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EFFICIENT & SUSTAINABLE WATER SYSTEMS MANAGEMENT TOWARD WORTH LIVING DEVELOPMENT

Water resources vulnerability assessment in the Adriatic Sea region: the case of Corfu Island

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Abstract Cross-border water resources management and protection is a complicated task to achieve, lacking a common methodological framework. Especially in the Adriatic region, water used for drinking water supply purposes pass from many different countries, turning its management into a hard task to achieve. During the DRINKADRIA project, a common methodological framework has been developed, for efficient and effective cross-border water supply and resources management, taking into consideration different resources types (surface and groundwater) emphasizing in drinking water supply intake. The common methodology for water resources management is based on four pillars: climate characteristics and climate change, water resources availability, quality, and security. The present paper assesses both present and future vulnerability of water resources in the Adriatic region, with special focus on Corfu Island, Greece. The results showed that climate change is expected to impact negatively on water resources availability while at the same time, water demand is expected to increase. Water quality problems will be intensified especially due to land use changes and salt water intrusion. The analysis identified areas where water resources are more vulnerable, allowing decision makers develop management strategies.

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Introduction

As water meets no borders, water resources management and protection within the borders of a country is complicated. There are numerous variables that need to be analyzed for water resources management and water supply such as climate conditions, land use, and pollution pressures affect water quality and quantity; water pressure, asset aging, leakages, and supply standards are important for operation and maintenance of water supply, while pricing policies affect water demand. Socio-economic factors as well as institutional and political factors must be analyzed for water resources management. The complication level gets even higher when cross-border (CB) water resources are involved. It is quite common that water resources used for drinking purposes in one country have recharge area in another country. As water demand is expected to increase in the coming years and water resources may become overexploited, policy coherence is one of the top priorities in the water sector, not only within the borders of one country but also across borders (UN World Water Development Report 2015). The Water Framework Directive 2000/60/EC defined the need for cooperation between countries sharing the same water resources and requires from the member-states to manage and protect their water resources. In the EU territory, 40 (out of the 110 in total) river basins are identified as transboundary, covering more than 60% of the EU territory (CEC 2007).

The DRINKADRIA project deals with CB water resources management focusing in water supply, in the Adriatic region, aiming at the development of a common methodological approach. One of the project's activities was the CB water resources management. During the implementation of the project (2013–2016), many tasks were achieved: analysis and development of climate and climate change database for the Adriatic region; identification of present and future risks for water resources availability with emphasis in drinking water; determination of present and future water quality risks and the causes for drinking water quality deterioration; and development of guidelines and protocols for the protection and management of CB water resources. The present paper presents the methodology followed during the project regarding CB water supply and resources management. As previously stated, CB water supply and resources management is a complicated task to deal with. There are many CB water resources shared among different countries in the Adriatic Sea region as many of these countries faced political changes in the near past. There are cases where a region is supplied with water from the water resources of the neighboring country. This is why, the management of such CB water resources is so important. The paper presents the methodology followed in the project to assess the vulnerability of CB water resources in the Adriatic region with special focus on the island of Corfu in Greece.

Corfu Island is located in the northwestern part of Greece and is one of the Ionian Islands. The island faces significant water supply problems as sulfate concentrations are high in groundwater. Although it seems that water availability in terms of quantity is not an issue, the water quality problems together with saltwater intrusion and excessive tourism (as Corfu is one of the most touristic Greek Islands) may cause problems to drinking water supply.

Literature review

Vulnerability is defined as "the degree, to which a system is susceptible to, or unable to cope with, adverse effects of environmental change" (IPCC 2001). A natural and socio-economic system's vulnerability depends both on the character, magnitude, and rate of the hazard on the one side and the system's sensitivity and adaptive capacity on the other (IPCC 2014; NERI 2002; Hamouda et al. 2009; Jun et al. 2011). Water resources vulnerability is complicated, related to many different factors, both natural and human. Such factors include water availability and quality, pollution, population growth, competition over water, and knowledge gaps (Brooks et al. 2005; Hamouda et al. 2009). Climate change is generally recognized as a major threat for water resources and water supply as its impacts are already visible in temperature and precipitation indices (Arnell et al., 1996; Kaczmarek et al., 1996; Hewitson and Crane 2006; Chung et al. 2011; Jun et al. 2011). Georgakakos et al. (2012) in their study state that as future climate is more variable, the historical hydrologic regimes cannot deal with it in an effective way. They propose that climate change impacts on water resources need to be estimated instead of only analyzing the historical climate characteristics and how these affected water resources in the past. Baruffi et al. (2012) used a modeling approach to provide climate change hazard scenarios for groundwater systems in Veneto and Friuli Plain (Northern Italy). Climate, hydrologic, and hydrogeologic models were used to evaluate the impacts of climate change on water quantity and quality. The results showed that the mean temperature is expected to increase while mean precipitation changes are less straight forward. Mean winter surface runoff seems to be increased while mean summer surface runoff seems to decrease. In general, surface water availability will be decreased affecting groundwater and aquifers' recharge. The same case study was used by Pasini et al. (2012), who used a regional risk assessment (RRA) methodology to identify the climate change impacts on groundwater and associated ecosystems. The methodology provided targets and areas at risk from climate change. Gutiérrez et al. (2014) and Sisto et al. (2016) strongly suggest that adaptation measures need to be taken to reduce the consequences of water crises in the future. Climate change is expected to impact in different ways on water in general. This is why assessments on water resources and water supply vulnerability, estimation of water scarcity, and analyses of droughts are necessary tools. Shi et al. (2017) quantified the vulnerability of surface water resources in Haihe river basin in China using a function model based on sensitivity, adaptability, exposure, and drought disaster risk. The river basin is characterized by great conflict between water supply and demand, exposure to disasters, high risk of droughts, and poor water quality. The model took into consideration climate change characteristics too. The study results showed that future climate change increases the system's vulnerability which is affected mainly by exposure, water disaster risk, and water quality factors. Liu and Liu (2017) presented an index-based methodology to assess water scarcity risk due to drought. Drought hazard index, exposure index, and vulnerability index were used to assess water scarcity risk. Then, an integrated water scarcity index (WSRI) was proposed and estimated in Xiu river, China. The results showed that the risk was low in the upper and middle reaches of the river, being in agreement with the water resources exploitation and utilization level.

