SUSTAINABLE AGRICULTURE DEVELOPMENT UNDER CLIMATE CHANGE IN A KARST COASTAL REGION: THE CASE OF SALENTO (SOUTHERN ITALY)

Romanazzi A.[1], Gentile F.[1], Polemio M.[2],Trisorio Liuzzi G.[1]

1) University of Study of "Aldo Moro" – DISAAT, Via G. Amendola, 165, 70126 Bari, e-mail: romanazziandrea@gmail.com
2) CNR – IRPI Bari

Abstract: The coastal karst aquifers are known to be highly vulnerable to anthropogenic and natural changes, and in particular to the overexploitation of groundwater resources. They are of strategic relevance, especially for the coastal areas of Asia, USA and Mediterranean Countries, where the urbanization and human activities are highly developed. In these coastal zones, densely populated areas and intensive agricultural activities always demand greater quantities of water to support their economy. Climate change may particularly aggravate these requirements, especially in the Mediterranean areas, due to the combined effects of reduced recharge and consequent increase of discharge. In addition, the seawater intrusion processes involve a deterioration of the water resource quality. These problems highlight the importance of a serious reflection on water resources management to ensure agricultural sustainability and good fresh water supply of the coastal areas. In Italy, Apulia, with its coastline extending over 800 km, is the region with the largest coastal karst aquifer. The predominant karst Apulian features make the region extremely poor of surface water resources but, at the same time, rich of groundwater resources, which allow the improvement of agricultural activitiejknbews in the whole region. In particular we focus on a coastal groundwater system that is already threatened by a high seawater level: Salento Peninsula. The aim of this paper is to simulate the effects of climate change on recharge, sea level rise and increase of crop water demand, using density-depending numerical codes MODFLOW and SEAWAT. A large-scale approach was chosen to assess the efficacy of modelling as a new management tool, and to develop predictive scenarios taking into account the irrigation needs.

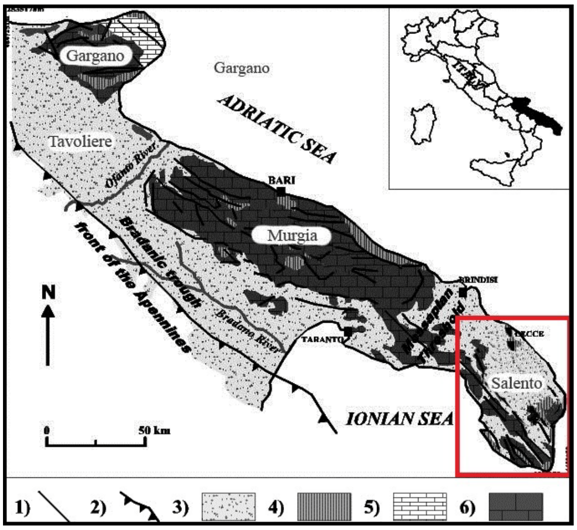
Key words: Seawater intrusion, numerical modelling, MODFLOW, SEAWAT, climate change, coastal karst aquifer

1. INTRODUCTION

Water is the most important resource for the survival of living organisms, for human health and related activities. Groundwater today meets the hydro-drinking needs of 2 billion individuals (Morris et al. 2003), supports the agricultural production of 230 billion dollars (Saha et al., 2007) and is an essential support for the development and growth of groundwater-dependent ecosystems. With regard to the interaction between human activities and environment, water consumption data of the World Bank estimate that about 70% of the available water is used for agriculture and that in the next twenty years, under the pressure of irrigation, urbanization and globalization, global demand will double. It is estimated that already in 2025 the regions of "water stress", i.e. where the consumption of water is higher than its natural renewal, will extend to about two-thirds of the world population (Rajan et al., 2006). Focusing on the Mediterranean countries, it is estimated that in 2025 no countries will have a resource of more than 500 m^3 pro capita per year, that is equivalent to the “minimum human consumption” (Rajan et al., 2006). This problem is even more important in the coastal areas, where population is concentrated, causing an overexploitation of water resources, especially where groundwater is the only source of water supply for drinking and irrigation needs. This problem is more emphasized in the case of coastal karst aquifers present in almost all the countries of the Mediterranean Basin and in particular in Italy, in the regions of Friuli, Sardinia, Lazio, Campania, Sicilia and Puglia. The aim of this paper is to describe the hydrogeological modeling and subsequent predictive scenarios for the karst aquifer of Salento. This modeling has been developed through the use of the numerical codes MODFLOW (McDonald and Harbaugh, 1998) and SEAWAT (Guo and Langevin, 2002). The approach chosen was the "partially physical-conceptual model", with the hypothesis of equivalent porous medium. The objective of the modeling is to define a new management tool for the future needs of groundwater in the Salento aquifer, where tourism and agriculture needs accounts for approximately 70% of groundwater resources, generating an uncontrolled overexploitation.

