Desalination and Water Treatment
www.deswater.com

doi: 10.5004/dwt.2020.26033

194 (2020) 304–314
August

The drought-alert decision support system for water resources management

Elisa Arnone[a,b], George Ch. Stavridis[c], Livia Ortolani[a], Thanos Rammos[c], Marco Cucchi[d,e], Anthoula Gkiourou[c], Sara Dal Gesso[a], Bill Psomas[c], Sandro Calmanti[f], Marcello Petitta[f,g,*]

[a]*Amigo s.r.l., via Flaminia 48, Rome 00196, Italy, emails: elisa.arnone@uniud.it (E. Arnone), livia.ortolani@amigoclimate.com (L. Ortolani), sara.dalgesso@amigoclimate.com (S. Dal Gesso)*
[b]*DPIA, Università degli Studi di Udine, Via del Cotonificio, 114, Udine 33100, Italy*
[c]*MaP Ltd., Aristotelous 6, Cholargos Athens 15562, Greece, emails: gstavridis@map4u.gr (G.C. Stavridis), arammos@map4u.gr (T. Rammos), agkiourou@map4u.gr (A. Gkiourou), psomasbill@gmail.com (B. Psomas)*
[d]*Department of Mathematics and Statistics, University of Reading, Whiteknights, P.O. Box: 220, Reading RG6 6AX, UK, email: mcucchi9@gmail.com (M. Cucchi)*
[e]*Centre for the Mathematics of Planet Earth, University of Reading, Whiteknights, P.O. Box: 220, Reading RG6 6AX, UK*
[f]*ENEA, SSPT-MET-CLIM, Via Anguillarese 301 00123 Rome, Italy, emails: marcello.petitta@enea.it (M. Petitta), Sandro.calmanti@enea.it (S. Calmanti)*
[g]*EURAC, Institute for Earth Observation, Viale Druso 1, Bolzano 39100, Italy*

Received 25 November 2019; Accepted 29 April 2020

ABSTRACT

In this paper, we discuss the drought-alert decision support system (DA-DSS), a solution developed by the Small Medium Enterprise Amigo s.r.l., (Rome, Italy) and MaP Ltd., (Athens, Greece). within the Horizon 2020 cross-sectoral project "cross-climate". DA-DSS is a prototype of the WebGIS application aimed to support the water utilities (WUs) in the management of drinking water in a changing climate. DA-DSS combines climate data, infrastructures geospatial data, and visualization tools. Climate data exploit the seasonal forecasts provided by the EU Copernicus services in order to obtain short and mid-term DA, up to a six months' time range. This information is integrated with geospatial data with advanced geographic information system technology, and finally implemented into a WebGIS application. Two small and medium WUs, located in Greece and Italy respectively, served as test cases for the system development in a co-design approach, based on their existing decision chains. The prototype system was then released in the municipality of Zakynthos, Greece. The investigation of the user's needs suggested that both the WUs are interested in predictions on 3 months-cumulated precipitation, 3 months in advance, from November to March. The test of the prototype in November 2017 demonstrated that the uncertainty, assessed in terms of false rate, is low for the short-term prediction (3 months).

Keywords: Drought; Decision support system; Seasonal forecasts; Water resources; Geographic information system

1. Introduction

Climate change conditions make optimal management of the water resources even more challenging [1]. Prolonged droughts, due to variations of the climate conditions, are expected to hit the Mediterranean area, one of the most vulnerable regions in Europe [2,3]. Climate alterations directly affect the surface water balance and the groundwater recharge [4], hence changing the reservoir inputs. The result is a reduction in the availability of resources used by water utilities (WUs) to fulfill the water demand [5]. However, as for now, WUs are not directly taking into account the effects of climate change in their decision-making process.

* Corresponding author.

Presented at the 7th International Conference on Sustainable Solid Waste Management, 26–29 June 2019, Heraklion, Crete Island, Greece

1944-3994/1944-3986 © 2020 Desalination Publications. All rights reserved.

The planning strategies used by the WUs worldwide, on both medium (from few months to a year) and long-term (from few years to decades), are based on the assumption of a stationary climate. The estimate of the future water supply is exclusively based on historical data [6]. More specifically, WUs use data related to the past to calculate and consider the distribution of the key meteorological variables, for example, precipitation. However, given the increasing climate volatility, this approach is no longer reliable. This results in high economic and societal costs [7]. For example in Rome (Italy), in 2017 the WU Azienda Comunale Elettricità e Acque - Electricity and Water Municipal Utility experienced a serious water shortage. The risk was not properly assessed in advance, and the WU had no proper contingency plan.

The missing link in the decision-making process in WUs is information on the rainfall anomaly of the upcoming season (up to 6 months). Seasonal forecasts (SFs) have been proved a valuable tool for supporting decisions in several climate-sensitive sectors [8,9]. However, these forecasts are still not widely used in Europe because of the uncertainties in the mid-latitude regions [10]. The EUPORIAS project provides several proofs of the concept of decision support system (DSS) based both on SF and on the interaction with the end-users [11]. For a complete overview of the current applications of climate data in Europe across different sectors Bruno Soares et al. [12].

Applications based on SF for water management seems very promising, especially in the fields of drought-risk assessment and mid-term reservoir management [13,14]. On the other hand, Marcos et al. [15] use SF for the prediction of reservoir-hydrological variables (e.g., reservoir monthly volume). The test on a river basin in Spain, based on multilinear regression models, has demonstrated the potential of this technique.

Climate data cannot be used alone in order to have a complete overview to support the water management decision process. At the same time, water infrastructure data need to be considered and integrated with other data, that is, climate data [16]. Geographic information system (GIS) systems ultimately support the visualization and integration of different types of data, resulting in more straightforward information.

The interest in developing a decision support tool that combines climate information based on SF and infrastructural data through GIS is not only scientific. The water management market is very attractive for two reasons. First of all, the WUs are becoming increasingly aware of the challenges set by climate change, and of the need for climate change-related tools. Furthermore, the market requires players in the field of climate services and GIS technologies.

In this project, we focused on small and medium WU utilities operating in two countries suffering from water scarcity emergency, Greece and Italy.

The Italian WU sector has been historically characterized by an intense fragmentation, with several providers operating on the national territory. A vertical integration process of the sector has been progressively enforced, leading to a new water supply chain, the integrated water service (Servizio Idrico Integrato, SII). The structure of the Greek water sector is not established at a national level: the two main urban areas, Athens and Thessaloniki, are served by two different companies, EYDAP (Athens, Greece) and EYATH (Thessaloniki, Central Macedonia, Greece). Both are private state-aided companies. Each company comprises two entities: a public one owning the infrastructure (dams, network) and a semi-private utility owning and managing treatment plants and water distribution networks [17]. The rest of the municipalities are served by the so-called DEYAs (Greece), companies fully owned and controlled by the municipalities themselves (in-house management). The assets remain of public property, while the utilities have the task of operating and maintaining those assets.