Many vulnerability indicators have been developed so far. Gleick (1990) connected vulnerability to climate change and applied five measures to major US water resources. Rogers et al. (1997) and Lane et al. (1999) developed environmental and water-related indicators, monitoring and assessing complex and dynamic systems such as economies and environmental systems. Lane et al. (1999) incorporated also poverty and economic strength indicators into the vulnerability index. Hurd et al. (1999) assessed the vulnerability of regional water resources using measures and criteria they developed, identified water-sensitive variables used at a regional scale consistent to the vulnerability measures, and applied their methodology to the US water resources. Hydrologic and socio-economic indicators have been used to form an integrated water resource vulnerability index (Raskin et al. 1997) and the impacts of climate change on US reservoirs have been assessed by Vogel et al. (1999). They used indicators of reservoir yield, reliability, resiliency, and vulnerability. Socio-economic aspects have been also taken into consideration, such as the water poverty index connecting water scarcity issues to socio-economic aspects (Sullivan 2002). Water stress index and adaptive capacity index are used to form a vulnerability index used in three sub-watersheds of the Bagmati River basin (Pandey et al. 2011). Balica et al. (2009) developed a flood vulnerability index by comparing vulnerability among river basin, sub-catchment, and urban areas. Vulnerability components including resource stress, development pressure, ecological security, and management challenges are used by Babel and Wahid (2009), Pandey et al. (2010), and Huang and Cai (2009). Stakeholders identified indicators forming a water vulnerability index in the South African portion of the Orange River basin (Sullivan 2011), giving the vulnerability index two dimensions: one from the part of water systems (supply-driven vulnerability) and the other from water users (demand-driven vulnerability). A study conducted by Gain et al. (2012) revealed research gaps regarding water resources vulnerability assessment and developed a framework applied at lower Brahmaputra River basin. A regional vulnerability assessment methodology has been used to evaluate coastal vulnerability (Torresan et al. 2012). The main aim of this study was to identify key vulnerable natural and human ecosystems, localizing vulnerable hot spot areas. The analysis was based on both bio-geophysical and socio-economic vulnerability indicators. The methodology was applied in North Adriatic Sea (Italy) ranking coastal receptors (beaches, river mouths, wetlands, etc.) in relation to climate change impacts. This methodology can be a useful tool to the decision makers in the spatial identification of the areas and in the definition of management options. Water resources are vulnerable in arid mountain areas due to environmental and climate change (Al-Kalbani et al. 2014). Pressures such as demographic trends, economic development, and land use changes affect directly water resources vulnerability. Al-Kalbani et al. (2014) assessed the vulnerability of water resources in Al Jabal Al Akhdar evaluating four components: water resources stress, water development pressure, ecological health, and management capacity. The results showed that water resources are facing excessive stress mainly due to ecosystem deterioration. The study revealed the aspects of water management contributing most to the water resources vulnerability, helping decision makers to understand various risks and suggest specific areas where management efforts should be more intensive. The study clearly stressed out the need to take specific technical measures and to define policies and strategies. Rawalpindi and Islamabad in Pakistan were the cases of the study by Shabbir and Ahmad (2015). They studied how climatic and non-climatic factors affect water resources vulnerability. Al-Saidi et al. (2016) developed a holistic country-based index (Country Vulnerability Index of Water Resources—CVIW) for the vulnerability assessment of water resources, instead of simple or sector-specific indices used so far. The index was used to provide a macro-level overview of water resources in the Middle East and North Africa, areas characterized by water scarcity. The index takes into consideration socio-economic and natural factors. The study showed that although water resources in the Middle East and North African countries will be vulnerable, it seems that they will be able to compensate extreme water scarcity in the future through trade, energy use, and technology. The Monterrey Metropolitan area of northern Mexico was the case for Sisto et al. (2016) to analyze climate change impact to water supply vulnerability. Simha et al. (2017) characterized water resources in the island of Lesvos in Greece using vulnerability assessment as a quantitative tool. A composite index was used based on a set of 25 indicators. High vulnerability values were estimated mainly due to natural and human pressures and a poor adaptive capacity. Simha et al. (2017) proposed a quantitative framework based on adaptive water management and vulnerability assessment for addressing water management problems. The study revealed that few studies quantify the impacts of management strategies to the vulnerability index.

Although water resources and water supply vulnerability assessments are addressed in the literature, only a few researchers have investigated measures and strategies for drinking water supply. Collet et al. (2015), Haque et al. (2015), and Meuleman et al. (2007) proposed such measures.

The methodology

CB water resources used for water supply are extremely important as they are used for drinking water needs. Many researchers dealt with water resources vulnerability using many methodologies and different indices. It is the first time that CB water resources vulnerability is assessed given that these resources are used for drinking water supply. It is generally accepted that water resources vulnerability is affected by climatic, hydrological, geological, and socio-economic factors. The methodology used for CB water resources management is based on four pillars: (a) climate characteristics and climate change; (b) water resources availability assessment; (c) water resources quality assessment; and (d) water resources safety and security assessment. The methodology applied examines the exposure (predicted changes in the climate), the sensitivity (how the system responds to climatic variability), and the adaptive capacity (the ability of a system to adjust to climate change). The study area covered is the whole Adriatic Sea region. To assess the vulnerability of water resources, nine test areas were selected during the project, located in all the countries involved (Italy, Slovenia, Croatia, Bosnia and Herzegovina, Montenegro, Serbia, Albania, and Greece). The test areas cover different types of water resources (surface, groundwater). The work elaborated during the project is very important for the specific region for the reasons mentioned earlier.

The first step is the analysis of the climate characteristics (temperature and precipitation) in national, regional, and test area level for the present state. The analysis was based on historical data from 1961 to 1990 as recommended by the World Meteorological Organization as the reference period. Literature was used to collect climate characteristics data for 1961–1990 at the national level, mainly based on national communications under the UNFCCC (United Nations Framework Convention on Climate Change, 2014), national studies, documents, and published papers (DRINKADRIA 2015; Kanakoudis et al., 2015a, b). Different climate models were used to model changes in temperature and precipitation for 2021–2050 period, and specifically the Special Report on Emissions Scenarios (SRES). On test area level, measured data on climate characteristics were gathered while climate change simulations were mostly based on three regional climate models (RCMs): ALADIN, Promes, and RegCM3, which were applied during the CC-WaterS project (CC-WaterS 2012). A database with climate characteristics and climate change data (climate and climate change database for Adriatic area) was developed during the DRINKADRIA project that can be used as reference for policy makers, water providers, practitioners, etc. (DRINKADRIA 2015).

