Chapter 10

Information-Communication Technologies as an Integrated Water Resources Management (IWRM) Tool for Sustainable Development

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Additional information is available at the end of the chapter

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Abstract

Sustainability is a crucial and at the same time vital approach for satisfying future generations' rights on natural resources. Toward this direction, global policies, supported by international organizations such as UNESCO and its international science programs, foster sustainable development as principal concept for the management of various thematic areas including the environment. The present work promotes the integration of information-communication technologies (ICTs) in the water resources management field as a state of the art concept that sets the basis for sustainable development at global scale. The research focuses on the ICTs contribution to the evolution of scientific and technological disciplines, such as satellite earth observations, real time monitoring networks, geographic information systems, and cloud-based geo information systems and their interconnection to integrated water resources management. Moreover, selected international research programs and activities of UNESCO International Hydrology Programme (IHP) are synoptically but comprehensively being presented to demonstrate the integration of the technological advances in water resources management and their role toward sustainable development.

Keywords: water resources, integrated management, sustainability, information-communication technologies, UNESCO-IHP

1. Introduction

Water is at the heart of sustainable development, i.e., integration of economic, socio-political, and ecological/environmental conditions for humans' development [1–3]. Currently, apart from the Goal 6 "Clean Water and Sanitation" of UN Sustainable Development Goals (SDGs) of the 2030 Agenda for sustainable development, water is included in various targets of the other Goals and is essential in achieving majority of SDGs [4]. Water resources, and the range of services they provide, underpin poverty reduction, economic growth, and environmental sustainability [3], as well as water is fundamental for adaptation to climate change.

However, water management and allocation apart from the current competing demands, such as water supply, agricultural irrigation, hydropower production, and ecosystems preservation, will be further affected mainly by demographic and climatic changes drivers that increase the stress on water resources [5, 6]. According to United Nations World Water Development Report [2], the 90% of the 3 billion people to be added to the population by 2050 may be in regions already experiencing water stress and with no sustainable access to drinking water. In terms of climate change, although humans historically developed settlements in floodplains, they continue to do so [7], in controversy of the adverse impacts, such as storm surges, sea level rise, and coastal flooding and inland flooding in some urban regions that are denoted in the IPCC RCP 8.5 scenario [8]. Even if developed countries are proceeding to the management of flood risk and the reduction of potential damages, i.e., the mapping of flood hazard areas and the generation of Digital Flood Insurance Rate Maps (DFIRMS) in the United States and the adoption of the Flood Directive in 2007 in the European Union that requires member states to assess the risk of flooding, to map potential flood extent, and to coordinate efforts to reduce flood risk [9], at global scale flood events can be considered one of the most consistent and recurring natural disasters experienced by human populations. Moreover, the IPCC RCP 8.5 scenario also designates that the frequency and magnitude of meteorological droughts in presently dry regions by the end of the twenty-first century are likely to be increased [10].

When dealing with transboundary waters, their management confronts augmented difficulties that could be comprised to the lack of (i) political willingness for cooperation, (ii) communication channels among decision makers, scientists, and stakeholders, and (iii) effective exchange mechanisms of data and information [11]. In the literature [2, 12], different models of collaborative activities for transboundary water resources management have been suggested. Even if the approach used in these models differs, depending on which particular scientific discipline or professional community has developed the model, the core element in all models is the data collection and information sharing. Regarding the later, it is mentioned [13] that more than half of the transboundary water agreements that include water resources data and information exchange and were signed in the last 50 years, (i) have direct mechanisms for exchange, with the percentage to present a steadily increase rate, and (ii) the exchange occurs in all geographic regions of the world.

A solution toward these increased threats is the integrated water resources management (IWRM) approach that promotes the way forward for efficient, equitable, and sustainable development and management of the world's limited water resources and for coping with

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conflicting demands. Implementing IWRM at the river basin level is an essential asset in managing water resources more sustainably leading to long-term social, economic, and environmental benefits [2]. The IWRM approaches include the establishment of an overall water policy and laws at basin scale, creation of water rights, use water pricing in allocation, and stakeholders participation in decision making [14]. On the other hand, although the principles and concepts of IWRM have been widely accepted, the level of integration of IWRM is not satisfactorily progressing in many basins.

Without accurate, intensive, and long-term data acquisition and exchange, the state of the world's water resources cannot be adequately assessed, effective preservation and remediation programs cannot be run, and program success cannot be properly evaluated [15]. The continuous emergence of the information-communication technologies (ICTs), nevertheless, has put new standards in the collection, management, and dissemination of water related data, and the coupling of ICTs with mathematical models is proposed as an adjuvant tool for the implementation of the IWRM concept to different socioeconomic environments. The increased efficient of telemetry monitoring networks in terms of real-time measurement of variable environmental parameters, of data storage capacity and power autonomy together with their decreased cost, of the use of Web-based information systems that facilitate spatial data, descriptive information, and observation data sharing over the cloud and are accessible through common Web browsers, of the plethora of free of charge high resolution remote sensing data, and of the direct or indirect integration of geographic information system (GIS) technology to water management issues and the open source mathematical models and tools are selective examples of the advances that ICTs could offer to the water sector.

The 2030 Agenda represents a significant step forward in terms of recognizing Science, Technology and Innovation (STI) as a driving force for sustainable development in its three pillars, environmental, social, and economic. As the only UN agency that includes science in its mandate, UNESCO finds itself at the heart of this initiative. Regarding the water sector, the UNESCO International Hydrological Programme (IHP) is the only intergovernmental program of the UN dedicated to water research, water resources management and security, education, and capacity building. Since its inception in 1975, IHP has evolved from an internationally coordinated hydrological research program into an encompassing, holistic program to facilitate education and capacity building and enhance water resources management and governance. IHP fosters a transdisciplinary, multidisciplinary, and integrated approach to watershed and aquifer management, which incorporates the social dimension of water resources and promotes and develops international research in hydrological and freshwater sciences. The current phase of IHP (2014–2021) on water security will contribute to the achievement of water-related SDGs and targets.