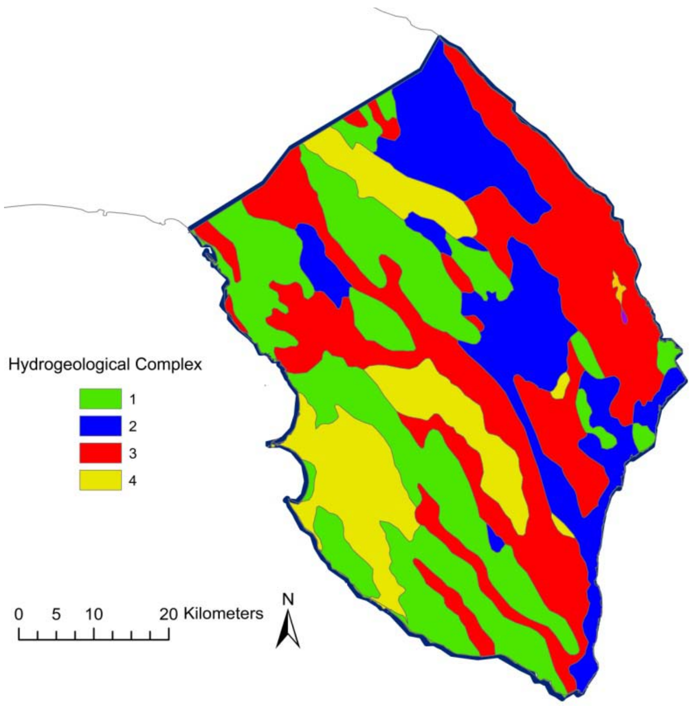
2. HYDROGEOLOGICAL FEATURES OF THE STUDY AREA

Apulia can be divided into four hydrogeological structures: Tavoliere, Gargano, Murgia and Salento, the last three being of karst origin (Fig. 1).



(Fig. 1) Geological scheme of Apulia. 1 Fault, 2 Front of the Apennines, 3 Recent clastic cover (Pliocene– Pleistocene), 4 Bioclastic carbonate rocks (Paleogene) and calcarenites (Miocene), 5 chert-carbonate rocks (Upper Jurassic-Cretaceous), 6 carbonate platform rocks (Upper Jurassic- Cretaceous). Red Line: study area

The study area, Salento Peninsula, has an Horst and Graben tabular morphology and extends for 2328 km^2 with a coastline of 175 km. Five hydrogeological complexes can be distinguished (Fig. 2).



(Fig. 2) Map of the hydrogeological complexes: 1) Limestones (including pre-neogene limestones of Altamura Limestone, Castro Limestone and Porto Badisco Calcarenite) 2) calcarenites and calcilutites (referable to Lecce Stone

and Andrano Calcarenites) 3) calcarenites (referable to Gravina Calcarenites or Salento Calcarenites) 4) sands (referable to marine terrace deposits). The fifth hydrogeological complex, Clays, in not reported as it is not outcropping.

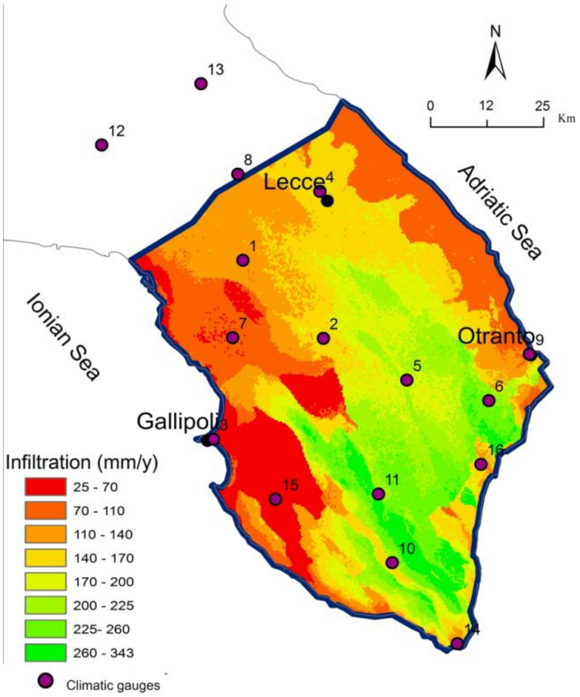
The Upper Cretaceous limestones are attributed to a shallow-marine carbonate succession known as Altamura Limestone. The Paleogene units outcropping in the study area are represented by successions which mainly have a calcarenite composition of platform environment. These successions are related to two overlapping stratigraphic units: Castro Limestone (Eocene-Oligocene) and Porto Badisco Calcarenites (Oligocene). At the top of the Pre-Neogene limestones, the Miocene transgressive calcarenites and calcilutites are found, they are represented by Pietra Leccese (Lecce Stone) and Andrano Calcarenites (Ciaranfi et alii, 1988). The Plio-Pleistocene formation is represented by Salento calcarenites (Lower Pleistocene). Finally, this area is characterized by the outcrops of Pleistocene sandy-calcarenite deposits made up of a succession of marine sediments, called terraced marine deposits (Middle and Upper Pleistocene). In this geological context, five hydrogeological complexes can be distinguished: limestones, calcarenites and calcilutites, calcarenite, clays and sands (Romanazzi and Polemio, 2013). In the limestone hydrogeological complex the groundwater aquifer is under pressure having at the top a complex of calcarenites and calcilutites, particularly in the eastern part of the peninsula. The piezometric gradient is generally low (0.3-0.5% as mean value), with maximum height values lower than 5 m a.s.l. Where limestones do not outcrop, some shallow aquifers can be distinguished, often limited in extension and generally interconnected with the deep aquifer (Calò et al., 1992; Maggiore and Pagliarulo, 2001).