The second step is the water resources availability assessment at the test area level. Initially, the impact of climate change on renewable water resources was analyzed, based on the results from the previous activity. Particularly, the long-term average water resources conditions and the characteristic renewable water resources were estimated for 1961–1990 period. Based on the precipitation and temperature estimation for the future gathered before, the long-term average conditions and the characteristic renewable water resources for the future (2021–2050) were also estimated, provided that the initial data are available.

As part of the same activity, the water exploitation index (WEI) was used to assess the risk of water resources availability for present and future state. The WEI is defined as the ratio of water demand (WD) and renewable water resources (WR) (Eq. 1).

$$WEI = \frac{WD}{WR} \tag{1}$$

Three water demand scenarios are analyzed: present state (scenario WD_0), present water demand increase by 25% (future scenario WD_1), and present water demand decrease by 25% (future scenario WD_2) (DRINKADRIA 2016a). Finally, four WEI indices are calculated: WEI_1, WEI_2, WEI_3, and WEI_4 as follows:

$$WEI_1 = \frac{WD_0}{WR_{1961-1990}} \tag{2}$$

$$WEI_2 = \frac{WD_0}{WR_{2021-2050}} \tag{3}$$

$$WEI_3 = \frac{WD_1}{WR_{2021-2050}} \tag{4}$$

$$WEI_4 = \frac{WD_2}{WR_{2021-2050}} \tag{5}$$

The third activity is related to water resources quality assessment as it is affected by both natural and human factors. This activity includes the development of a database with related legislative documents (at EU and national level) on water resources monitoring in the countries involved in the project (DRINKADRIA 2016b). Water resources quality problems were identified in the test areas. The impact of land use changes to water quality was also assessed, using also the DPSIR (drivers, pressures, state, impact, responses) framework.

Finally, in terms of water resources safety, the implementation of the Hazards Analysis and Critical Control Points (HACCP) plans or water safety plans is investigated. Also, the methodologies for delineation of drinking water protection zones were investigated among the partner countries.

Results

Analysis and prediction of climate characteristics and climate change impact

The analysis of climate characteristics (temperature and precipitation) results at the present state showed that increased temperature is observed in the Adriatic region and in the test areas examined (Fig. 1a). Based on the observed data, the precipitation levels decrease in some regions (Italy—Marche region, Serbia, and Greece) and increase in others (Fig. 2a). Both precipitation increase and decrease are observed in Slovenia, Croatia, Bosnia and Herzegovina, and Montenegro depending on the season and the study area (Kanakoudis et al. 2016). The comparison of future and baseline regional mean temperatures according to selected RCMs (Fig. 1b) suggests increase of temperature in individual regions in all seasons (DRINKADRIA 2016e). Generally, the highest changes in temperatures are shown in summer and winter, while in

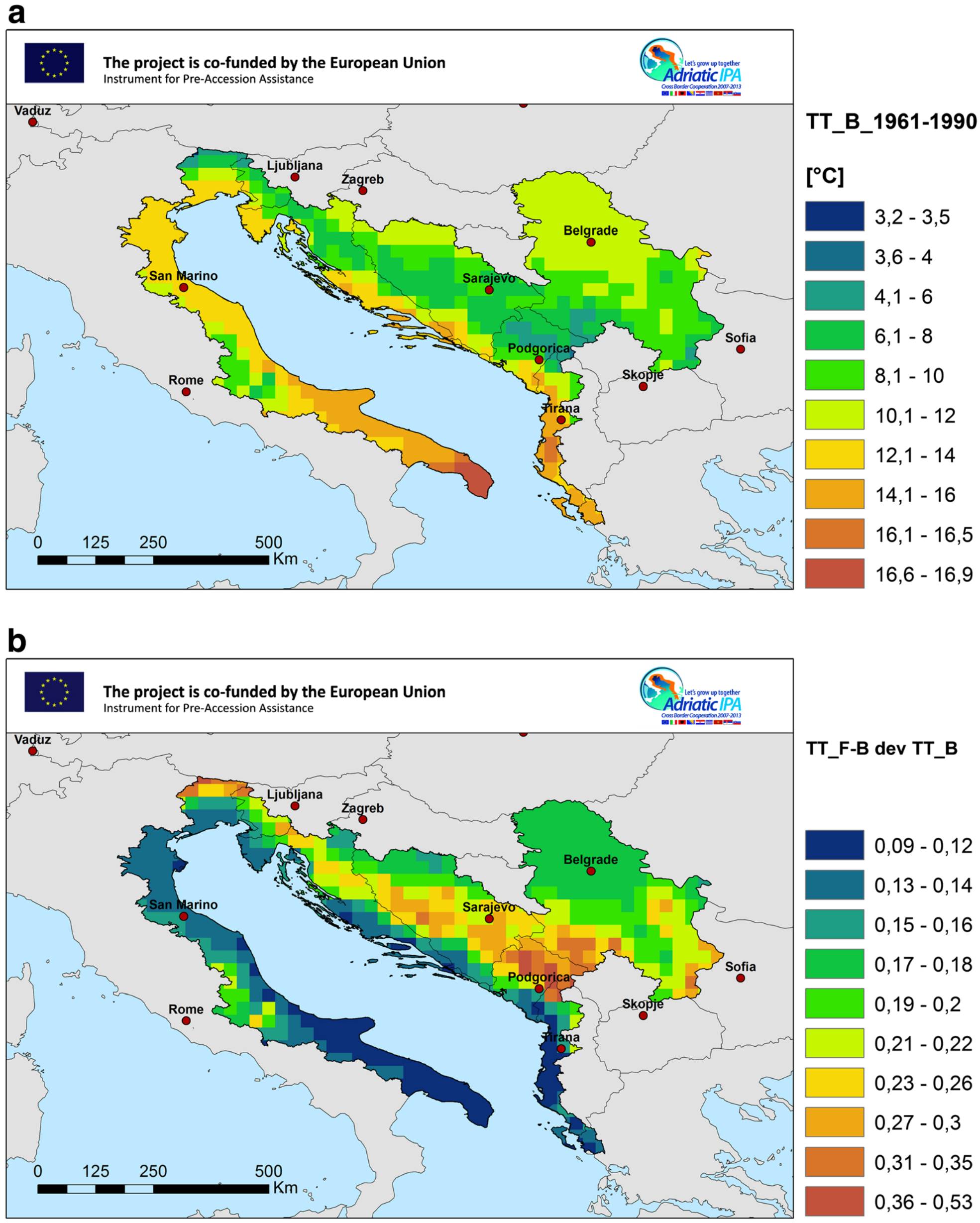


Fig. 1 **a** Temperature for baseline (*B*) period based on mean annual ensemble values of RegCM3, ALADIN, and PROMES models. **b** Relative differences in average temperature values between future (2021–2050) and baseline (1961–1990) period