The aim of this research is twofold and aims at: (i) synoptically presenting the contribution of ICTs advancements in the field of monitoring of the environment and the potentiality derived from cloud technologies and (ii) demonstrating the integration of the technological progress in the UNESCO IHP and UNESCO Chairs programs as a tool to decision makers, policy makers, engineers, researchers, etc., in environmental and management issues. From the following analysis is clearly denoted that ICTs form inextricable part in the integrated management of water resources.

2. Evolution of ICTs and implementation on water related issues

The latest technological developments brought communications at the forefront of the technology advancements. Evolutions on communication, i.e., transfer of any type and form of information with high speed internet networks of global coverage, on computing machines, i.e., transformation of personal computers to powerful workstations as well as cloud computing, and on storage capabilities, i.e., cloud backup and storage services with unlimited utilities, have direct impact on technologies, such as remote sensing, monitoring equipment, data bases, and spatial data analysis, that have traditionally been used for the management of water resources.

2.1. Satellite remote sensing

Over the last decade, significant advances in remote sensing techniques have led to a more complete overview of the water cycle at the global scale. Satellite earth observation can provide direct information to processes such as estimation of evapotranspiration [16], precipitation [17], and snowcover/snowmelt [18, 19]. Indirect methods, such as the coupling of remote sensing data with groundwater models, can be used for the assessment of the infiltration process and the recharge of the aquifers. Launched in 2002, the NASA Gravity Recovery and Climate Experiment satellites (GRACE) is the first satellite mission able to provide global observations of terrestrial water storage changes. Many negative trends have been observed in north-west India [20], the Middle East [21], northern China [22], the Caspian Sea and the Aral Sea regions [23], and the southern part of the La Plata basin [24]. Significant positive trends were found in southern Africa, near the Upper Zambezi and Okavango river basins, as well as in the Sahel and the Niger basin [25] and in the Amazon [26].

Regarding water quality characteristics, satellite RS has been used with high levels of accuracy for monitoring marine and coastal ecosystems [27]. Moreover, the specific technology provides essential information on the functioning of ecosystems and on the environmental change drivers [28]. Earth observation together with national statistics, field-based observations, and numerical simulation models are designated as the main source of information for the global monitoring of ecosystem services [29]. A recent study demonstrated that environmental parameters, such as chlorophyll-a (Chl-a) and total suspended matters (TSM), can be investigated at river basin scale through direct and indirect remote sensed observations [30]. On the other hand, in situ measurements for various ecological parameters are limited to a few experiments sites due to severe economic cost, difficulty in accessing the area of interest and a posteriori highly laborious procedures. Moreover, according to a survey of 52 papers chosen randomly from the journal Ecology, the most ecological sampling is conducted at small spatial scales or consists of infrequent or one-time sampling [31].

In the irrigation sector, satellite earth observation is a useful tool for the retrieval of data that are required for an irrigation system characterization, a process that is necessary for effective water management, as it provides essential knowledge through performance and accounting indicators [32]. In particular, recent advances in satellite earth observation can provide several parameters related to irrigation management, such as the extent of the irrigated area, evapotranspiration [33], biomass and yield estimation [34], and irrigation system performance [35].

A further contribution of remote sensing techniques such as light detection and ranging (LiDAR), interferometric synthetic aperture radar (InSAR), and photogrammetry is the construction of Digital Elevation Models (DEMs) [36]. The latter has been proved as a significant tool both for hydrological and hydraulic modeling procedures. In the first case, a DEM can be used for extracting vital topographic and water targeted information including basin boundaries, area and perimeter, watershed delineation, stream definition, flow direction and accumulation, total length and slopes of stream channels, average stream length ratio, drainage density, etc. All the aforementioned information is introduced in spatial distributed or lumped hydrological models for calculating critical parameters, such as the time of concentration [37] and flow accumulation to the basin outlet.

At the same time, DEMs are currently routinely being used together with hydrodynamic models in order to simulate the inundation area after a flood event. Some authors [38] assess the impact of riverbed geometry mapping techniques, by comparing various terrain models, on the performance of a 1D hydraulic model in predicting the flood events. However, 2D hydraulic models are considered the most modern tool for flood inundation and flood hazard studies, where the hydrodynamic model could be coupled with terrain models in order to offer nearly automated flood mapping results [39]. The latter is proposed by the European Union Directive on the assessment and management of flood risks, as the most appropriate tools for generation of flood hazard maps.

2.2. Real time remote monitoring

Telemetric monitoring systems have long been used in the water sector, for remotely monitoring river flows, water quality, and reservoir level to aid water resources management or assist in flood early warnings [40]. However, it was only the last years that the technological emergence in the fields of (i) electronics and microelectronics, such as advancements in new sensor technologies and automated controls, (ii) energy efficiency and autonomy, e.g., the use of photovoltaic panels coupled with electric batteries which have limited life range, (iii) communication technologies with GPRS/GSM extended coverage, (iv) computer technology with the creation of microprocessors and unlimited storage capabilities, and (v) costs in terms of the large cost decrease trend of the aforementioned technologies, boosted the continuous monitoring capabilities of the telemetric monitoring system. Other researchers, see [31] for example, facilitated the telemetric monitoring technology in order to investigate a natural and isolated lake in Northern Taiwan which was inaccessible for extended periods due to extreme climatic conditions caused by typhoons.