The drought-alert decision support system (DA-DSS) described in this paper has been developed in a well-defined co-design process with two small WUs located in Greece and Italy respectively, allowing us to address the management needs. The prototype has been released only for the Greek DEYA (Greece) participating in the test case.

2. Methods and materials

The DA-DSS addresses the challenge of improving the water supply planning capabilities of WUs by integrating climate information with geospatial and water infrastructure data. Its main function is to assist WUs in the evaluation of water availability on operational timescales, in order to take incremental no-regret decisions, that is, answer questions such as: should we start buying additional resources? Should we have our transportation ready because an emergency is likely approaching?

The DA-DSS is a water-management oriented application of the modular workflow shown in Fig. 1, comprised of four functional blocks: (i) user needs; (ii) climate data; (iii) water infrastructures; (iv) DSS.

The identification of user needs is the first crucial step for the development of the system, and it starts from the analysis of existing decision-making processes for water management. The interaction with the WUs and the evaluation of the risk perception enables the co-design process.

The climate data block includes the methodology developed by Amigo s.r.l., (Rome, Italy) to transform SF data into alert services. Important aspects of this step are the operation timescales to implement the water management planning and the quantification of the associated uncertainty. Suited weekly forecasts, daily weather forecasts, and climate change scenarios cannot provide the kind of information needed for operational planning. In the first two cases, the time range is too short, while in the latter, the time range is too long. For this reason, the DA-DSS uses the climate and SF provided by the EU Copernicus data store to release a monthly assessment of the possibility of droughts in the upcoming months.

Water infrastructures block broadly includes the geospatial data related to water infrastructures, water basins, network distributions, and other site-specific data to be used to identify the end-user operation domain. Data were collected, integrated and made accessible by using the most recent technologies on visualization tools and GIS systems provided by MaP Ltd., (Athens, Greece).

The integration of all the components in a well-defined system architecture ultimately leads to the DSS in the form

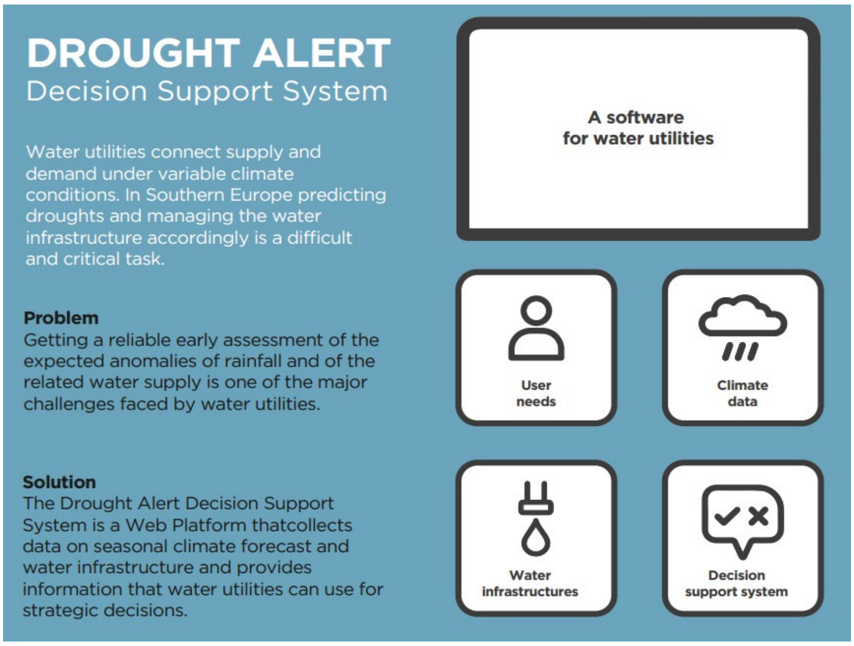

Fig. 1. DA-DSS the concept idea.

of a WebGIS application. Technicians of WUs can use the application by accessing a single web page.

2.1. Identification of user's needs

In order to explore the interest in the new service and to gain a complete and wide vision of the possible needs of WUs, we first administered a systematic survey as defined by Check and Schutt [18]. We used a mixed quantitative and qualitative research strategy based on questionnaires with numerically rated items and open-ended questions.

Specifically, we developed two different questionnaires focused on collecting information on (i) technical characteristics of the water supply systems and (ii) the decision-making process that the WUs use in case of extreme events causing water shortage.

In April 2018, the two questionnaires were sent via email to more than 100 WUs across Italy with the aim of identifying interested users to be involved in the project. Siciliacque S.p.A. (hereinafter Siciliacque, Palermo, Sicily, Italy), a company located in Sicily (Italy), showed interest in the service. In Sicily the issue of water scarcity due to drought events is recurrent. For this reason, Siciliacque (Palermo, Sicily, Italy) was selected as a case study for Italy. The case study in Greece was instead selected based on size, data availability and past collaborations with the DEYA (Greece) located in Zakynthos.

Two physical meetings took place with the potential users, one in Greece and one in Italy. A first overview of the WU needs was obtained by administering two questionnaires to both companies.

2.2. Climate data

SFs are climate predictions for the next few months, starting from any initial date. They are produced with numerical models of the climate system that are very similar to those adopted for forecasting the weather for the next few days [19]. However, unlike weather forecasts, SFs aim at predicting the status of the slow component of the climate system (essentially ocean and land cover), as well as what possible states of the fast component (the atmosphere) are more likely to be associated with the status of the slow component. For example, providing an expected warm anomaly in the tropical Pacific Ocean, what is the likelihood of a wetter season in some other remote areas? Or, provided the current lack of moisture in the soil, what is the likelihood of a forthcoming drier season?

In seasonal climate predictions, as in any chaotic system, tiny variations of the initial state lead to diverging trajectories. A predetermined number of predictions is performed with the numerical climate model, and the whole set of predictions is referred to as the ensemble, while every single result is defined as a member of the ensemble. The initial states of the ensemble members differ only slightly, and the spread is consistent with the observation of uncertainties. However, the predictions might differ substantially further ahead in the future. In this way, it is possible to identify the uncertainty level in the forecasts.

In this project, we used the System 5 (SEAS5) SF data of precipitation released by the European Centre for Medium-Range Weather Forecasts (ECMWF) and made available by the EU Copernicus climate data store. SEAS5 uses the Nucleus for European Modelling of the Ocean (NEMO) [20] as the oceanic component. The horizontal resolution is 0.25° grid, and it includes 75 levels in the vertical one. As part of NEMO, the sea-ice is calculated through the Louvain-la-Neuve sea Ice Model [21]. The atmospheric component is based on the cycle 43 r1 of the ECMWF integrated forecast system. The horizontal resolution is approximately 36 km, while the component includes 91 levels in the vertical one, up to approximately 80 km. The time-step is approximately 20 min.