spring, temperature changes are significantly lower. The temperature increase level depends on the SRES scenario, the season of the year, the test area, etc. Regional distribution of precipitation in all periods generally follows the geomorphologic characteristics of the area, and a decreasing trend is observed in the future (Fig. 2b; DRINKADRIA 2016e). It has to be stressed that trends in precipitations differ on local level and there are areas with slightly increasing trends and also slight decreasing trends, which are not statistically significant (DRINKADRIA 2015). Different precipitation trends on local level depend on the country, the selected station, the climate simulation model and time series used, etc. In general precipitation, scenarios are less reliable than the temperature scenarios (Karleusa et al. 2016; Kanakoudis et al. 2016).

Water resources availability assessment

Water resources availability assessment provided results for the long-term average water resources conditions and the characteristic renewable water resources in the present and future period. The changes between present and future period were assessed using the classification defined in CC-WaterS project (CC-WaterS 2012): (a) low changes ≤10%; (b) medium changes 11–25%; (c) high changes 26–50%; and (d) extreme changes >50% (Karleusa et al. 2016).

WEI indices are estimated for the test areas. The same WEI threshold values used to classify the vulnerability or risk have been also used in CC-WaterS project. WEI values below 0.5 indicate low risk; WEI values ranging from 0.51 to 0.70