3. HYDROLOGICAL AND AGRICULTURAL BALANCES

An important input of the model was the water budget, the estimate of cultivated areas and type of crop water requirements. The hydrological balance in karst aquifers is particularly influenced by the role of epigean karst forms and by the presence of endorheic areas. In the study area, or its immediate surroundings, monthly data from 1915 to 2000 were used, relating to 15 rain gauges (9 of which were also thermometric). Multiple linear regressions of precipitation and temperature have been elaborated as a function of altitude and distance from the Adriatic Sea with R^2 values respectively equal to 0.94 and 0.93. From this analysis, the mean annual rainfall value resulted equal to 730 mm. This value is in accordance with other sources, such as COST (2005), which estimates that the average rainfall in the Salento is 700 mm, including portions of the territory north of the study area with less rainfall. The rainfall increased in the area moving from NW to SE, while the temperature varied from 16 to 17.5 °C. Evapotranspiration was calculated through the formula of Turc and ranges between 473 and 602 mm. The effective rainfall was calculated cell by cell as the difference between rainfall and Turc evapotranspiration. Subsequently the infiltration was calculated using the coefficients of infiltration for each hydrogeological complex (Table 1) and multiplying them by the effective rainfall (fig.3).

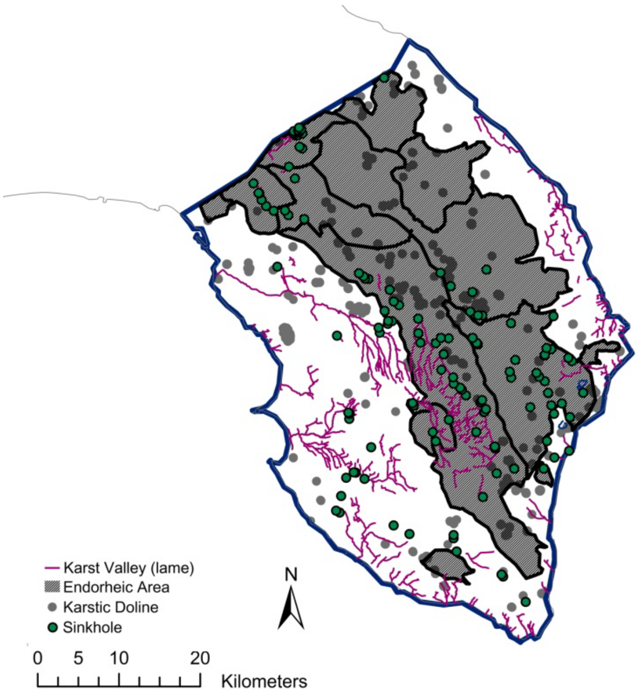
Hydrogeological Complex	Range	Mean Value
Limestones	0.75 - 1	0.9
Calcarenites and calcilutites	0.55-0.65	0.6
Calcarenites	0.6-0.8	0.7
Sands	0.3-0.4	0.35

Tab.1 Coefficients of infiltration of the hydrogeological complexes



(Fig. 3). Based on the knowledge on climate trends in southern Italy and the actual availability of continuous time series free from gaps, the 1925-1975 period was selected to determine the monthly and annual average values and characterise those hydrological factors to be applied in the steady-state simulations.

Particularly important are the endorheic areas. In fact the study area is characterised by the presence of an extended karst surface morphology that can create direct link between rainwater and the deep karst system. More of 1300 sinkholes and doline (Alemanno et al., 2009) were identified in Salento and lot of karst valley named “lame”. Endorheic areas and superficial karst formations were thus bounded in the GIS, analysing the altimetry, the geomorphological cartography and all of the information derived from the available geological and topographical cartography (Fig.4). For the endorheic areas, a value of the effective infiltration coefficient equal to one was assigned regardless of the hydrogeological complex.



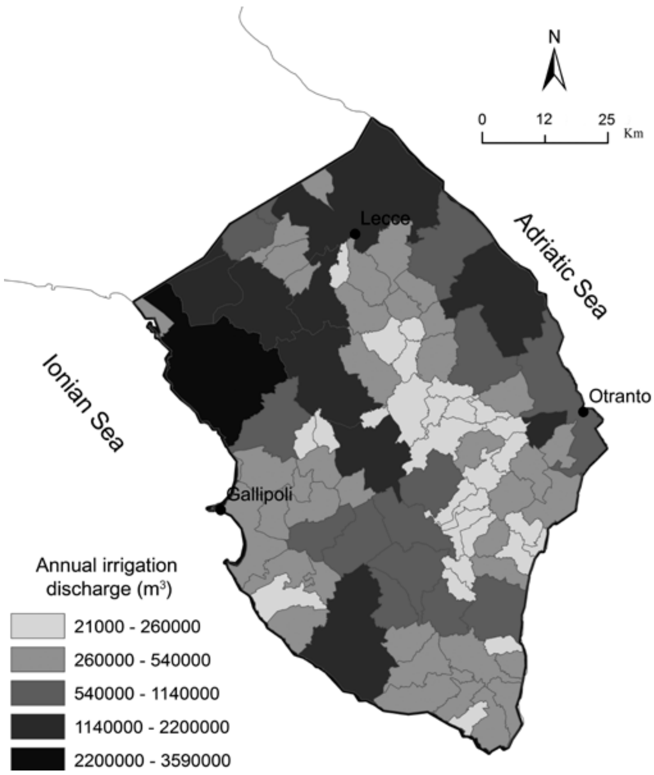
(Fig. 4) Map of karst surface and sub-surface forms