The SF ensemble contains 51 members. In order to estimate the reliability of SEAS5, hindcasts are available from 1981 to 2016 and have 25 ensemble members. For the sake of data understanding, Fig. 2 shows a graphical representation of the forecast time series for a selected grid point.

We retrieved the observations for a selected time, as well as climatology (i.e., average values over a long time range) from the reanalysis data ERA-INTERIM, from 1981 to 2016, which served as reference dataset to evaluate the reliability of SF (section 3).

2.3. Geospatial data

MaP Ltd., (Athens, Greece) was responsible for the collection, exploitation and analysis of geospatial data. Specifically, data used for this project are geographic information layers that were managed with the GIS open-source software QGIS. The criteria for the selection of the geospatial data were based on the availability of open data, while data subject to intellectual property rights were used to a minor extent. For the latter, permits were requested and granted. The coordinate reference system is the Greek Geodetic Reference System (EGSA87), EPSG2100 in international coding, and easily converted to EPSG4326 (WGS84). The following data were included and used in the system:

Data were collected for the case study of DEYA located in Zakynthos (Zante), Greece. Zakynthos is an island situated in the Ionian Sea (central Mediterranean) (Fig. 3) covering an area of 406 km^2. The island has experienced rapid urbanization and tourist development over the last decade.

The main water reservoir is the groundwater, serving water for domestic, agricultural and industrial use. Its quality and quantity play an important role in the economy and social life of the island. There is a lack of significant surface runoff water (rivers, lakes, etc), therefore both the local economy and social infrastructures are based on the island's aquifers. Furthermore, the population is highly variable during the year, with a considerable increase in the summer-time, which makes the fulfilling of water demand more challenging. Moreover, the increase in agricultural water demands, the urbanization and tourist development has caused a high degradation of the groundwater quality [22].

The map of the water meters, as a vector point dataset, consists of ~45.000 points. This information layer allows us to obtain an accurate estimation of water demand in terms of quantity and spatial distribution. Moreover, this dataset strengthens the ability to produce analytics.

The administrative boundaries of the municipality are provided as a vector polygon layer.

The Corine land cover map, as a vector polygon layer, provides the spatial distribution of the main land-use types.

Geological formations (vector polygon layer) were derived from the geological map 1: 50,000 (map sheet 211-Zakynthos), published by the Institute of Geology and Mineral Exploration (IGME). The vector map resulted in executing the activities of scanning, georeferencing and digitizing. This information layer is crucial to identify the distribution of soil water permeability, which affects the timing and quantity of the acquirer recharge.

The digital terrain model (DTM) (raster layer) has a grid size 20 m × 20 m and has been produced using aerial imagery acquired and processed by MaP Ltd., (Athens, Greece) in 2011.

The groundwater body is the management unit under the water framework directive (WFD). Groundwater bodies are subdivisions of large geographical areas of aquifers so that they can be effectively managed in order to protect the groundwater and linked surface waters. The dataset has been downloaded from the special secretariat of water.

The thematic layer of water points (vector point layer) (Fig. 4a) includes the information on the distribution of drillings, wells, and tanks that have been used by the DEYA (Greece) of Zakynthos. This information can be used to optimize the use of the specific water point, depending on the prediction of the level of water recharge needed by the acquirer.

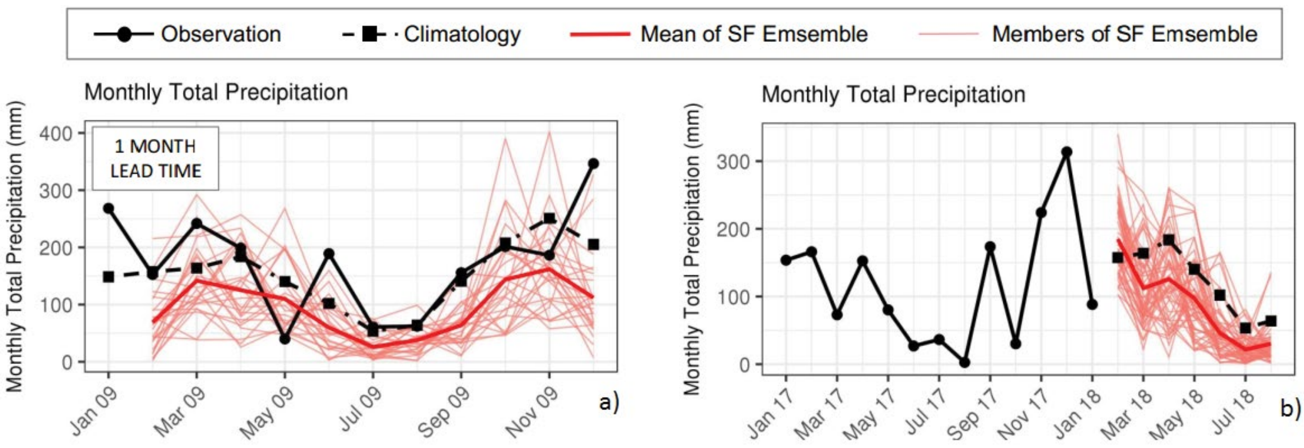

Fig. 2. Forecast time series for a selected grid point: comparison with hindcasts for 2009 of monthly total precipitation (a); observed time series (2017) and future SF time series (2018) of monthly total precipitation (b).

Fig. 3. Zakynthos Island, Greece, and DEYA (Greece) location.

The thematic layer of water pipelines (vector line layer) (Fig. 4b) consists of the water pipe network that has been used by the DEYA (Greece). Among others, the following types and categories are included: pipeline diameter, material source of data per pipeline.

Lastly, we added hydrological information about the streamflow network and watershed. The water streams (vector line layer) have been calculated using the DTM. The categorization is done according to the Horton-Strahler classification. The water basins (vector polygon layer) have been calculated using the DTM and resulted in nine water catchments.

2.4. Drought alert definition

The methodology to define a drought alert exploits the predictions on precipitation for the next few months, in order to evaluate the climate state of the upcoming months compared to climatology. The procedure aims at answering the following questions: (i) Are the upcoming months going to be dry? and (ii) How confident are we that the upcoming months are going to be either dry or not?

At a given month, the climate state of the upcoming months is evaluated based on the prediction of cumulative precipitation computed over a cumulation period (CP) of a given length, that is, the number of months over which precipitation is cumulated. CP may vary from 1 to 6. Once CP is selected, precipitation is cumulated over a rolling window of CP length that determines the period of forecast (e.g., CP3 leads to a three-month rolling window of periods June-July-August, July-August-September,…).

Predictions for each period are compared with the climatology of the same period, assessed over the hindcast data. The terciles of the distribution identify three classes: 1st ‘dry’, 2nd ‘normal’ and 3rd ‘wet’. The comparison between predictions and climatology will reveal whether the forecasts will belong to the dry class or not, based on a discriminate threshold frequency.

The procedure evaluates different monthly responses based on the lead time (LT), which is the temporal distance, in months, between the release of the SF and the first month of the CP. LT may vary from 0 to 5. Technically, the procedure applies to all the possible combinations between CP and LT.