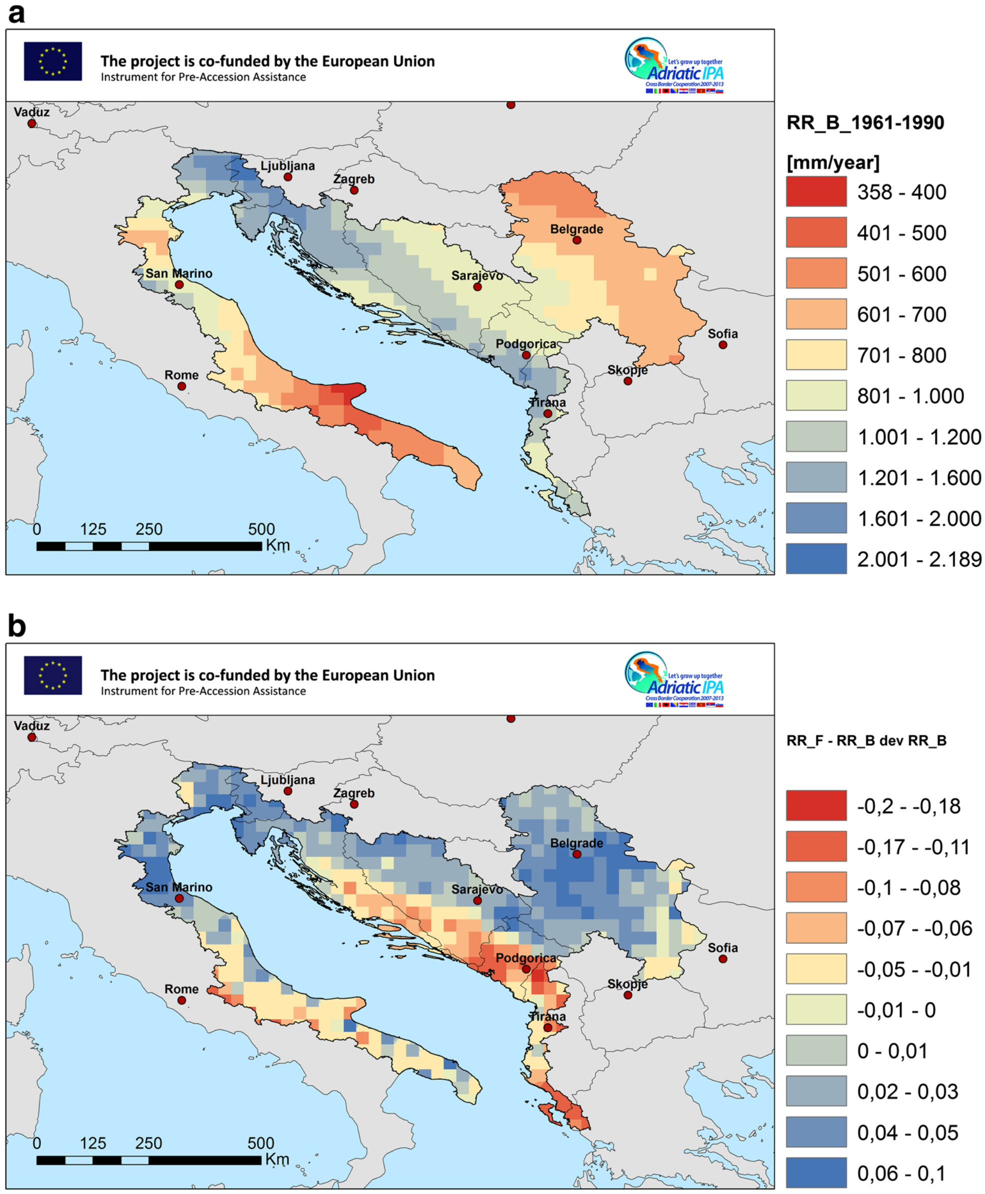


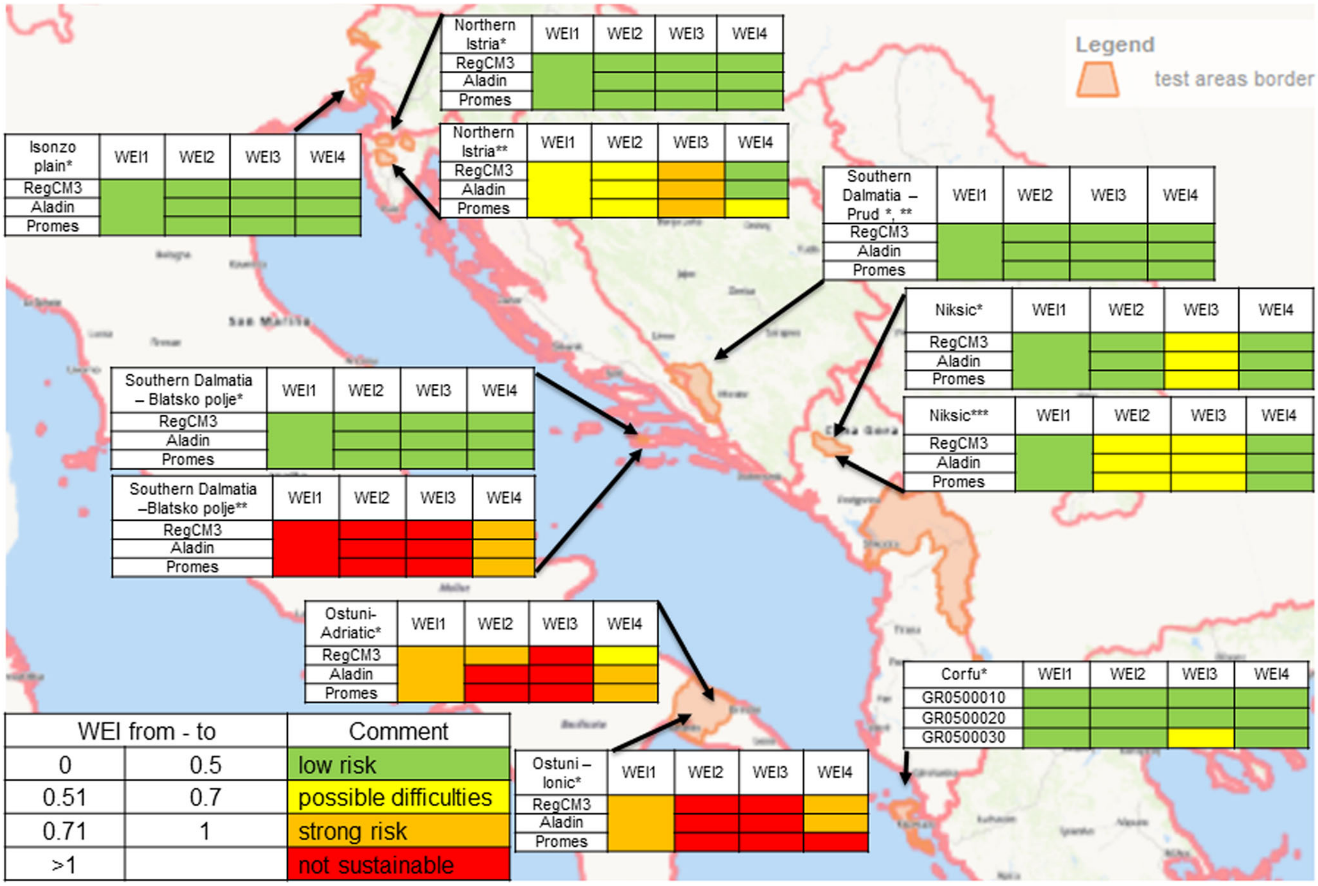
Fig. 2 **a** Annual precipitation amount for baseline (*B*) period based on mean annual ensemble values of RegCM3, ALADIN, and PROMES models. **b** Relative changes in annual precipitation amount between future (2021–2050) and baseline (1961–1990) period

indicate possible problems; WEI values ranging from 0.71 to 1.00 indicate strong risk; and WEI values above 1.00 indicate that water resources availability is not sustainable (DRINKADRIA 2016a) (Fig. 3). WEI values were also estimated only for drinking water use in some test areas, following the same scenarios.

The results from the analysis showed that climate change will impact on water resources availability in the future, mainly due to decreased available water quantities. The decrease level varies greatly from one test area to the other, showing that changes are lower in the Northern part compared to the Southern part of the study area, where water resources quantities are expected to decrease more (DRINKADRIA 2016a; Karleusa et al. 2016; Kanakoudis et al. 2016). The various climate models used provided also different results. Promes and ALADIN climate models provided greater changes in water availability as opposed to RegCM3 climate model (Karleusa et al. 2016; Kanakoudis et al. 2016). The analysis of WEI in the test areas identified different water availability risks (Fig. 3). The methodological approach used provides a better understanding of the impact climate change will have on water resources availability as well as on the possible risks related to the water resources with emphasis on those providing water for drinking purposes. Problems are identified and possible measures can be applied.

Water resources quality assessment

The most important water resources quality problems identified in test areas include the following: existence of nitrates,



ACWR – average conditions water resource
CRWR - characteristic renewable water resource
AAAQ – average annual abstracted quantities
LTMAMAAQ – long-term mean of August monthly averages of abstracted quantities
AMS- abstraction that incorporate max values during the summer

* AAAQ / ACWR
** LTMAMAAQ / CRWR
*** AMS / ACWR

Fig. 3 WEI values in test areas

suspended soils, sulfates, seawater intrusion and groundwater salinization, and microbiological contamination. Particularly in groundwater bodies, the main water quality problems identified include high concentrations of nitrates (Isonzo plain, Corfu) and chlorides (in some cases in Corfu) and groundwater salinization (Ostuni). Increased concentration of sulfates was identified (Isonzo plain, Corfu), but in some cases, they are due to the gypsum presence in underground (Corfu). In surface water, increasing trends of BOD (biochemical oxygen demand) were observed in certain cases in Serbia and Albania; nitrogen shows an increasing trend (in Ohrid lake, Albania) and high oxygen saturation values are observed (Bosnia-Herzegovina). Also, increased concentrations of copper and total chromium are observed in Bosnia and Herzegovina. Increased concentrations of phosphorus are observed in Albania. Spring water quality analysis showed increased turbidity in Montenegro and mild microbiological contamination in Croatia, Montenegro, and Bosnia and Herzegovina. In other springs in Croatia and Slovenia, an increasing trend of total suspended solids is observed (DRINKADRIA 2016g).