Discharges from groundwater are an important element for budget estimation and management of groundwater resources of the area. According to the National Institute of Statistics Data, (ISTAT, 2000) the region covers about 2 million hectares, of which 1.43 million are used for agriculture. The utilized agricultural area thus accounts for 72% of the total area and is composed by the 49% by arable land, 43% by tree crops and the remaining (about 8%) by meadows and cereals. In this scenario a strategic importance is given to irrigation. Irrigated agriculture accounts for 43% of the value of all agricultural production in the region. Focusing on the study area, the irrigated area detected by the National Institute of Agricultural Economics (INEA), using an infrared satellite, accounts approximately to 43,040.69 ha (INEA 2001), while only 15,638.03 ha were declared by ISTAT (ISTAT 2001). To eliminate the problem of unauthorized discharge INEA and ISTAT data were combined. INEA identified irrigated areas flying over by plane, which allowed to identify abusive crops, not reported in ISTAT data, based on self reporting thus only showing which are the cultivated areas, without distinguishing between irrigated and non-irrigated. A ratio factor was calculated at the municipal level, by crop type, merging among INEA irrigated and ISTAT cultivated areas. To calculate crop needs, the territory was divided into homogeneous climatic areas (H.C.A.) and then the annual irrigation requirement for each of the considered crops was calculated. The irrigation requirements computation took into account also the distribution efficiency, estimated to be approximately 80 to 90% for drip and sprinkler irrigation methods. In order to make a comparison with the INEA data 5 groups were identified, namely herbaceous open field (cereals, corn, foraggifere), horticultural crops (including potatoes and legumes) , vineyards, fruits and olive trees (Tab. 2).

Group of crop	**irrigation requirement (m^3ha^{-1}) H.C.A. 6**	**irrigation requirement (m^3ha^{-1}) H.C.A. 9**
Grapevine	2737	2870
Olive tree	849	863
Fruit	4257	4325
Cereal	2848	2848
Vegetable	2384	2384

Tab. 2 Subdivision of crops for homogeneous climatic areas

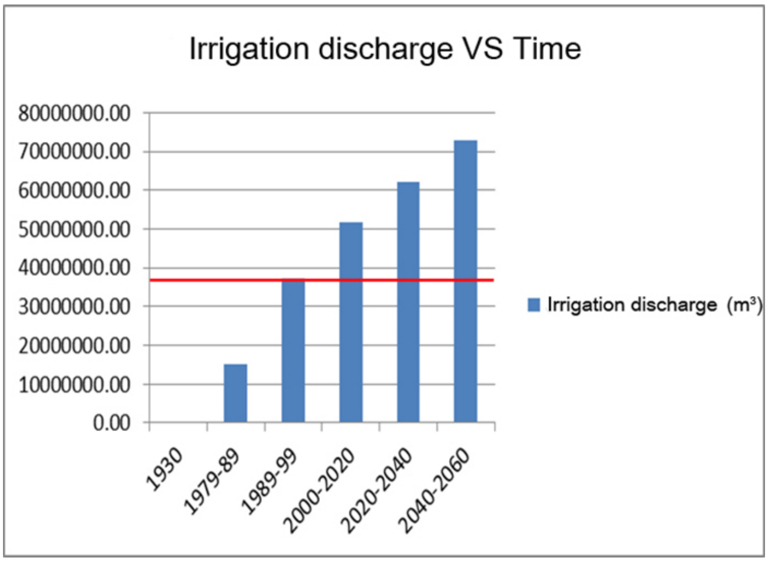
The annual irrigation requirement resulted equal to 51,772,279 m^3 for a total irrigated area of 40.528 m^2 (Fig.5). To relate these data to the time intervals examined, ISTAT data available from 1971 to 2001 were used to estimate the growth trends of the agricultural activity. Concerning the consumption of drinking water, AQP (Apulian Aqueduct) data were used.