The state of drought alert (DA) is triggered when predictions fall within the ‘dry’ class. Conversely, a state of no-alert is released, that is, normal and wet conditions are not contemplated by the procedure.

The reliability of the climate information is estimated to evaluate the uncertainty associated with the DA state. When the DA state is released, we ask ourselves how confident we are that the information is not wrong. More specifically, we want to evaluate whether the tool is missing alerts or is giving false alarms.

For this purpose, we developed a procedure defining reliability in terms of false rate (FR), (0%–100%) of the prediction [23]. It is a metric that depends on two factors: (i) the system capability of discriminating two different states and (ii) the predictability of the next precipitation forecasts. Specifically, the FR is computed as a function of two indices, that is, sensitivity and specificity, which are a measure of the portion of true positive (TP) and true negative (TN), respectively. They are also correctly identified as such [23]. In order to compute the FR, we used the ERA-INTERIM data as reference data for the observations across the hindcast period, that is, 1981–2016.

Sensitivity/specificity values vary with the threshold of frequency members used to discriminate the classes. We will describe an example for the CP = 3 months and LT = 0 months. Fig. 5 represents the sensitivity/specificity curves. discriminant threshold frequency (DTF) indicates the discriminating threshold frequency, that is, the value that optimizes the capacity of the algorithm to correctly attribute the dry class to forecasts and to correctly discard forecasts from dry class for the given LT-CP.

Case 1 (Fig. 5a): assuming that the frequency of members of the next precipitation forecasts (prediction dataset) is 0.43

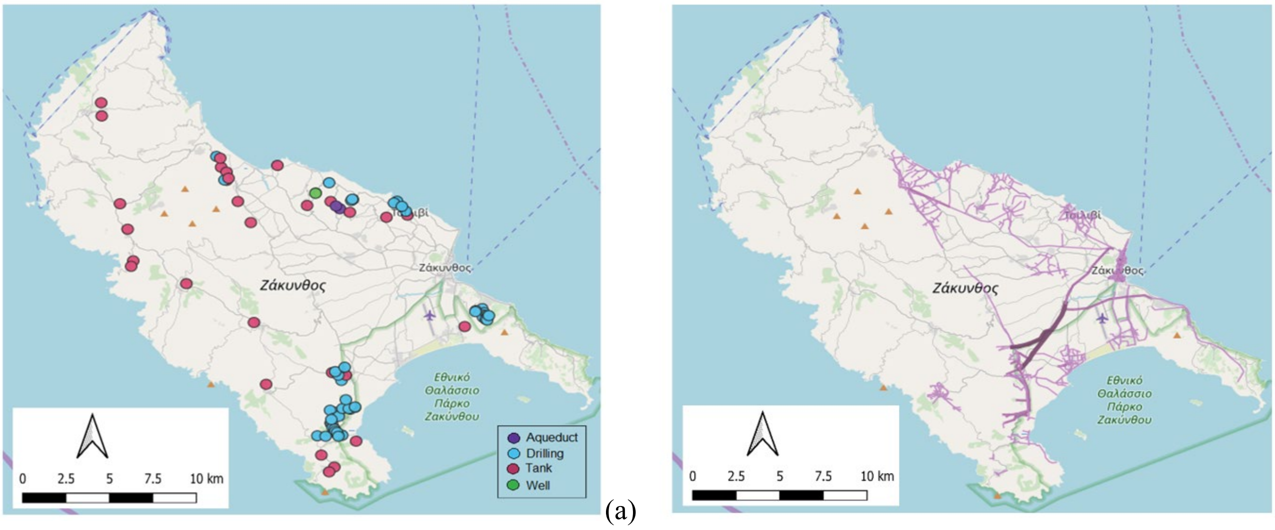

Fig. 4. Water points (a) and water pipelines (b).

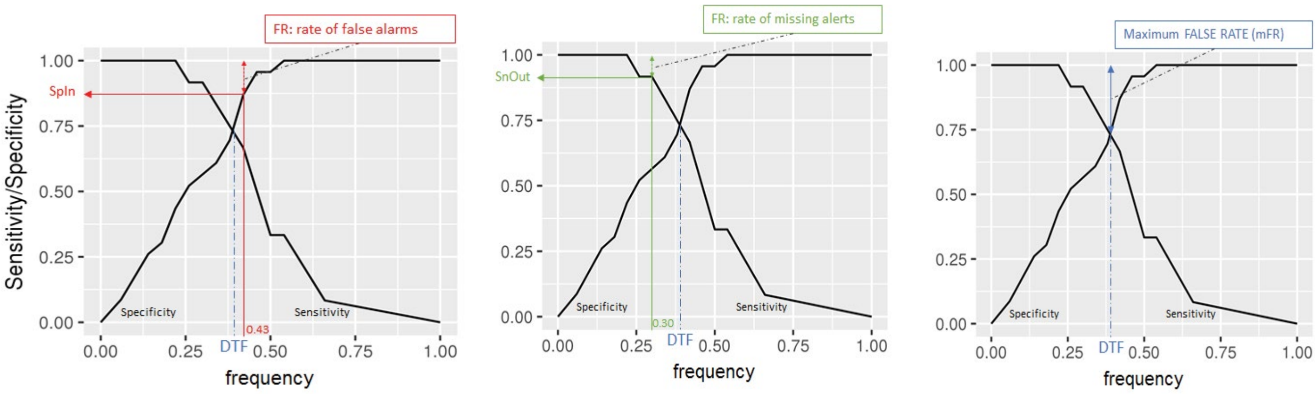

Fig. 5. Definition of 'false rate' based on sensitivity and specificity.

and is higher than the DTF, the forecasts are attributed to the dry class and the alarm state is released. We denote with SpIn the specificity value associated to 0.43, equal to about 0.87 (red line). This value indicates that, for that frequency (0.43), the algorithm correctly discarded the events from the dry class in 87% of the cases (true negative, TN) then it is likely certain that the analyzed event with 0.43 frequency belongs to the dry class. The value 1-SpIn indicates the cases in which the algorithm wrongly attributed the events to the dry class (false positive, FP) when they actually did not belong to it. Therefore, it represents the frequency of false alarms.

Case 2 (Fig. 5b): the frequency of members of the next precipitation forecasts, in this case, is 0.30 and therefore is below the DTF. The forecasts are discarded from the dry class (no alarm). We denote with SnOut the sensitivity value associated with 0.30, equal to about 0.92 (green line). This value indicates that, for that frequency (0.02), the algorithm correctly attributed the events to dry class in 82% of the cases (true positive, TP). Therefore it is likely certain that the analyzed event with 0.30 frequency does not belong to the dry class. The value 1-SnOut indicates the cases in which the algorithm wrongly discarded the events from the dry class (false negative, FN) when they actually did belong to it. Therefore, it represents the frequency of missing alerts.