Telemetric monitoring systems consist of two principal components: the field equipment and the base station equipment. The field equipment in general includes measuring sensors, a data logger system for data storage and a modem for data transmission, while the base station includes the database and the appropriate software. At the sensor level, the primary issues are the sensor suitability for placement in a field environment, its cost and its power requirements

[31], with sensors for physical parameters, such as temperature, moisture, light, etc., to be widely available, while nitrate and carbon dioxide sensors have to be currently very expensive and have moderate power requirements. As far water quantity observation is concerned, the use of electronics in water velocity instruments is responsible for the decommissioning of the traditional flow velocity measurements that were based on mechanical propeller velocity meters [41]. The velocity measurements coupled with water level observations were used for establishing a stage-discharge relationship (so-called rating curve) [42], a method that demonstrated several limitations due to changes in the channel geometry or roughness (vegetation for instance). The main reason behind this transition is the higher efficiency and easier operation that the new electronic equipment presents [43]. Currently, the progress that has been conducted in optics, radar, acoustics, and electromagnetism has led to a new generation of flow measurement devices, which can offer greater efficiency and performance to map river hydrodynamics [41, 44]. Toward this direction, the continuous acoustic Doppler current profiler (ADCP) flowmeters are used to measure the bulk velocity in the acoustic beam, with the length of the river reach as well as the width of the river sections not being determining factors for the implementation of the ADCP method [38].

Solutions to the power requirements of telemetry water monitoring systems can currently be given with the integration of solar photovoltaic (SPV) cells to the system infrastructure. The produced power of such systems is more than adequate, since similar approaches have been tested in energy intensive installations such as water pumping with SPV and been implemented around the globe as an alternative electric energy source for water pumping at remote locations [45]. As for the data transmission, it is revealed [46] that mobile phone is covering rural areas where few other services might be available (e.g., grid electricity or piped water supply), while it was estimated that in 2012, more people in sub-Saharan Africa had access to the mobile phone network than to improved water supplies. Consequently, the use of general packet radio service (GPRS) protocol, which is a packet-oriented mobile data service used in 2G and 3G cellular global system for mobile communications (GSM) [47], can satisfy the demands for observed data transmission to the base station.

However, it should be mentioned that sensor networks are not a panacea in data collection, since they are susceptible to malfunctions that can result in lost or poor-quality data [48, 49]. The fact that environmental sensors can be damaged or destroyed both by natural phenomena (e.g., floods, fire, animal activity), and by malicious human activity (e.g., theft, vandalism), as well as the not properly maintenance of the sensors, may produce low-quality data. Therefore, in order to secure the reliability and accuracy of the massive quantities of data that are collected by the automated monitoring networks, these new data streams require automated quality assurance and quality control processes in order to ensure the minimum bias, and because the manual methods are inadequate for the volumes of data and the time constraints imposed by near-real-time data processing [50].

2.3. Geographic information systems

Despite its broad use, GIS technology was not specifically developed for engineering modeling applications, but it was launched as a general tool to store, retrieve, manipulate, analyze, and map spatial data [51]. Nevertheless, it was proved that because of the spatial nature of the required data in water resources modeling and management, GIS can be effectively utilized in both aforesaid water processes [52]. Currently, GIS technology is successfully being combined with surface hydrological models, groundwater models, water supply and irrigations systems, hydrodynamic models for floodplain management, water quality models, water resources monitoring and forecasting, and river basin management [52, 53]. Moreover, at the present state, the vast majority of water related models incorporate modules that are completely linked with GIS software in order both to retrieve the input data and to visualize the final outputs. The Soil and Water Assessment Tool (SWAT) model, for example, is a robust watershed modeling tool that uses the ArcSWAT interface, which is an extension to ArcGIS environment to create its inputs [54]. Similarly, a lot of the models developed by the U.S. Army Corps of Engineers Hydrologic Engineering Center (HEC), such as the Ecosystem Functions Model (HEC-EFM), Hydrologic Modeling System (HEC-HMS), and River Analysis System (HEC-RAS), have a set of procedures, tools, and utilities for processing geospatial data in ArcGIS using a graphical user interface (GUI) for the preparation of data.

However, this significant advantage of GIS capability to incorporate related spatial data into traditional water resources databases and then retrieved by water-related models can also be exploited by programming and the development of custom graphical user interfaces (GUI). In other words, GUI is a bridging software that makes the communication links between the GIS databases and the model interface by transforming the data on the format that is required by the model. GUI and query languages permit rapid selection and modification of attribute data and parameter values, allowing for swift sensitivity analyses and multiple scheme evaluation [51].

Prior to performing actual simulation, water resources modeling requires a number of time-consuming steps, including collection, compilation, storage, retrieval, and manipulation of spatial data. With their ability to combine various data sets, GIS software changed the way water resources modeling is handled [55]. In surface water hydrology at river basin scale for example, the data required for the assessment of hydrological parameters such as time of concentration, infiltration rate, etc., depend on a big data set related to the following: geology, edaphology, land uses, land cover, and ground relief. At the same time, the meteorological information usually comes from specific monitoring stations, i.e., point sources, or is given in the form of a mesh. GIS technology enables the coupling of all the previous information in order to be spatially distributed in the hydrological model units and thereafter the model to simulate the rainfall-runoff process [56]. The usefulness of GIS can also be proved when dealing with climate change assessment at river basin scale [57]. In that case, the gridded climate change data were spatially distributed over the hydrological units derived by the MODCOU hydrological model [58] in order to simulate a transboundary river discharges under specific climate change emission scenarios.

2.4. Geo-information cloud databases

The development of cooperative databases has been fostered by the improvement of GIS technology which, among its other capabilities, combines the storage of descriptive and observational information with coverage characteristics [59]. At the same time, with the continuous emergence of new Internet technology, GIS are becoming more open and accessible, thereby facilitating the democratization of sharing spatial data, open accessibility, and effective dissemination of information [60]. Furthermore, the implementation of a relational database management system (RDBMS), which is related to geographical objects through geodatabases, enables the coupling of spatial information with tabulate data in order to store, update, manage, and properly allocate information. This means, for example, that a substance of concern that is recorded by a gauge station of a telemetric monitoring network can be connected to a number of spatial elements, such as the downstream water body, inhabited areas, and environmental protected areas.