The impact of land uses to water quality is also investigated, using different tools. Corine Land Cover was used to compare past and present land uses changes, as these changes in the future are expected to affect water resources quality. The DPSIR framework is also used to determine past, present, and future land uses impact on water resources quality (DRINKADRIA 2016f). Despite the DPSIR framework's shortcomings (oversimplifying, does not cover all needs to assess environmental processes), the method is used together with other tools safeguarding the results of this activity. The identification of land use negative impacts on water resources quality serves as the starting point for measures application. Finally, a database with already implemented or planned measures in the test areas to improve water resources quality is formed. Such measures include monitoring programs, development of spatial plans, and artificial recharge.

Water resources safety

Water resources safety is of great importance especially when CB water resources are involved. The water resources vulnerability, risk and hazards determination, delineation of drinking water protection areas, and measures proposal for CB water resources management were elaborated in this activity. Drinking water risks and hazards assessment took place at the national level, including the implementation of HACCP and water safety plans (WSP). The results showed that there are different approaches regarding water security and safety among the countries involved. There are countries where HACCP and/or WSP are obligatory and countries where only the national legislation is applied (DRINKADRIA 2016c). In some cases, the water utilities have the independence to adopt such tools or not (Kanakoudis et al. 2016).

All countries involved in the project have established practice of drinking water protection zones through legislation; however, the responsibility for their implementation relies on different authorities at local or state level. In all participating countries, drinking water resource recharge area protection is based on the zoning principles and hierarchy of protection measures. In all states, the principles are based on the classification of water resources types. The basic framework and structure of the common protocol for monitoring activities on CB water resources used for drinking water purposes were proposed (DRINKADRIA 2016d). Guidelines for the bilateral protocol for monitoring activities on CB water resources used for human consumption include the following (DRINKADRIA 2016d):

1. Relevant institutions on both sides;
2. The procedure for exchange of results from national level monitoring and other levels of monitoring between relevant institutions of both countries;
3. The procedure for exchange of planned monitoring programs or even the preparation of joint monitoring programs;
4. The procedure to enable access to monitoring locations in the neighbor country;
5. The procedure of sample collection;
6. The monitoring methods for both parties that should be standardized and comparable;
7. The procedures regarding data and information use and publication;
8. The procedure covering of additional monitoring costs;
9. Human resources and capacities development;
10. Others that might address cross-border water resources used for human consumption management.

Water resources vulnerability

Water resources vulnerability was assessed at the transnational scale (Adriatic region). To achieve this task, the adaptive capacity is estimated based on socio-economic factors and ecosystems services assessment. The final output is the integrated assessment of water resources vulnerability to climate change. The methodology applied also in the Adriatic region is the same as the one followed during CC-WARE project (CC-WARE 2013). The methodology examines the exposure, sensitivity, and adaptive capacity (Cencur Curk and Nistor 2016; DRINKADRIA 2016e). Exposure involves climate changes (including temperature and precipitation). Sensitivity refers to the degree the system responds to changes. Under sensitivity, the indicators studied include water resources availability and water resources quality assessment. Adaptive capacity refers to the ability of the system to adapt or modify to cope with the climate changes to which it is exposed to reduce harm. Adaptive capacity was assessed considering natural system (ecosystem services) and socio-economic conditions (GDP) (Cencur Curk and Nistor 2016). Integrated vulnerability was assessed by combining water resources exposure, sensitivity, and adaptive capacity. It must be stressed that all indicators were normalized and applied on regional level.

The case of Corfu Island, Greece

One of the nine test areas studied during the DRINKADRIA project is Corfu Island located in the northwestern side of Greece, belonging to the Ionian Islands region. The island's surface is 588 km^2, its length is 64 km, and its width is 32 km (in its wider part). According to WFD 2000/60/EC, River Basin Management Plans (RBMP) have to be developed for all river basins in the EU countries. In Greece, 14 water districts are determined (Kanakoudis and Tsitsifli 2010). Corfu Island belongs to the water district of Epirus. The RBMP of Epirus identifies surface waters including three small rivers, three lagoons, and three groundwater bodies in Corfu (River Basin Management Plan of Epirus Water District 2010, Kanakoudis et al. 2015).

Climate characteristics (temperature and precipitation) for Corfu are obtained from the Hellenic National Meteorological Service (http://www.emy.gr/) for the period 1955–2014. Both temperature and precipitation values observed tend to increase in the Corfu test area. The results of project Geoklima (http://www.geoclima.eu/) were used to simulate climate condition for the future. The climate models Ensemble (A1B), Prudence (A2 and B2), and REGCM (A1B) are taken into consideration. Temperature is expected to increase (minimum, maximum, and average values) during all the seasons and annually. Temperature increase varies among the different models (Prudence A2 estimating the highest increase and Ensemble

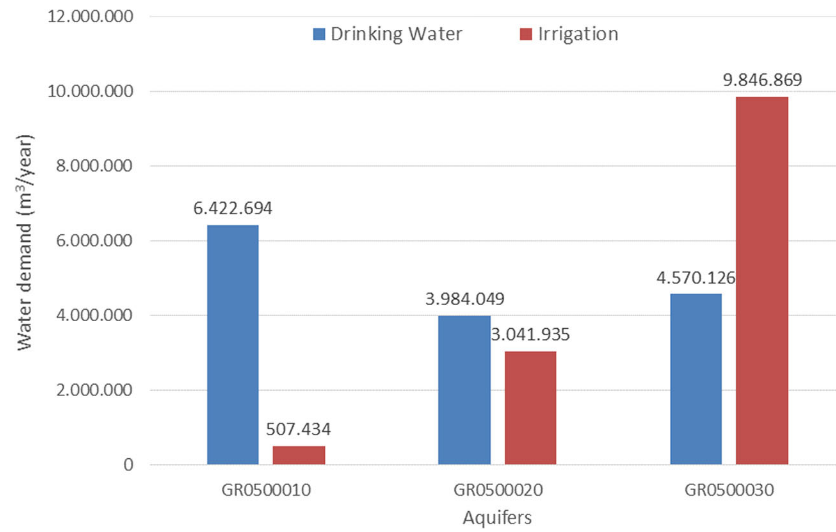


Fig. 4 Water abstracted for irrigation and drinking purposes from the three aquifers in Corfu (average values 1990–2010) (data based on (River Basin Management Plan of Epirus Water District, 2010))

and REGCM estimating the lowest ones). The average annual temperature is expected to increase from 1.23 to 4.27 °C. The total precipitation is expected to decrease especially in the summer months, from 3.93 to 25.4% depending on the model (http://www.geoclima.eu/).