In conclusion, in case of an alert, the FR is the expected frequency of false alarm and it is given by Eq. (1):

$$\mathrm{FR} = 1 - \mathrm{Specificity} = 1 - \frac{\mathrm{TN}}{\mathrm{TN} + \mathrm{FP}} \tag{1}$$

Conversely, in case of no-alert, the FR is the expected frequency of missing alerts and it is given by Eq. (2):

$$\mathrm{FR} = 1 - \mathrm{Sensitivity} = 1 - \frac{\mathrm{TP}}{\mathrm{TP} + \mathrm{FN}} \tag{2}$$

For a frequency value equal to the DTF, sensitivity equals specificity and the FR reaches the maximum possible value (*m*FR, Fig. 5c) and it represents the FR of either giving false alarms or having missing alert. *m*FR depends on the sensitivity/specificity curves for each LT-CP combination, and it is related to the overall skill of the tool. It is possible to conclude that the FR gives an assessment of the possible chance of the tool to fail, and it is representative of the skill.

A full description of the methodology developed to define the drought state and the associated reliability is provided in Arnone et al., [24].

2.5. System architecture

The components described above are integrated into a WebGIS application which constitutes the DA-DSS.

The architecture of the WebGIS platform consists of four key components (Fig. 6):

- Desktop workstations use QGIS to create, edit and visualize the different spatial and attribute data.
- PostgreSQL and PostGIS control the creation, maintenance, and use of the database, updated with monthly releases (climate service).
- A Geoserver retrieves the spatial information and attributes data from the PostGIS, then shares them in the network. An Apache Web Server shares the WebGIS application. The application uses OpenLayers, an open-source visualization toolkit, in order to request the spatial and attribute data from the Geoserver and then visualize and publish them. Apache Web Server, Apache Tomcat and Geoserver are installed in an Ubuntu Server.
- Users may reach the WebGIS application through web browsers.

The desktop, the database, the Database Management System, the map server and the webserver are on the server-side. OpenLayers (for data visualization) and the latest WebGIS application are on the client-side. Between those two there is the Web Map Service Interface Standard (WMS), a simple HyperText Transfer Protocol (HTTP) interface for requesting geo-registered map images from one or more geospatial databases. The WMS request defines the geographic layer (or layers) to be processed, along with the area of interest. The response is one or more geo-registered map images that are published through the webserver, visualized through OpenLayers and displayed in a web browser.

The architecture of our WebGIS application is characterized as a single-page web application architecture. The user downloads a single page. This page is an HyperText Markup Language file containing Cascading Style Sheets for styling and Javascript files that can freely communicate with web services on the server, and make real-time updates to themselves.

The layers of our WebGIS application were initially created in desktop workstations using QGIS. The layers include spatial and attribute data, and are stored in a database created, maintained and used by the object-relational database management system PostgreSQL and especially by the PostGIS geographic extension of it.

In order to publish the data in the network, Geoserver was installed in an Ubuntu Server. Geoserver is an open-source server written in Java that allows users to share, process and edit geospatial data. Apache Tomcat is an open-source java servlet container required for the Geoserver installation. Apache HTTP Server is a free and open-source cross-platform web server, which was also installed in the Ubuntu Server in order to publish the WebGIS application. The code of the application is linked to OpenLayers in order to request the data from the Geoserver and then visualize and publish them. The WebGIS application can be reached through web browsers. Along with that, the client may also reach some analytics in a dashboard through Metabase. This WebGIS app architecture forms an integrated solution that fully corresponds to user-needs and may be installed on a virtual machine.

3. Results

The discussions with the two WUs raised the main possible challenges for the use of climate services in water management, as described below.

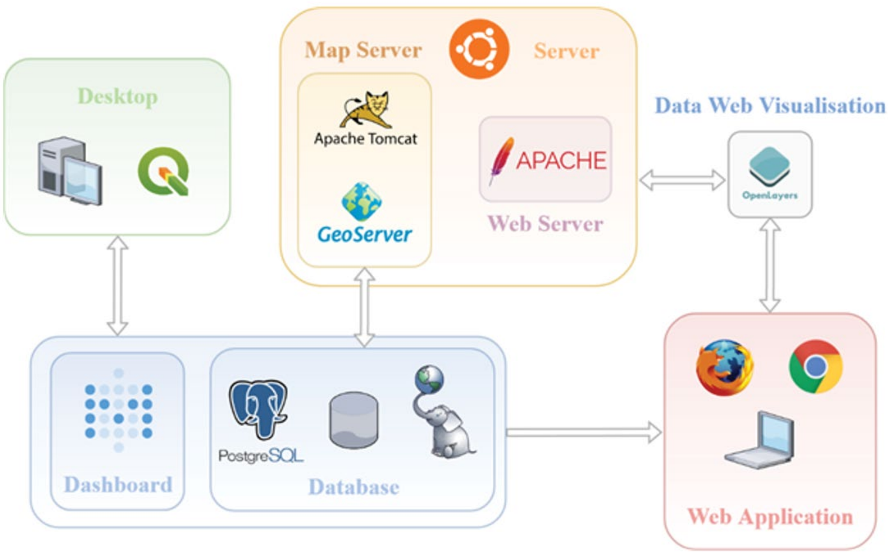

Fig. 6. System architecture.

Siciliacque (Palermo, Sicily, Italy) is an SII company, a private state-aided company. It manages an average of 88,000,000 m^3 of water in the entrance and distributes around 63,300,000 m^3 of water. On the other hand, DEYA (Greece) manages an average of 8,000,000 m^3 of water in the entrance, serving 4,300,000 inhabitants, with an average consumption of 93 m^3 per inhabitant per year.

WUs monitor the water supply with meters that measure the amount of available water in the reservoirs. The WUs have a good knowledge of the average water availability at the annual level, and they also use historical data for future previsions.

The technical department uses hydrometric data to develop the curves of annual water availability trends. The main observations are based on average values at the month and seasonal levels. For the time being, both the WUs are not using any specific software to estimate the hydrological balance or the balance between demand and offer of water resources. Climate data are not used routinely.

As for the correlations between annual precipitations and capacity to address water demand, Siciliacque (Palermo, Sicily, Italy) has a direct relationship with the University of Palermo. DEYA (Greece) has not mentioned any specific actions taken.

In Italy, the latest 3 extreme events reported by Siciliacque (Palermo, Sicily, Italy) are dated 2001, 2009 and 2016–2017. In those years there was here was a non-predictable water shortage. Specifically, there was a delay in recharge, due to difficulties in reaching the maximum level of water available in reserves.

In Greece, the latest 3 extreme events according to DEYA (Greece) are related to the summer of 2015, 2016 and 2017. The problems were the same registered in Italy: non-predictable water shortage, delay in recharge, difficulties in reaching the maximum level of water available in reserves. According to the DEYA (Greece) experts, rare rainfall has not caused water scarcity. In recent years, however, the climate has undergone significant change and will need further studies to assess it. The abundant quantity of groundwater is estimated at 6,000,000 m^3/y, while the demand, as mentioned above, is estimated at 8,000,000 m^3/y, and is increasing due to the growing tourism-related infrastructures. The most important problem is possible to network losses. Part of the water supply is covered by wells, private drilling and aquifers (water tracks).