(Fig. 5) Map of annual irrigation discharge in each municipality

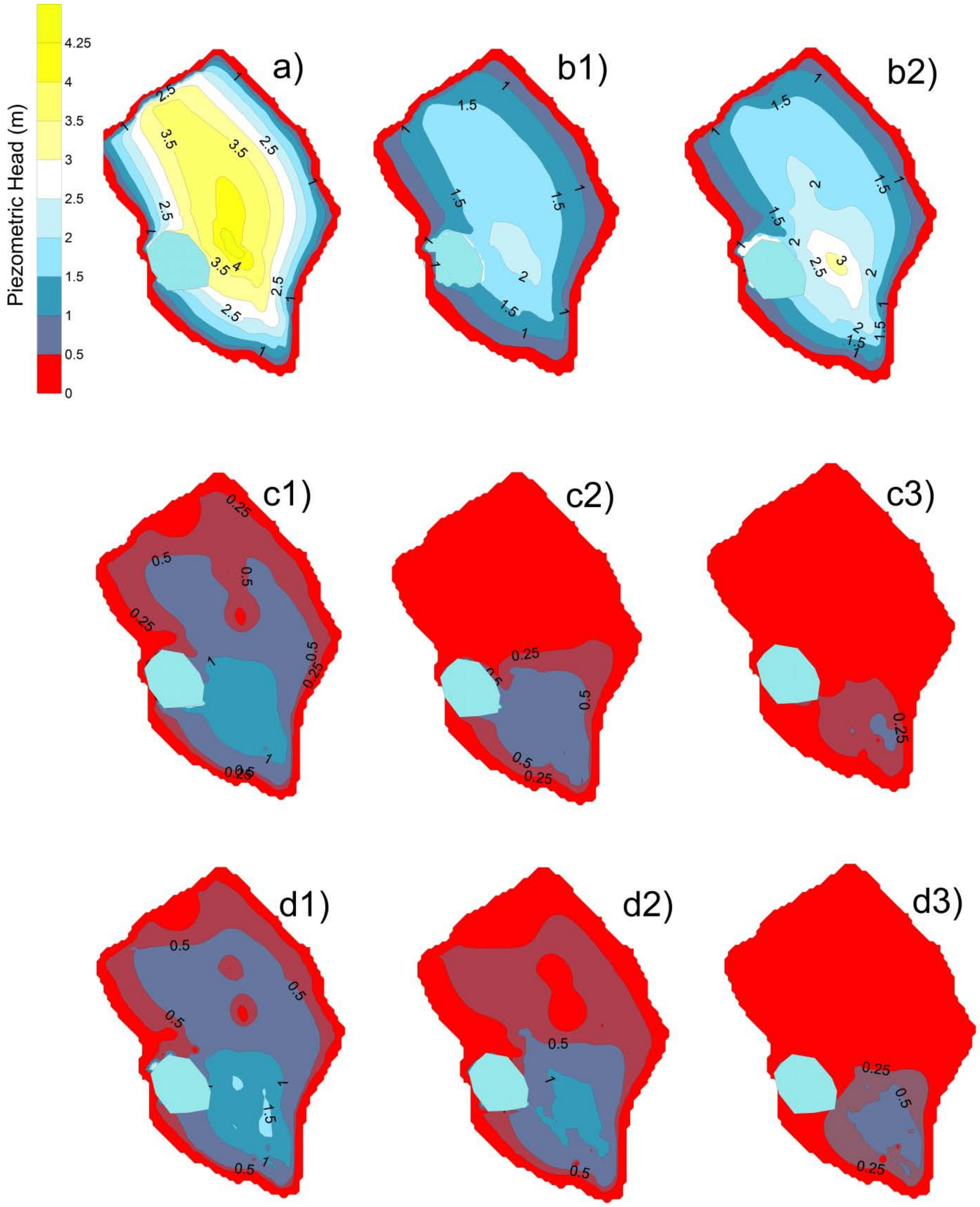
4. NUMERICAL MODELING AND FORECAST SCENARIOS

For the implementation of the model a finite difference approach based on the assumption of equivalent porous medium was used. The numerical codes used were the groundwater flow code MODFLOW (McDonald and Harbaught, 1988) and the SEAWAT code (Langevin et alii, 2003b) for simulating three-dimensional variable density groundwater flow. The active domain (active cells) covered an area of approximately 2,300 km^2 with 45,925 cells. To define the surface morphology (altitude from 0 to 214 m a.s.l.) a DEM ASTER was used with a resolution of 25 meters. As boundary conditions , a Dirichlet condition for the coastal boundary was used, a no-flow condition for the border areas, while to simulate the discharges a Cauchy condition was used in each cell where wells were assigned. The recharge condition was applied to all active cells. The model was run into steady-state condition and then calibrated through the use of the Non-Linear Parameter Estimation (PEST) code. A correlation coefficient equal to 0.903 and a standard deviation equal to 0.33 were obtained. The model was validated on 1979 and 1989. Romanazzi and Polemio (2013) describe in details the implementation, calibration and validation of the model. On the basis of the calibrated model six transient scenarios of the resource, referred to the twenties 2000-2020, 2020-2040 and 2040-2060 have been implemented, with the aim of predicting their piezometric level and defining their decreasing trend. With regard to climate and its change in the Mediterranean Basin, literature offers many examples of predictive models. For temperatures, all the models agree on an increasing trend (Gibelin and Deque, 2003; Goubanova and Li, 2007; Alpert et al., 2008; Jacobeit and Hertig, 2008; Sanchez-Gomez et al., 2009), while for the precipitation trends are conflicting. In this model the hypothesis of a general decrease of rainfall was assumed (Ragab and Prudhomme, 2002; Gibelin and Deque, 2003; Giorgi et al., 2004; Goubanova and Li, 2007). In detail, with regard to rainfall, for the twenty years from 2001 to 2020 a reduction of precipitation equal to 3.95% with respect to the '90s value was applied, while for the twenty years from 2021 to 2040 and from 2041 to 2060 a decrease of 6.05% was considered in both cases. As for the temperature, an increase of 0.9, 1.5 and 2°C respectively for the three above mentioned decades was implemented (Brunetti et al., 2004b; Bertin, 2008; Giannakopoulos et al., 2005; Giorgi and Lionello, 2008). A new water budget for the years 2020, 2040 and 2060 was then implemented in the model with a subsequent reduction of recharge, respect to the 2000, of 16.7%, 33.6% and 50%, according to other climate forecasts (Stigter et al., 2012). The new discharges were then implemented. In fact, in view of the climate change, water demand will increase, especially in the agricultural industry. Manufacturing and drinking consumptions were assumed unchanged in the three scenarios and equal to the 2000 discharges. For manifacturing