In the latest years, both open source (OS) and commercial geo information systems are being routinely used, not only for sharing spatial datasets and monitoring observations but also for advanced geoprocessing functions across the Web [61]. In order to bypass interoperability problems and the data not only be easily accessible but also easily operated, international communication standards, including Open Geospatial Consortium (OGC) standard-compliant services, have been developed to support the establishment of Spatial Data Infrastructures (SDI) [62]. The OGC Web Processing Service (WPS), for example, defines a standard interface to access geoprocessing functions through Web services, while the Catalog Service for the Web (CSW) defines a standard way for publishing and discovering geospatial resources. Similar approaches to the structure of spatial data have been adopted at European level by the INSPIRE Directive of the European Community (EC) [63] that triggers the creation of a European spatial data infrastructure which delivers integrated spatial information services linked by common standards and protocols to users.

The evolution of the WebGIS systems in the early 1990s from the use of the Extensible Markup Language (XML) to the later use of geography mark-up language (GML) and scalable vector graphics (SVG) as well as the integration of Web Feature Services (WFS) and Web Map Services (WMS) to the current WebGIS systems is presented in the literature [64, 59]. Currently, one of the most up to date technologies for spatial information sharing is the Google Fusion Tables (GFTs). GFT is a cloud computing database that provides services on the Web for data management and integration. These services can be accessed directly over the Internet through a browser and permits programmatic access via application programming interface and integration of existing tabular data. The specific technology works by exporting data values from the tables created online or from a user provided spreadsheet and converting it into a meaningful graphical data representation. This collaborative scientific platform has started penetrating into the scientific community. In particular, GFTs coupled with Google Earth were used for time-critical geo-visualizations of the NASA Airborne Visible/Infrared Imaging Spectrometer (AVIRIS) Deepwater Horizon oil spill imaging campaign [65]. In this case, the GFT service was applied to create a highly interactive image archive and mapping display, while its Application programming interfaces (API) was utilized to create a flexible PHP-based interface for metadata creation as the basis for an interactive data catalog. Researchers combined GFT with the OGC sensor observation service (SOS), which can provide real-time or near-real-time observations, in order to manage and analyze in situ sensor observations of soil moisture due to its impacts on agricultural and hydrological processes [66]. The literature also shows that GFTs were used for the development of a geo-referenced information system developed for the

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transboundary aquifers in Africa. The aim of this system was to provide appropriate tools under a Web-based platform for water management institutions in the region [59].

3. ICTs implementation on selective UNESCO IHP case studies

3.1. Remote sensing

Remote sensing precipitation and atmospheric analysis data have been used by UNESCO-IHP in collaboration with Princeton University for the development of an experimental drought and forecast system for Africa, Latin America, and the Caribbean [10] (accessible at http://stream.princeton.edu/). In particular, the historic and real-time data are calculated using the Variable Infiltration Capacity (VIC) land surface hydrological model [67], and the system allows monitoring of meteorological, hydrological, and agricultural droughts in developing regions, where institutional capacity is generally lacking and access to information and technology prevents the development of systems locally. It has the advantage of providing a standardized format for any of the components of the water balance, providing a comprehensive analysis for any point location within the Monitor's domain (currently covering Africa, Latin America, and the Caribbean and the United States), while providing an overview of the regional, transboundary extent of drought hazards.

Similarly, UNESCO-IHP has collaborated with the Center for Hydrometeorology and Remote Sensing (CHRS), University of California, Irvine, on the development of tools to provide near real-time global satellite precipitation estimates at high spatial and temporal resolutions, including the Precipitation Estimation from Remotely Sensed Information using Artificial Neural Networks-Cloud Classification System (PERSIANN-CCS) [68]. The specific system is used to inform emergency planning and management of hydrological risks, such as floods, droughts, and extreme weather events, with the Namibia Drought Hydrological Services (NHS), for example, using it to prepare daily bulletins with up-to-date information on flood and drought conditions for local communities.

Moreover, nowadays, ICTs coincide with the mobile phones and APIs blooming. Following this technological trend, in 2016, IHP and the Center for Hydrometeorology and Remote Sensing (CHRS) at the University of California-Irvine launched the iRain mobile application, devoted to facilitate people's involvement in collecting local data for global precipitation monitoring (http://en.unesco.org/news/irain-new-mobile-app-promote-citizen-science-and-support-water-management). The specific application allows users to visualize real-time global satellite precipitation observations, track extreme precipitation events worldwide, and report local rainfall information using crowd-sourcing functionality to supplement the data. The specific application works together with the PERSIANN-CSS tool and provides real time observation for the amelioration of the remote sensing precipitation estimations.

Within the framework of its groundwater and climate change programme (GRAPHIC) (http://en.unesco.org/graphic), UNESCO-IHP undertook an in-depth assessment of climate variability impacts on total water storage across Africa using a simplified water balance model and

GRACE satellites observations. Results indicate that rainfall patterns associated to the North Atlantic Oscillation (NAO) and El Niño Southern Oscillation (ENSO) are the main drivers of inter-annual water storage changes in Northern Africa and Sub-Saharan Africa, respectively. The Atlantic Multidecadal Oscillation (AMO) plays a significant role in decadal to multidecadal variability, particularly in the Sahel. The findings of this study could be beneficial to decision-makers and help to adequately prepare effective climate variability and adaptation plans (e.g., managed aquifer recharge—MAR) both at national and transboundary level through river basin organizations.

3.2. Monitoring networks for water

On the field of monitoring networks, the importance of groundwater resources is denoted by the Global Groundwater Monitoring Network (GGMN). GGMN is a participative, Web-based network of networks that was set up to improve quality and accessibility of groundwater monitoring information and subsequently the knowledge on the state of groundwater resources at global scale. GGMN is a UNESCO IHP programme, implemented by the International Groundwater Resources Assessment Centre (IGRAC) and supported by many global and regional partners. The GGMN portal (https://ggmn.un-igrac.org/) contains information on the availability of groundwater monitoring data through space and time, and through the portal, groundwater level data and changes can be displayed on a regional scale.