The main strategy of Siciliacque (Palermo, Sicily, Italy) in case of water shortage is connected to the possibility of changing the supply planning in order to distribute water from those reserves where the level is higher. The water distribution network is well interconnected, and thanks to previous investments it is possible to face water shortage by changing the source of water supply. In the past, Siciliacque (Palermo, Sicily, Italy) was using also a number of desalinization plants for emergency situations. However, the management of such plants is particularly expensive and they were able to dismiss most of them. They still exist only in small islands, like Lampedusa. The management of critical events is connected to the trimestral plan for water supply developed by the Environmental Department of the Regional Administration. The technical unit of the WU takes action and develops the new distribution strategies according to a plan that gives priorities to the sectors to be considered as a priority in case of shortage. In general, civil use has the priority, followed by the agricultural use and finally by the industrial use. It is important to note that the plan of the regional administration is a normative document rather than a forecast one.

Similarly, in DEYA (Greece), the management of critical events is connected to the plan for water supply developed by the Ionian Water Directorate, which is responsible in particular for the protection and management of waters across the Ionian Islands (Zakynthos is one of them).

Having information on SF three months in advance would be helpful for both the WUs, in order to develop a new distribution strategy. WUs are most interested in incoming information at the end/beginning of the year, in order to have forecasts for the summer, which is often the most critical period for both islands.

Based on the specific needs of the WU in Zakynthos, we analyzed the drought alert states for the combinations LT0-CP3, LT0-CP5, LT3-CP3, which are representative of different horizontal time predictions (Table 1)

The WebGIS application releases a state of drought alert when predictions fall within the 'dry' class. Conversely, a state of no-alert is released. Additionally, the reliability information is assessed.

Overall, the WebGIS application releases a monthly datasheet containing the set of climate information together with an assessment of the reliability. The datasheet includes the parameters reported in Table 2.

The way how the drought alert is implemented in the WebGIS application is described below, in the prototype demonstration of the DA-DSS.

Besides the GIS system, key information of geospatial data can be visualized throughout dashboard analytics tools. Fig. 7 shows the analytics of key spatial information which are reported in the latest DA-DSS. Specifically, statistics on the following water network data are reported: water pipeline data source, water pipeline ID with length, water pipeline material. Clearly, dashboard analytics cannot show their full potential in screenshots as they offer more data by scrolling over the cursor.

The prototype of the DA-DSS is available at the following link: http://mapdomain.no-ip.org:5562/neptune/.

The user will be able to: access the release of the drought alert state, access the climatic reference data, statistics of water infrastructures data, a water basin, and land-use, and surf through the map layers characterizing the area.

Fig. 8 shows the screenshot of the webpage, which is divided into three 'areas': the left side reports the Dashboard and all its information, the right side implements the MapGIS open layers. Users can surf the two areas independently and visualize the required information. Additionally, the interface presents a 'download area' in the

Table 1
LT-CP combinations selected for the predictions

Combination	Horizontal time of prediction	Description
LT0-CP3	Next 3 months	Short-term
LT0-CP5	Next 5 month	Long-term
LT3-CP3	3 months from the next 2 months	Outlook

Table 2
Parameters ultimately released by the climate service component

Parameter	Symbol	Description
Lead time	LT	The time distance between the forecast issue time and the beginning of the forecast target period in months. Value 0 means that the forecast target period begins the same month of the release; value 3 means that the target period begins 3 months after the release.
Cumulation period	CP	Months of the cumulation period of the forecast target, that is, 3-months and 5-months rolling windows, depending on the lead time.
Drought alert	DA	Whether there is a state of drought alert (yes) or not (no).
False rate	FR	Expected frequency of false alarm/missing alert.

bottom left side, from where the user is allowed to download a pdf file containing the following information:

- *Data as pdf*: a 'report sheet' which provides the key information on the last monthly release, that is, the drought alert status and the dashboard analytics on the key geospatial data.
- *Project flyer*: flyer describing the project and the DA-DSS system.
- *User guide*: document which describes how to use the DA-DSS system and which report the key definitions.

The dashboard reports the climate information, the dashboards analytics of the map features, the watersheds information. The first box on the top shows the most important information on the climate service system, that is, the monthly report on the DA. Fig. 8 shows the case for November 2017. Additionally, the alert status is depicted as an information layer in the MapGIS part and covers the study area. Specifically, MapGIS implements three layers named drought alert–short term, drought alert–long term and drought alert–outlook. They refer to the three periods of forecasts, that is, the next 3 months, next 5 months, and 3 months from the next 2 months, respectively. The green color denotes no alert (No) whereas the red color denotes alert (Yes) (Fig. 8). The shape and size of the map depending on the format of climate data.

By scrolling down the dashboard section, the user can visualize the climatic reference part, which consists of 2 graphs reporting the expected cumulated precipitation over 3 months and 5 months. When the user hovers the mouse over the bars of each graph, an information box is activated, which reports the amount of cumulated precipitation for the selected period. The user can use this as a reference in case of DA release since it means that the forecasted value for the next months is likely 'much lower'.

The MapGIS section is implemented on the right side of the WebGIS application; it reports spatial information that characterizes the area by means of information layers. The list of available layers is activated by hovering the mouse over the blue button on the top-right corner. Users can activate the layer of interest by clicking on the corresponding box. Once it is active, it turns dark-grey. The map-s legend is visualized when the user hovers the mouse over the active layer box. Fig. 8 gives an example of multiple layers visualization, that is, digital elevation model, a water basin,

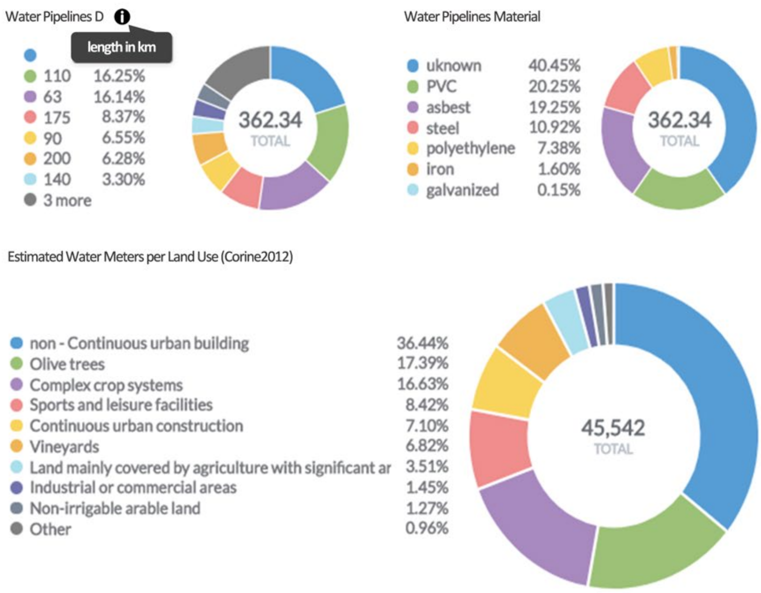

Fig. 7. Geospatial information visualized through dashboard analytics; information on water infrastructures and Corine land use.

groundwater bodies, water stream network, and water points (i.e. aqueduct, drilling, tank, and well). Among others, this mode allows the user to identify the water basins with drills, or from which groundwater bodies the pumping process does occur.