Water resources availability is estimated for the Corfu test area. Drinking and irrigation water demand values are gathered from the RBMP (Fig. 4) (water abstracted from the three aquifers, namely, GR500010, GR 500020, GR 500030) (Kanakoudis and Tsitsifli 2015). Several scenarios are identified examining the water demand variations from −25 to +25% with a step of 5% for the three aquifers. The same percentage variations (from −25 to +25%) are also examined for water natural recharge. The results show that in all three aquifers, the water inflow is greater than water demand in all cases. In aquifer GR0500010, water inflow values range from 56.25 (−25% variation) to 93.75 (+25% variation) hm^3/year while water demand values range from 5.175 (−25% variation) to 8.625 (+25% variation) hm^3/year. In aquifer GR0500020, water inflow values range from 30 (−25% variation) to 50 (+25% variation) hm^3/year while water demand values range from 5.25 (−25% variation) to 8.75 (+25% variation) hm^3/year. In aquifer GR0500030, water inflow values range from 30 (−25% variation) to 50 (+25% variation) hm^3/year while water demand values range from 10.8 (−25% variation) to 17.28 (+25% variation) hm^3/year.

WEI has been estimated for 121 scenarios and both for total water use and for drinking water use. WEI values for the aquifer GR0500010 range from 0.055 to 0.153 for total water use while for drinking water use, its values range from 0.051 to 0.143 (Fig. 5). For the aquifer GR0500020, WEI values range from 0.105 to 0.292 (total water use) and from 0.06 to 0.166 (drinking water use). For the aquifer GR0500030, WEI values range from 0.216 to 0.6 (total use) and from 0.069 to 0.19 (drinking water use) (Fig. 5). In all three aquifers, the WEI values are low showing that even if water demand increases by 25% and the water natural inflow reduces by 25%, the aquifers will not suffer from availability problems. There are only some exceptions where WEI values are higher than 0.5 but lower than 0.7, indicating some possible problems in the future. Specifically, when the water demand will increase from 10 to 25%, while at the same time, the characteristic

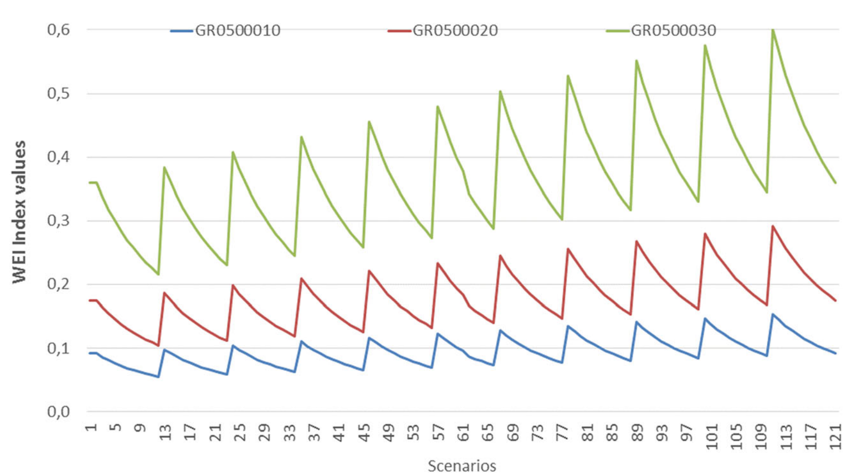


Fig. 5 WEI values for the three aquifers for all 121 scenarios (total water use)

Tale 1 Qualitative and quantitative status of Corfu's aquifers (data based on RBMP)

Aquifer's ID number	GR0500010	GR0500020	GR0500030
Pollution	Locally increased NO_3 concentration values due to agricultural activities	Natural charge of SO_4 due to gypsum. Locally increased NO_3 concentration values due to agricultural activities	Locally increased NO_3 concentration values due to agricultural activities. Natural charge of SO_4 due to gypsum.
Sea water intrusion	Yes. Local water salination mainly in the northern part	No	Yes. In coastal areas, the chloride concentration gets bigger due to seawater intrusion.
Qualitative status	Point and diffuse pollution sources additionally to the local minor agricultural activities. No pollution trend is noted. Good chemical status.	No point or diffuse pollution sources except of local minor agricultural activities and urbanization. No pollution trend is noted. Good chemical status.	Point and diffuse pollution sources additionally to the local minor agricultural activities. No pollution trend is noted. Good chemical status.
Quantitative status	There is no indication of over-exploitation	There is no indication of over-exploitation	There is no indication of over-exploitation

renewable water resources will decrease from 10 to 25%, then the aquifer may face some water availability difficulties. In general, the WEI values are lower for aquifer GR0500010 and higher for aquifer GR0500030 (Fig. 5).

Assessing water resources quality in Corfu, some problems were identified. The RBMP indicated high concentrations of sulfates met locally because of the natural background (gypsum presence). In the groundwater bodies, there are increased concentrations of nitrates and ammonium of local importance due to the point and diffuse sources of pollution (River Basin Management Plan of Epirus Water District 2010). Locally, there are high concentrations of chlorides in the coastal zones because of the sea intrusion due to excessive pumping and natural causes (Table 1). In general, there are no problems of groundwater exploitation.

Land uses impacts on water resources are also analyzed based on Corine Land Cover (http://www.eea.europa.eu). The dominant land use is agricultural areas (84.04%) followed by forests and semi-natural areas (9.52%), artificial surfaces (5.24%), and surfaces under water (1.2%). The main part of agricultural areas is covered by permanent crops (Fig. 6). Urban areas cover 4.84% of the total area of the island, based on the Corine Land Cover program (http://www.eea.europa.eu). An excessive analysis for every point and diffuse pollution pressure is performed for Corfu Island. The DPSIR approach is also used for the present and future state. Agricultural activities, oil mills, forestry, tourism, and climate change are putting pressures on water resources due to pollution, high water abstraction levels, and land use changes. As tourism is the population's main activity, there is a conflict of land used for agriculture and tourism in the island according to its spatial plan (Prefectural Administration of Corfu 2008).

Water utilities in Greece do not implement HACCP. Large water utilities are obliged to elaborate WSPs as it is determined in the Programs of Measures elaborated within the RBMPs. The national legislation and the RBMPs determine the drinking water protection zones for the whole country.