an average value of 6.00 mm/y allocated on the territory was considered, giving a total amount of 293430.26 m^3, while for drinking the consumption was assumed equal to 98135677.98 m^3. As regard to the irrigation, not being possible to predict discharges, two hypothesis have been made. The first assumes that the pressure on groundwater resource will further rise and crop demand increase due to climate change (Dragoni and Sukhjia, 2008; Goderniaux et al., 2008). A linear increase of the discharge was considered, by a percentage equal to the decrease of infiltration (fig. 6). In the second hypotesis the irrigation discharges were left constant and equal to those of the years 1989-1999 (fig. 6). In both cases in the last scenario (2040-60) a rising sea level equal to 0.05 meters was also considered (Giorgi and Lionello, 2008).



(Fig. 6) Data and projections of irrigation discharge in Salento. Red line shows the cubic meters of irrigation used in the hypothesis of constant irrigation discharge

To describe the changes in the piezometric head and to compare them with the previous stationary simulation in the thirties and with 1979-1989 and 1989-1999 data, the most representative layer, placed between -50 and -100 m above sea level, interested in general by the presence of freshwater, was considered. In this level, there is also a shallow aquifer of modest size in the sand formations that is not important in the study of the deep aquifer. The comparison between the '30s years (Fig.7a) and ninety (Fig.7b1-7b2) scenarios showed a drawdown ranging from 0.1 to 2.5 meters. The scenarios identified in Figure 7 as "c" show the trend of piezometry in 2000-2020, 2020-2040 and 2040-2060 in the case of an increase of the irrigation discharge. The results show, with the selected hypothesis, an important decrease of the piezometric head in the next sixty years. In the case of the constant discharges scenario (fig. 7d1-d2-d3) the lowering of the groundwater level is lower but also considerable in the long period.



(Fig. 7) Different piezometric scenarios simulations – a) Steady state simulation on Thirties; b1-b2) Transient simulation on 1979-89 and 1989-99; c1-c2-c3) Transient simulation scenarios with increase of irrigation discharges; d1-d2-d3) Transient simulation scenarios with constant irrigation discharges. In blue the shallow aquifer.

The same scenarios were used to evaluate the seawater intrusion in the aquifer as lateral saline intrusion and upcoming phenomenon (Post and Barca, 2010). The SEAWAT code was used to model and understand the relevant salinization process. In particular the constant irrigation discharge was overlook and the less precautionary hypothesis, the linear increase of irrigation discharge, was considered. The same layer, the -50 and -100 m above sea level, was chosen as the most representative. The comparisons between the '30s years (Fig.8a), the ninety (Fig.8b1-8b2) and the following 2000-2020, 2020-2040 and 2040-2060 (Fig.8b1-8b2) scenarios show a low but constant increase of the salinity concentration, especially near the more important discharge areas like the well fields hold by AQP.