The DA-DSS enables WUs to implement a standardized four-step workflow. The first step of the workflow consists of the identification of the most vulnerable areas of the water network. This is enabled by the integration and analysis of all geospatial data available and relevant to the operation of the water infrastructure and by the visualization of the extracted information on a map and on an interactive dashboard, as shown in Fig. 8. Despite its operational and financial importance, the identification of the vulnerable points of the water network is a complex process, along with the use of such information for operational planning. The reason is that the relevant data are in general either unavailable or scattered through the organization. Therefore, it is usually virtually impossible to use it consistently in the decision-making process. The second step of the workflow consists of the evaluation of the climatology of the weather indicator, that is, the cumulated precipitations over the period. The climatology provides the benchmark to be compared with the likelihood of water availability-related alerts in the upcoming months. The third step of the workflow consists of consulting on the dashboard the monthly water availability report. The fourth and final step includes all the elements contributing to the decision-making process. They are presented in a clear and understandable way in order to let the user access this information.

4. Discussions and conclusions

This paper discussed a prototype of a decision support system, named DA-DSS, which is addressed to the WUs, in order to support them on the short/mid-term drinking water management and planning. The solution was developed by the Small Medium Enterprise (SMEs) Amigo s.r.l., (Rome, Italy) and MaP Ltd., (Athens, Greece) and is designed for small-medium water services of Southern Europe, the most affected by water scarcity.

Under conditions of a changing climate, the use of traditional tools based on stationary assumptions and historical data may no longer be sufficient to manage situations of water shortage.

SF as a tool for active water management is still not practically used, even if several initiatives across Europe tried to address the problem. Here, for the first time, two European SMEs designed, validated and produced a tool for the application of SF to water management. The tool, denominated DA-DSS, was designed based on the requests and the needs of the final users, namely the WUs. After that, a WebGIS platform has been developed. It includes the required information by integrating the geospatial data and the SFs from the Copernicus initiative.

The DA-DSS system enables decision-makers of WUs to focus on risk evaluation and actual decision making

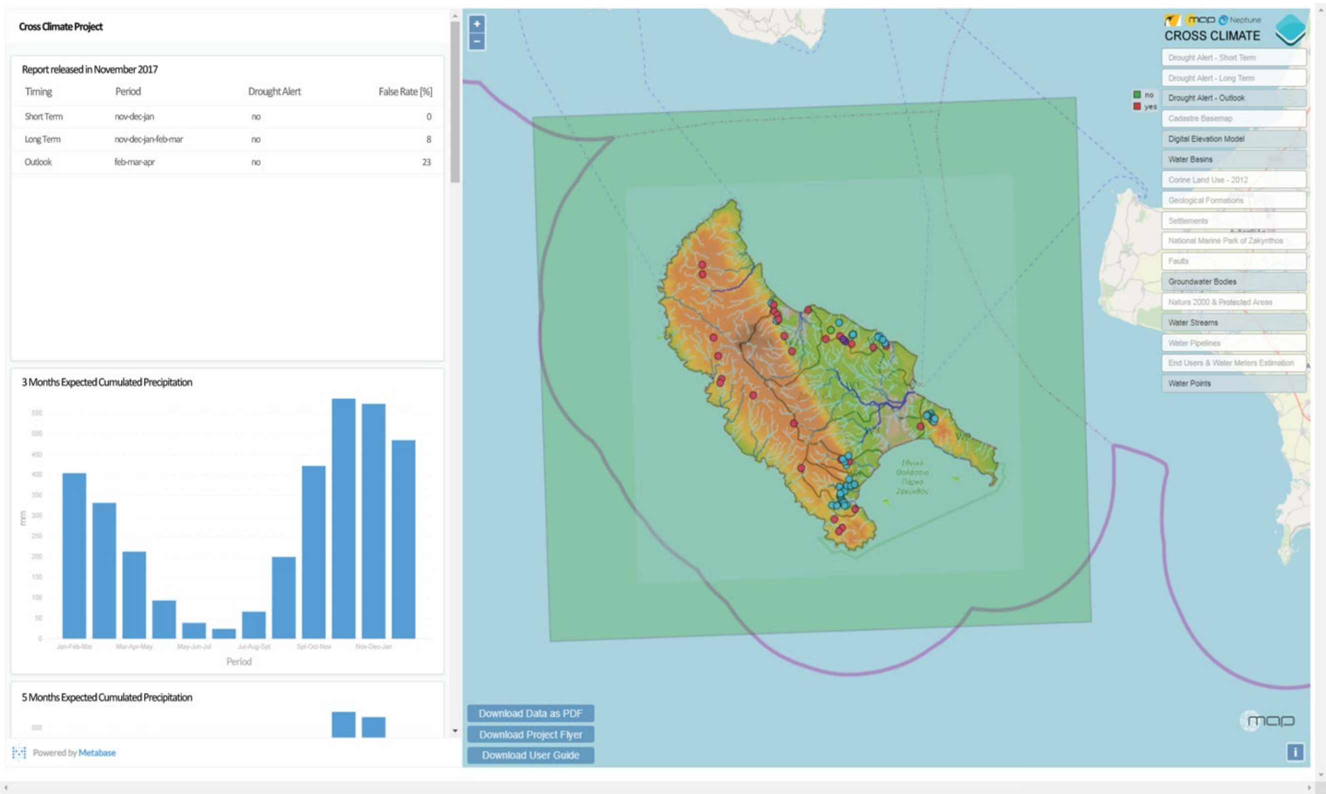

Fig. 8. Screenshot of the WebGIS application: drought alert status in the dashboard and information layer in the MapGIS for the outlook case (green: no alert, red: alert).

without having to deal with the technical aspects related to such process.

While the methodology used to obtain, process and deliver climate-enhanced information is standardized, certain system parameters are WU-dependent (i.e. the combination of cumulation period, CP and lead time, LT), in order to allow for product customization. This implies that the DA-DSS is not delivered as-it-is, but it needs a setup process, which is expected to take less than two months once in the production phase.