Analysis and discussion

Water resources vulnerability assessment is a complicated task as many parameters have to be analyzed. The Adriatic region is characterized by many CB water resources where water is used in a country coming from an aquifer located in two or even three countries. The paper presents an integrated methodological framework estimating CB water resources vulnerability in the Adriatic region. This framework was elaborated during DRINKADRIA project. The following steps were followed: (a) the development of an overview, and evaluation and simulation of climate change

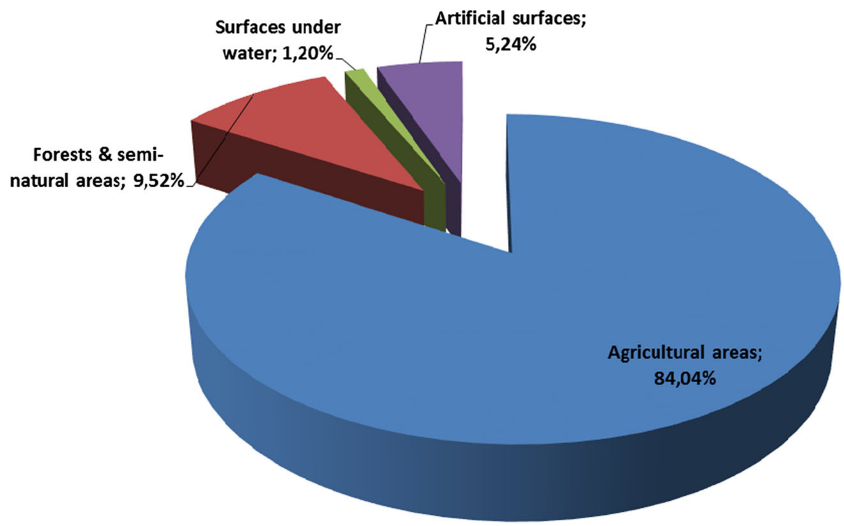


Fig. 6 Land uses in Corfu Island as percent of total area (Corine Land Cover data)

characteristics in the future; (b) water resources availability assessment; (c) development of a set of data of water quality analysis and trends; and (d) development of protocols regarding water resources safety. Regarding climate characteristics, the analysis conducted in the DRINKADRIA project provided temperature and precipitation values observed at national and test area level. Different climate models and methodologies were used for future climate scenarios, at national and test area level. The study results showed that temperature tends to increase in the future as expected. However, precipitation trends are both increasing and decreasing. This finding is in agreement with findings from other studies. Precipitation changes are subject to the country and the model used. As expected, climate change is found to impact negatively to water resources availability.

Water resources in the Adriatic region face different quality problems ranging from pollution due to human activities to saltwater intrusion. Quality trends are presented for the study areas, and the impact of land uses changes on water quality in the future is assessed. The results indicated different water resources quality problems in different test areas. Water resources quality assessment in test areas demonstrated the presence of nitrates (due to agricultural activities), chlorides (due to saltwater intrusion), sulfates (due to geological reasons), increasing BOD and nitrogen trend in surface waters, indications of microbiological contamination, and increasing trend of suspended solids. Land uses changes and DSPIR framework were used as helping tools to determine possible water resources quality problems in the future. It is expected that land uses changes in the future will impact water resources quality.

CB water resources safety is extremely important. As every country follows its own guidelines (coming from the EU and national legislation), the different ways to cope with water safety are recorded. For example, HACCP or WSPs are not obligatory in all countries and in many cases, it is up to the water utility to decide. Delineation of drinking water protection zones in the participating countries is also examined. All countries delineate drinking water protection zones following however different criteria on the zones' borders.

Water resources vulnerability assessment in the Adriatic region identified that there are different conditions in different areas and in some cases, there is a high complexity. This finding is in line with findings in other studies. In general, the vulnerability assessment should be used as a tool for decision makers to identify the more vulnerable areas where adaptation and mitigation measures need to be taken.

Conclusions

The paper assesses the vulnerability of water resources used for water supply in the Adriatic Sea region with special focus on the island of Corfu in Greece. The climate characteristics and climate changes have been analyzed showing that the temperature is expected to increase in the future while precipitation trends are both increasing and decreasing, depending on the country and the model used. Different climate models provide different levels of temperature increase and precipitation decrease, with the latter to be less reliable. Corfu island case in Greece is expected to face increased temperature and decreased precipitation in the future, especially in summer months. It has to be stressed that Corfu Island is located in the western part of the country where precipitation levels are higher than those of the country's average. Climate change will impact negatively water resources availability, resulting in decreased water availability, while increased water demand will stress water resources even more. More specifically, the most significant decrease in precipitation is observed in the southern areas of the Adriatic region, resulting in a stronger reduction in terms of water availability. WEI for present and future state is estimated for the test areas. The analysis showed that some areas are likely to face more severe water shortage problems and the findings can become the starting point for measures design and implementation on time. Corfu test area is likely not to face water availability problems. Water resources quality in the Adriatic Sea region is affected by human and natural factors and at the same time, sea water intrusion phenomena are present in some coastal areas. Future assessment of water resources quality showed that land uses will impact water resources quality. Coming to Corfu test area, water resources quality is assessed as good in general with some problems with nitrates and sulfates concentrations and also restricted saltwater intrusion problems. To avoid future problems with water quality, mitigation measures need to be applied. Water resources safety was also assessed, investigating how the involved countries cope with drinking water resources safety. Each country follows its own guidelines and there are cases where HACCP or water safety plans are used. Finally, water resources vulnerability in the Adriatic Sea region depends on different conditions met in different areas. In some cases, water resources are identified being at risk and this is why common adaptive methodologies and tools need to be applied. In fact, this is a prerequisite of the WFD 2000/60/EC in CB (international) river basins.

The proposed methodology represents a useful tool for stakeholders and decision makers to consider climate change-related issues in CB water resources and develop sustainable integrated water resources management strategies. As both natural and human factors affect water resources (including climate change), it is extremely important to identify the problems and the most vulnerable areas. The methodology followed in the DRINKADRIA project highlighted problems in certain areas, allowing the policy makers to take immediate corrective measures. Such a methodology can be a proactive measure in other regions. Especially in the cases where CB water resources are involved, the need is more urgent as the complexity is higher.

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