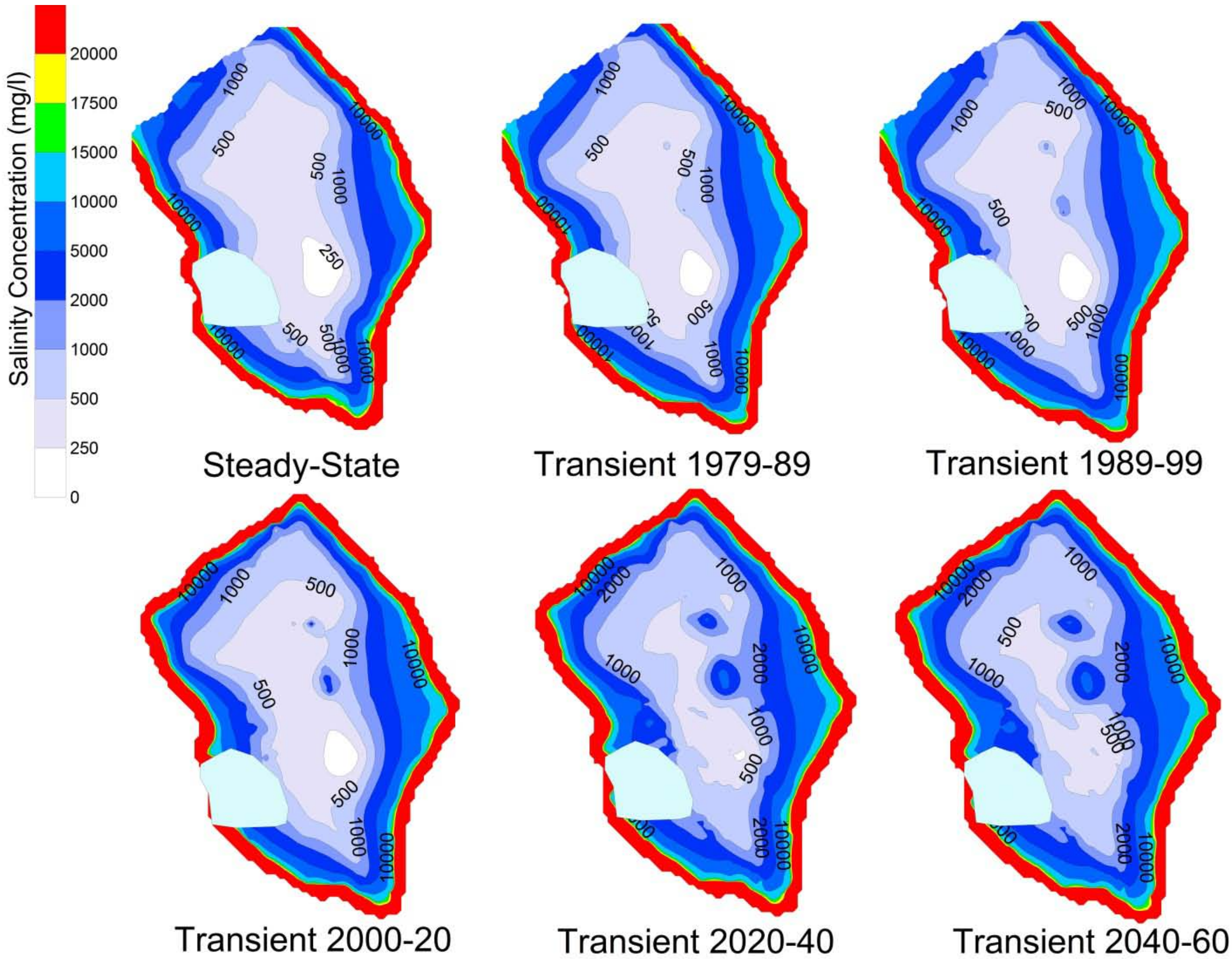


Fig.8 Different simulations referred to salinity concentration scenarios– a) Steady state simulation on Thirties; b1-b2) Transient simulation on 1979-89 and 1989-99; c1-c2-c3) Transient simulation with increase of irrigation discharges

CONCLUSIONS

In the last century we witnessed an increase of the population concentration in coastal areas on a global scale. This trend is often associated with a growing demand for water, which is satisfied mainly using groundwater resources. It is estimated that 25% of the world's population uses such resources for drinking purposes, especially in Southeast Asia, in the United States and in Mediterranean countries. In Europe many countries receive 50% of drinking water from groundwater karst systems. This over-exploitation of the groundwater involves a quantitative and qualitative degradation of the resource. For example, the phenomenon of seawater intrusion is becoming a more serious problem for most coastal aquifers. New management approaches, also based on the use of numerical models, and correct hydrogeological balances are increasingly necessary. Focusing on a study area, a hydrogeological model was used to define forecast scenarios and help stakeholders to test new hypothesis about the management of groundwater, in relation to the effects induced by climate change. The results show a general decrease of the piezometric head and a deterioration of water quality caused by seawater intrusion. It clearly appears how the coastal aquifer of Salento is generally overexploited. It is concluded that for a sustainable management, it becomes necessary to adopt appropriate land use policies and to implement new management techniques. Furthermore the use of hydrogeological models like the one presented here, can help policy makers to know the future availability of groundwater and the dynamics of seawater intrusion, in the perspective of defining new agricultural strategies.

REFERENCES

Alemanno D., Damato B., Denora D., Di Santo A.R., Fiore A., Iacobellis V. and Intini V., 2009. il ruolo delle voragini nella valutazione della pericolosità idraulica delle aree endoreiche della penisola salentina, in Atti Workshop Internazionale I Sinkholes, Roma 3-4 Dicembre 1999.

Alpert, P., Krichak, S.O., Shafir, H., Haim, D. and Osandinsky, I., 2008. Climatic trends to extremes employing regional modeling and statistical interpretation over the E. Mediterranean. Global and Planetary Change 63, 163–170.

Anekovic I., Antonic O., Krizan J., Bukovec D. and Bakran-Pandricioli T., 2006. Modelling basic physical parameters in the Adriatic Sea as the basis for marine benthic habitats mapping, Ecological Modelling, 194, 6-69.

Bertin, R.I., 2008. Plant phenology and distribution in relation to recent climate change. Journal of the Torrey Botanical Society 135, 126–146.