Within the co-design approach, the identification of the specific operational context and needs of the WU was accomplished by actively involving the WU in the design of the system through direct interaction. This means analyzing together the existing decisional processes of water management, the organizational priorities, the practical needs. Then, we can use such information in combination with the geospatial data to identify the critical points and the relevant climate variables to be used, as well as the correct system calibration. For example, depending on the climatology characterizing the area and on the dominant water extraction practices, some WUs may be interested in forecasts with different lead times or in different variables and climatic indices. This would imply defining which degree and kind of post-processing they need to obtain the forecast.

The integration of the user-provided information with geospatial data and infrastructure mapping allows us to identify the critical points of the system, such as potential infrastructure breakdowns, short alert timings, etc. It contributes to the identification of useful variables. Furthermore, the assessment of the drought-alert reliability allows the user the make decisions based on the specific circumstances and the predicted risk.

The product has significant business potential, as it provides, in the context of changing climate, a solution to the increasing demand for DSS based on advanced climate-data analysis for mid-term planning.

Acknowledgment

This work was the result of a coordinated effort within the NEPTUNE Consortium and co-financed by the EU Horizon 2020 Program under the Grant Agreement 691554 for Amigo s.r.l., (Rome, Italy) and MaP Ltd., (Athens, Greece).

References

[1] S. Ward, D.S. Borden, A. Kabo-Bah, A.N. Fatawu, X.F. Mwinkom, Water resources data, models and decisions: international expert opinion on knowledge management for an uncertain but resilient future, J. Hydroinf., 21 (2019) 32–44.

[2] A. Forestieri, E. Arnone, S. Blenkinsop, A. Candela, H. Fowler, L.V. Noto, The impact of climate change on extreme precipitation in Sicily, Italy, Hydrol. Processes, 32 (2018) 332–348.

[3] T.F. Stocker, D. Qin, G.-K. Plattner, M.M.B. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex, P.M. Midgley, Eds., Climate Change 2013: The Physical Science Basis, The Working Group I Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC), Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 2013, 1535 pp.

[4] E. Arnone, D. Pumo, A. Francipane, G. La Loggia, L.V. Noto, The role of urban growth, climate change, and their interplay in altering runoff extremes, Hydrol. Processes, 32 (2018) 1755–1770.

[5] E. Fallah-Mehdipour, O. Bozorg-Haddad, H.A. Loáiciga, Climate-environment-water: integrated and non-integrated approaches to reservoir operation, Environ. Monit. Assess., 192 (2020) 60.

[6] A. Danilenko, E. Dickson, M. Jacobsen, Climate Change and Urban Water Utilities: Challenges and Opportunities, Water Working Notes, Note No. 24, World Bank, Washington, DC, 2010.

[7] R.C. Brears, Climatic Challenges to Water in the Linear Economy, R.C. Brears, Ed., Developing the Circular Water Economy, Palgrave Pivot, 2020, pp. 5–17.

[8] M. De Felice, A. Alessandri, F. Catalano, Seasonal climate forecasts for medium-term electricity demand forecasting, Appl. Energy, 137 (2015). 435–444.

[9] R.T. Clark, P.E. Bett, H.E. Thornton, A.A. Scaife, Skilful seasonal predictions for the European energy industry, Environ. Res. Lett., 12 (2017), https://doi.org/10.1088/1748–9326/aa57ab.

[10] F.J. Doblas-Reyes, Seasonal Prediction Over Europe, Seminar on Predictability in the European and Atlantic Regions, European Centre for Medium-Range Weather Forecasts (ECMWF), Shinfield Park, Reading, 2010. Available at: https://www.ecmwf.int/sites/default/files/elibrary/2012/9070-seasonal-prediction-over-europe.pdf (accessed March 2, 2020).

[11] C. Buontempo, H.M. Hanlon, M. Bruno Soares, I. Christel, J.-M. Soubeyroux, C. Viel, S. Calmanti, L. Bosi, P. Falloon, E.J. Palin, E. Vanvyve, V. Torralba, N. Gonzalez-Reviriego, F. Doblas-Reyes, E.C.D. Pope, P. Newton, F. Liggins, What have we learnt from EUPORIAS climate service prototypes?, Clim. Serv., 9 (2018) 21–32.

[12] M. Bruno Soares, M. Alexander, S. Dessai, Sectoral use of climate information in Europe: a synoptic overview, Clim. Serv., 9 (2018) 5–20.

[13] C. Viel, A.-L. Beaulant, J.-M. Soubeyroux, J.-P. Céron, How seasonal forecast could help a decision maker: an example of climate service for water resource management, Adv. Sci. Res., 13 (2016). 51–55.

[14] L. Crochemore, M.-H. Ramos, F. Pappenberger, C. Perrin, Seasonal streamflow forecasting by conditioning climatology with precipitation indices, Hydrol. Earth Syst. Sci., 21 (2017) 1573–2017.

[15] R. Marcos, M.C. Llasat, P. Quintana-Seguí, M. Turco, Seasonal predictability of water resources in a Mediterranean freshwater reservoir and assessment of its utility for end-users, Sci. Total Environ., 575 (2017) 681–691.

[16] H.M. Ramos, A. McNabola, P.A. López-Jiménez, M. Pérez-Sánchez, Smart water management towards future water sustainable networks, Water, 12 (2019) 58.

[17] P. Stathatou, E. Manoli, D. Assimacopoulos, Sustainability of Water & Sanitation Services in Greece, School of Chemical Engineering, National Technical University of Athens, Greece, 2012.

[18] J. Check, R.K. Schutt, Research Methods in Education, 55 City Road, SAGE Publications, Inc., (2017), doi: 10.4135/9781544307725.

[19] B. Hoskins, The potential for skill across the range of the seamless weather-climate prediction problem: a stimulus for our science, Q. J. R. Meteorolog. Soc., 139 (2013) 573–584.

[20] G. Madec, The NEMO Team, NEMO Ocean Engine, Note Du Pôle Modélisation, 2016. https://doi.org/10.1016/j.joms.2014.06.438.

[21] T. Fichefet, M.A.M. Maqueda, Sensitivity of a global sea ice model to the treatment of ice thermodynamics and dynamics, J. Geophys. Res. Oceans, 102 (1997) 12609–12646.

[22] P. Megalovasilis, A. Kalimeris, D. Founda, C. Giannakopoulos, Climatic Modelling and Groundwater Recharge Affecting Future Water Demands in Zakynthos Island, Ionian Sea, Greece, N. Lambrakis, G. Stournaras, K. Katsanou, Eds., Advances in the Research of Aquatic Environment, Environmental Earth Sciences, Springer, Berlin, Heidelberg, 2011, doi.org/10.1007/978-3-642-19902-8_11.

[23] T. Fawcett, An introduction to ROC analysis, Pattern Recognit. Lett., 27 (2006) 861–874.

[24] E. Arnone, M. Cucchi, S. Dal Gesso, M. Petitta, S. Calmanti, Droughts prediction: a methodology based on climate seasonal forecasts, Water Resour. Manage., (2020) (in Press), doi: 10.1007/s11269-020-02623-3.