Users are allowed to upload, interpolate, and analyze the groundwater data using the following options:

- Representative groundwater point measurements can be uploaded as well as can be transferred from a national system via Web services, while the data can be displayed showing the mean, range, or change in groundwater level for a selected time period.
- Point measurements can be combined with proxy information and personal expertise to create groundwater level maps. Produced groundwater maps can be shared via the online GGMN Portal.
- Time series analysis can be performed for each point measurement location to better understand temporal changes of groundwater levels. The time series analysis is a step-by-step procedure to identify trends, periodic fluctuations and autoregressive model. Time series analysis helps defining optimal monitoring frequencies, one of the key components of groundwater monitoring network design.

Moreover, the produced documentation, manuals, and material by UNESCO IHP in the field of monitoring networks have been adopted at national level by many countries, e.g., the New Zealand's IHP National Committee has implemented the UNESCO IHP guidelines in order to benchmark its hydrological activities with those of the rest of the world and in particular introducing data telemetry [69].

3.3. GIS on water resources

The use of GIS is an integral part of programs related with the management of spatial information, such as water bodies, aquifers, and wetlands. Among UNESCO-IHP's activities on coastal aquifers, groundwater-related wetlands in the Mediterranean region, under the GEF/UNEP-MAP Strategic Partnership for the Mediterranean Sea Large Marine Ecosystem (MedPartnership) project, were the creation of detailed digital maps with the use of GIS, **Figure 1**, demonstrating the aforementioned water bodies and wetlands in the specific region [70].

For the creation of the specific map, apart from the data and descriptive information received by the project partners that indicates the characteristics of the coastal aquifers and wetlands, digital data about the groundwater resources and recharge were retrieved by the World-wide Hydrogeological Mapping and Assessment Programme (WHYMAP) (https://www.whymap.org), where UNESCO IHP has leading role in the joint program consortium. Maps prepared by WHYMAP include the Groundwater resources of the world (2008), River and groundwater basins of the world (2012), Global groundwater vulnerability to floods and droughts (2015), as well as the World karst aquifer map (2017).

3.4. Web-based databases

The publication and dissemination of spatial and descriptive information on the cloud are fostered by geo-referenced Web-based databases. The results of the PERSIANN-CCS project are included in the UNESCO-IHP's Global Network on Water and Development Information in Arid Lands (G-WADI) GeoServer (http://hydis.eng.uci.edu/gwadi/), which provides real-time

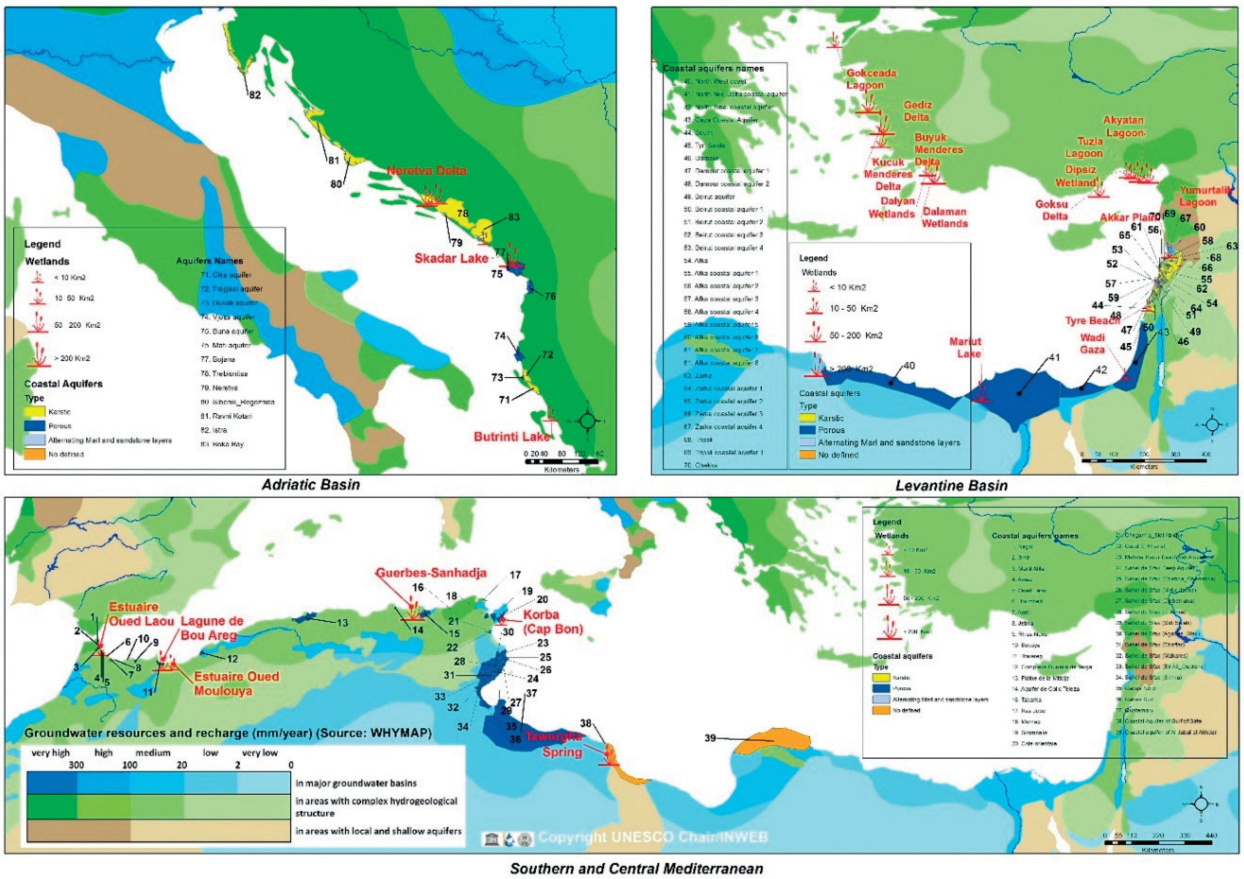

Figure 1. Main Mediterranean coastal aquifers and representative wetlands assessed by UNESCO-IHP for the MedPartnership.

precipitation estimates for water resources managers. By providing updated precipitation observations at the global level, the usefulness of the GeoServer is a direct support to meteorological drought monitoring and early warning worldwide and a contribution to the Global Framework for Climate Services (GFCS) hosted by WMO [71].

