhouse expansion area. Most of SEL samples show low SAR and EC, indicative of good quality water, suitable for irrigation, which comes from the regional recharge of the nearby carbonate masses surrounding the plain (Fig. SM1), as also testified by the prevailing Ca-Mg-HCO_3 water type (Fig. 2). Anyway, a few monitoring wells (e.g. SEL 24 in Fig. 7), which are not interested by salinization, show decreasing values of BEX in the last few years suggesting a progressive risk of SWI (Fig. 3c), which seems here the only reason for the deterioration of the water quality for irrigation, as confirmed by the positive correlation between SAR and Cl (Table 5).

Table 7: Selected Pearson coefficients representing the variables that most influence Salinity and SAR in coastal plains (GAR, VCP, SAR, SEL), volcanic districts (PHLE and VES) and carbonate massifs (MAS and LAT).

	Salinity						**SAR**		
	Mg	**Na**	**Cl**	**SO_4**	**DC***	**WD#**	**K**	**Cl**	**WD#**
GAR									
VCP	0.98	0.99	0.99	0.98		0.94	0.95	0.98	0.94
SAR					-0.87	-0.87	0.92	0.89	
SEL								0.95	
PHLE									
VES									
MAS	0.91	0.90	0.95		-0.99	-0.99		0.92	-0.90
LAT									

**Distance from the Coastline; #Well Density*

Like for the Volturno Plain, the main drivers of groundwater salinization are attributable to both natural (mainly erosion in the SEL area) and anthropic factors (mainly over abstraction due to a vast greenhouses area) are believed to be worsen by the climate and land use changes forecasted for the Mediterranean region, with the serious risk of making groundwater unsuitable for irrigation also in other coastal areas of SEL. Summarizing, especially in those areas characterized by high salinization risk, the implementation of anti-soil and groundwater salinization actions are mandatory further considering the various effect of climate and land use changes that will characterize the next decades (Uri, 2018). These countermeasures could range from more detailed analysis to better characterize SWI within coastal areas (Folch et al., 2020), to delineate suitable zone for managed aquifer recharge (Kazakis, 2018) and to the possibility to use natural zeolite as Na-filter conditioner in the soil (Ferretti et al., 2018).

5. CONCLUSIONS

The development of a conceptual model of a representative Mediterranean coastal area (the Campania Plain) has led to an improved spatial and temporal understanding of the hydrology and hydrochemistry of the system. The variation in the distribution of salinity between 2006 and 2016, together with highly positive and highly negative BEX values indicating unstable conditions for the future, suggest that the groundwater system has not equilibrated to the significant changes imposed by both natural and anthropic stresses to the system. This demonstrates the importance of considering the slow temporal dynamics of groundwater responses in coastal areas. Given the large size of the study area, this demonstrates the major impact that widespread anthropic activities can have on groundwater system behaviour and quality, despite the dominant influence that local geological, stratigraphic, and morphological features exert on the area. The rapid, and largely uncontrolled, expansion in groundwater exploitation in some cases is not physically sustainable in the longer term, and in numerous others can lead to aquifer degradation. The most evident of these involves aquifer salinization, which is quasi irreversible, and could be a problem for virtually all uses, and in particular for irrigation. This study has demonstrated that sound conceptual models and spatial-temporal data analysis can contribute to the objective understanding required for the design, management, and operation of irrigation strategies in coastal areas, under changing climate and local environmental pressures.

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