Brunetti, M., Buffoni, L., Mangianti, F., Maugeri, M. and Nanni, T., 2004. Temperature, precipitation and extreme events during the last century in Italy. Global and Planetary Change 40, 141–149.

Calò G., Gnoni R. and Stani M., 1992. Caratteri idrogeologici delle falde superficiali della penisola salentina e valutazione della vulnerabilità degli acquiferi, Amministrazione Provinciale di Lecce.

Ciaranfi N., Pieri P. and Ricchetti G., 1988. Carta geologica delle Murge e Salento, Mem. Soc. Geol. It., 42.

Dragoni W and Sukhija BS., 2008. Climate change and groundwater: a short review. Special Publication No 288. The Geological Society London, pp 1–12

Giannakopoulos C., Bindi M., Moriondo M., le Sager P. and Tin T, 2005. Climate change impacts in the Mediterranean resulting from a 2°C global temperature rise. 2005. Report for WWF, 1 July 2005.

Gibelin, A.-L. and Déqué, M., 2003. Anthropogenic climate change over the Mediterranean region simulated by a global variable resolution model. Climate Dynamics 20, 327–339.

Giorgi, F. and Lionello, P., 2008. Climate change projections for the Mediterranean region. Global and Planetary Change 63, 90–104.

Giorgi, F., Bi, X. and Pal, J.S., 2004. Mean interannual variability and trends in a regional climate change experiment over Europe. I. Present-day climate (1961–1990). Climate Dynamics 22, 733–756.

Goderniaux P, Brouye`re S, Fowler HJ, Blenkinsop S, Therrien R, Orban Ph. and Dassargues A., 2009. Large scale surface – subsurface hydrological model to assess climate change impacts on groundwater reserves. J Hydrol 373:122–138.

Goubanova, K. and Li, L., 2007. Extremes in temperature and precipitation around the Mediterranean basin in an ensemble of future climate scenario simulations. Global and Planetary Change 57, 27–42.

Guo W. and Langevin C.D., 2002. User's Guide to SEAWAT: A Computer Program for Simulation of Three-Dimensional Variable-Density Ground-Water Flow, U.S. Geological Survey Open-File Report 01-4340.

Jacobeit, J., and Hertig, E., 2008. Downscaling future climate change: temperature scenarios for the Mediterranean area. Global and Planetary Change 63, 127–131

INEA, Istituto Nazionale di Economia Agraria, 2001. Stato dell'irrigazione in Puglia, 1, Roma.

ISTAT, Istituto Nazionale di Statistica, 2001. Rapporto annuale, Roma.

ISTAT, Istituto Nazionale di Statistica, 2011. Rapporto annuale, Roma

Langevin, C. D., 2003b. Simulation of Submarine Ground Water Discharge to a Marine Estuary: Biscayne Bay, Florida, Ground Water, 41, 6, 758–771.

Maggiore M. and Pagliarulo P., 2001. Groundwater vulnerability and pollution sources in the Apulian region (southern Italy), Proceedings 2nd Symposium "Protection of Groundwater from Pollution and Sea-water Intrusion", Bari (Italy), September 27 - October 1, 1999, 9-20.

McDonald M.G. and Harbaugh A.W., 1988. A modular three-dimensional finite-difference ground-water flow model, Techniques of Water-Resources Investigations of the United States Geological Survey, book 6.

Morris BL., Lawrence ARL. and Chilton P.J.C., 2003. Groundwater and its susceptibility to degradation: a global assessment of the problem and options for management, Early warning and assessment report series, RS. 03-3. UN Environment Programme, Nairobi, Kenya.

Post, V. E. A. and Abarca, E.: Preface: Saltwater and freshwater interactions in coastal aquifers, Hydrogeol. J., 18, 1–4, 2010.

Ragab, R. and Prudhomme, C., 2002. Climate change and water resources management in arid and semi-arid regions: Prospective and challenges for the 21st century. Biosystems Engineering 81, 3

Rajan P., Kazama S. and Sawamoto M., 2006. Effects of climate and land use changes on groundwater resources in coastal aquifers, Journal of Environmental Management, 80, 25-35

Romanazzi A. and Polemio M., 2013. Modelling of coastal karst aquifers for management support: Study of Salento (Apulia, Italy), Italian Journal of Engineering Geology and Environment, 13, 1, 65-83

Saha A.K., Saha S., Sadle J., Jiang J., Ross M.S. and Price R.M. 2011. Sea level rise and South Florida coastal forests. Climatic Change, 107, 81–108.

Sanchez-Gomez, E., Somot, S., and Mariotti, A., 2009. Future changes in the Mediterranean water budget projected by an ensemble of regional climate models. Geophysical Research Letters 36

Stigter, T.Y., Nunes, J.P., Pisani, B., Fakir, Y., Hugman, R., Li, Y., Tomé, S., Ribeiro, L., Samper, J., Oliveira, R., Monteiro, J.P., Silva, A., Tavares, P.C.F., Shapouri, M., Cancela da Fonseca, L. and H. El Himer, 2012. Comparative assessment of climate change and its impacts on three coastal aquifers in the Mediterranean. Regional Environmental Change. DOI 10.1007/s10113-012-0377-3. Published online 12 December 2012.