Moreover, the UNESCO Chair International Network of Water-Environment Centres for the Balkans (INWEB) has developed, with the use of different technologies, cloud-based databases for the internationally shared aquifers in the SE Europe, North Africa, and in the Middle East. These databases provide dynamic maps where descriptive information and aquifers characteristics can be easily retrieved by the users with the use of the customized Graphical Users Interface (GUI).

The utilization of the Google Fusion Tables Technology by the UNESCO Chair INWEB resulted in the construction of a prototype geo-referenced information system developed for the transboundary aquifers in Africa [59]. The specific information system contains different forms of interactions such as (i) the visualization of an aquifer's spatial extent and projection over the African continent, (ii) the acknowledge of the type of aquifers and the data availability, (iii) downloading capabilities of the data, and (iv) a customized search module that enables the identification of aquifers according to specific criteria, e.g., specific type of aquifers, e.g., porous, with an extent smaller or greater than a specific value and/or where the country population is smaller or greater than a second specific value, and/or where water recharge is more or less than a third specific value. The final output of the search queries is directly linked to the overlaid layers, i.e., only the aquifers which fulfill the search criteria are shown on the map.

The knowledge gained by the aforementioned geo-information system was used in the UNESCO-IHP's activities on coastal groundwater-related wetlands in the Mediterranean region, under the MedPartnership project (http://www.inweb.gr/fusion/coastal_wetlands/coastal_wetlands.html), **Figure 2**. In particular, after the population of a Web database with the 82 coastal aquifers and the 26 wetlands characteristics, JavaScript and HTML5 Web programming languages were used for the creation of the platform interface and the linkage with the database. The final output aimed at (i) facilitating water users to easily retrieve data (spatial and descriptive) related to the coastal wetlands in the Mediterranean, (ii) informing users for the relation of coastal wetlands with underlayed coastal aquifers, (iii) supporting public participation by allowing users to provide comments (either general comments or comments related to a specific geolocation) on the water bodies and environmental areas that appear on the base map, and (iv) enhancing communication by automatically generate emails to specific workgroups whenever comments are made.

As a result of the GEF-funded Transboundary Waters Assessment Programme (TWAP) project, UNESCO-IHP and IGRAC executed an assessment of 199 transboundary aquifers and 43 Small Island Developing States (SIDS) groundwater systems. The data include indicators describing the hydrogeological, environmental, socioeconomic and governance dimensions of tranboundary aquifers and SIDS groundwater systems and are available on IGRAC's Global Groundwater Information System (GGIS) (https://www.un-igrac.org/global-groundwater--information-system-ggis).

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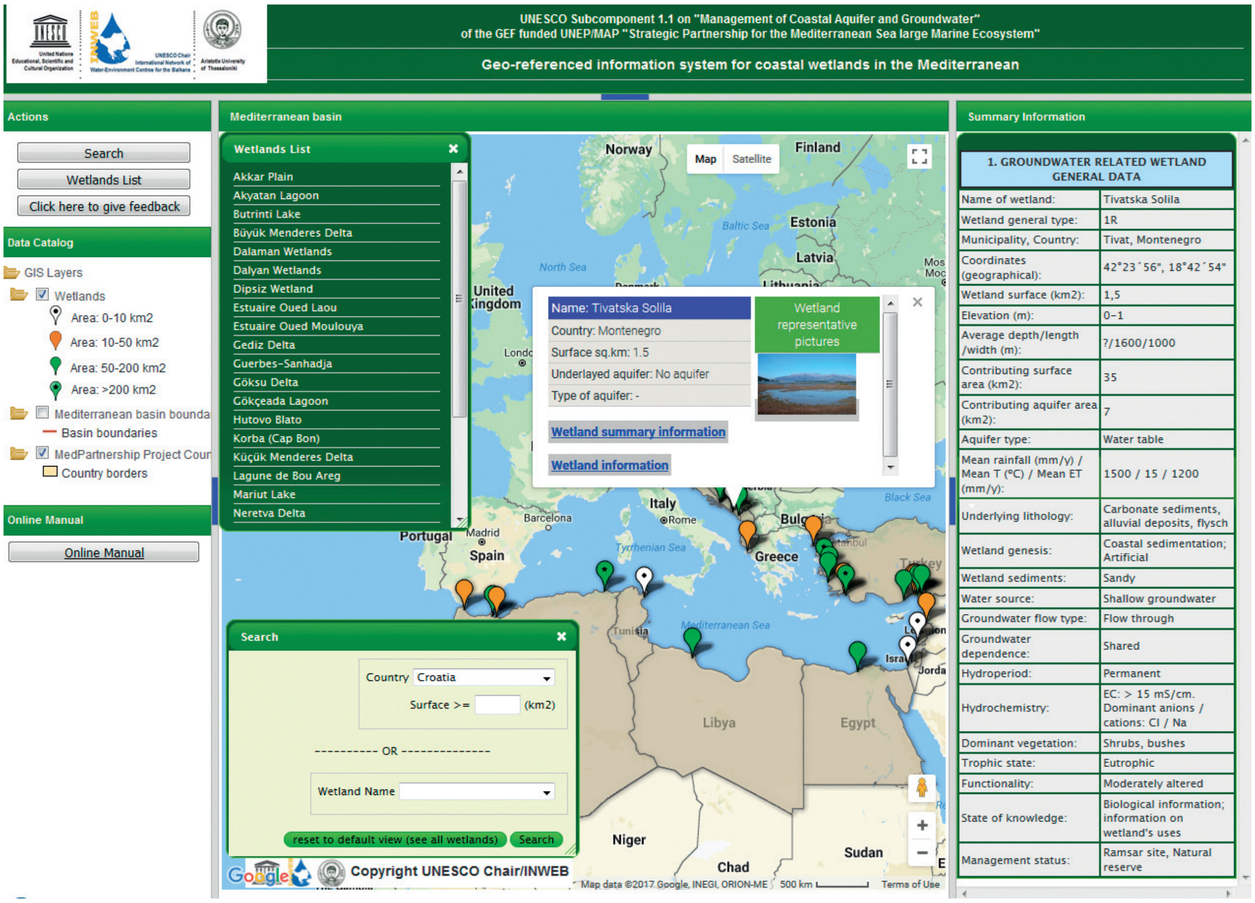

Figure 2. Illustration of the geo-referenced information system and its functionality tolls for coastal groundwater related wetlands in the Mediterranean basin.

UNESCO-IHP is highly involved in the promotion of ICTs tool for water resources management. In June 2013, the UNESCO-IHP launched the Hydro free and/or Open-source software Platform for Experts initiative (also known as HOPE: http://www.hope-initiative.net/). The initiative brings together experts from several fields of water resources to engage in capacity building and trainings based on the use of Free and Open Source Software (FOSS) [72]. Indeed, the FOSS provides reliable sustainable basis for scientific decision-making, which is essential for the sound governance of water resources. In that sense, HOPE offers a more integrative, international and solutions-oriented approach, with the aim of linking high-quality focused scientific research to policy-relevant interdisciplinary efforts for global sustainability. Because of its decreased software costs, FOSS contributes to improve access to technologies and more specifically in the developing world. The initiative also intends to stimulate cooperation in research and development and to enhance their dissemination. Furthermore, since education continues to be ever more linked to technologies, it is essential to promote and foster equal access to ICTs in order to improve the quality of education in the water sector. HOPE participates to that achievement by providing trainings on FOSS and e-Learning open solutions toward Inclusive Knowledge Societies. As a result, capacities of youth and young professionals in the water sector are reinforced, making them more fit and facilitating their integration in a constantly evolving environment. In that sense, HOPE encourages linkages between SDG 6[1] and SDG 8[2] with a focus on fostering innovative job creation.

In partnership with 18 universities, centers, and other organizations, UNESCO-IHP is also collaborating on the FREEWAT (FREE and open source tools for WATer resource management: http://www.freewat.eu/) project, a HORIZON 2020 project financed by the EU Commission. FREEWAT is an innovative participatory approach gathering technical staff and relevant stakeholders, including policy and decision makers, in designing scenarios for the proper application of conjunctive water policies [73]. The consortium organized also capacity building workshops and seminars and provided training to 700 participants.

In the framework of the promotion of open-source and free software, UNESCO is coordinating with the Vrije Universiteit Brussel, the OpenWater Symposium. The symposium focuses on sharing experiences newly lead research using open source software and open access tools within the field of water management and hydrology.

UNESCO-IHP is also behind the Water Information Network System (IHP-WINS), which was launched in January 2017 [74]. This online platform (available at: http://ihp-wins.unesco.org/) incorporates GIS data on water resources into a cooperative and open-access participatory database to foster knowledge-sharing and access to information. IHP-WINS is freely made available by UNESCO's IHP to Member States, water stakeholders, and partners with the aim of facilitating access to information and encouraging contributors to share data on water. Thanks to those contributions, the platform benefits from continuous enrichments with spatial data and documents, coming from various sources. A variety of spatial data is shared and accessible on the platform: scale varies from the global to the very local level, information can be quantitative or qualitative, and both raster and vector are available. Additionally, because the platform is open to a variety of contributors, information covers a large array of water-related topics ranging from quality to risk, to gender, etc. Users can combine those layers of information to create maps tailored to their own needs. Transparency and respect of authorship are guaranteed as all information provided benefit from metadata in a standardized format and from a Digital Object Identifier (DOI). This allows for an accurate identification and crediting of any contribution and easy later sharing. Inter-disciplinary collaboration, professional networking, and mentoring are also stimulated through working groups, where users can exchange and provide feedbacks on their ongoing work. This involvement and participation contributes to the building of an online community. By gathering global and inclusive knowledge on water, and facilitating interdisciplinary collaboration, IHP-WINS aims overall at supporting Members States and stakeholders involved in resources management. The platform will also contribute to close the gap between North and South in terms of access to knowledge. The initiative contributes to the follow-up on the monitoring and implementation of the targets of Sustainable Development Goal 6 (SDG 6) and those of other water-related goals.

IHP-WINS offers different spatial information that can be overlaid to create tailored maps. As illustrated at **Figure 3**, which was developed by IGRAC and UNESCO-IHP in 2015, by

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[1]Ensure availability and sustainable management of water and sanitation for all.

[2]Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all.

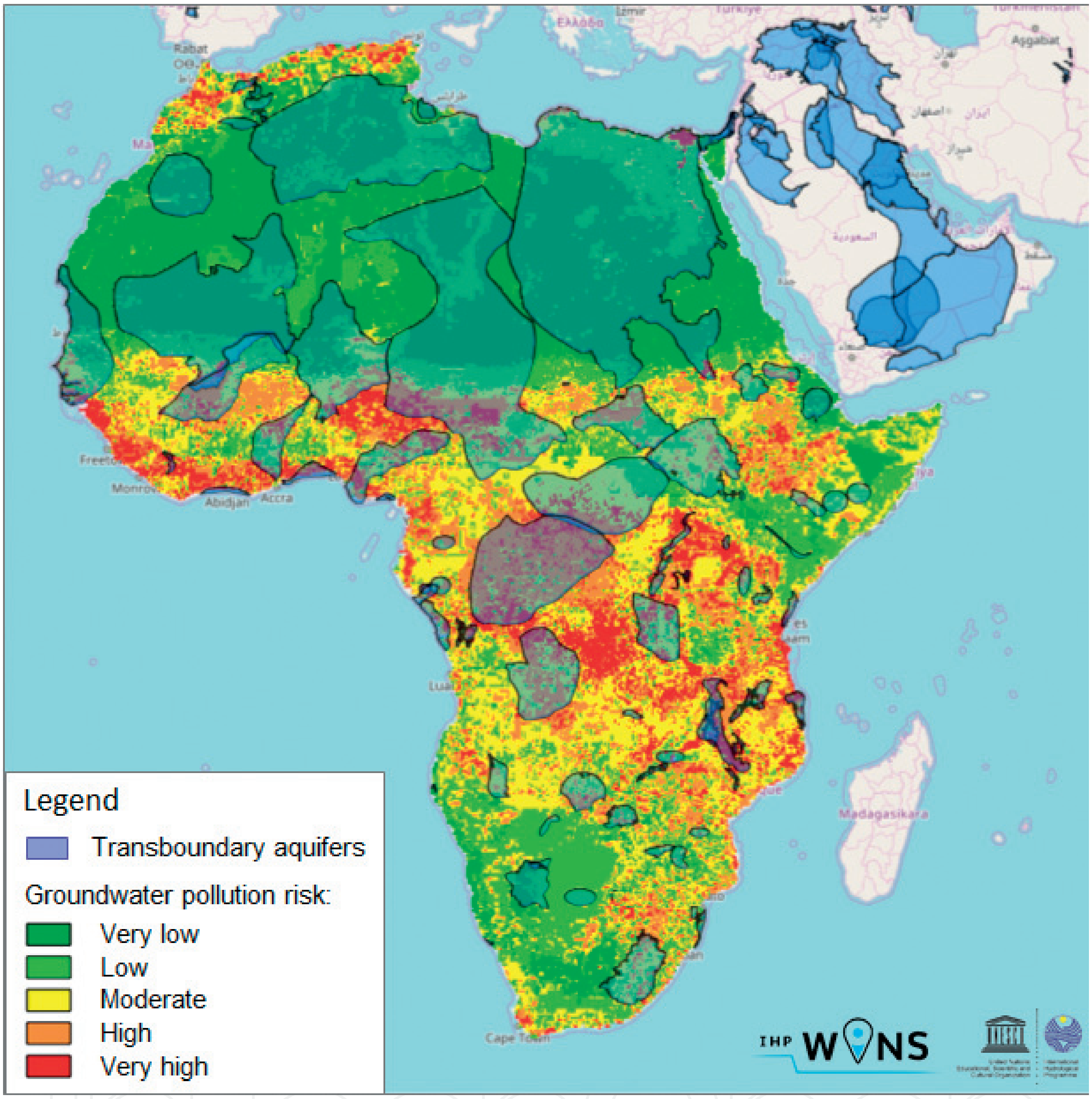

Figure 3. Transboundary aquifers and groundwater pollution risk in Africa.

superimposing information on the spatial extent of transboundary aquifers (1st layer) and groundwater pollution risk (2nd layer), users can quickly identify transboundary resources potentially at risk and the areas where inter-state cooperation for water management should be encouraged.

4. Conclusions

The way in which nowadays information is shared and communication takes place has changed the perspective of our world. The recent revolutionary progress of science, technology, and global communication has put new standards at national and international level, while this progress is also transforming the structure of the economic and social activities. The present work demonstrates that the exponential advances of the information-communication technologies (ICTs) have been also encapsulated in the environmental sector, with special emphasis to be given to the water sector, and international organizations, such as UNESCO-IHP, have adopted this potentiality in their various programs.

The specific work gives also emphasis to the use of ICTs that have been used in different UNESCO IHP programs in order to (i) strengthen the capacity building of water management institutions to implement sustainable forms of utilization, management and protection of transboundary water resources, (ii) facilitate water users to retrieve data related to transboundary water resources, (iii) enable water experts to share data, and (iv) support public participation.

ICTs can also contribute to other thematic fields. A holistic and comprehensive approach to promoting ICT in education, for example, has been conducted by UNESCO [75]. Particularly, UNESCO's Intersectoral Platform emphases on the joint work of the ICTs with science in order to support universal access to education, equity in education, the delivery of quality learning and teaching, teachers' professional development and more efficient education management, governance, and administration.

Integrated environmental data management is concerned with providing an opportunity to draw together relevant data on a transient or permanent basis within the same or across disciplinary boundaries so as to address through analyses, modeling or other means, environmental issues of local, regional, national, or international interest or concern [76]. In the water sector and especially in the integrated water resources management (IWRM), ICTs can provide solutions for its implementation. Particularly, technologies such as satellite earth observation, telemetric monitoring networks, and GIS and Web-based geo-referenced information systems could smooth any differences in the use of technical standards and specifications for data collection and information sharing at national and international level when dealing with transboundary water resources. In the case of engineers, hydrologists, environmental professionals, etc. where emphasis is given on modeling the hydro systems, the aforementioned tools could contribute for a more accurate modeling procedure, since accuracy is subjected to data availability and precision and thereafter for analyzing relationships between physical and ecological variables such as precipitation, river flow, or groundwater recharge [12]. The results of the modeling procedure are useful for understanding how the physical and ecological transboundary systems behave under natural conditions and when anthropogenic pressure is implemented.

However, the proper and standardized utilization of ICTs are a common problem in developing countries. For example, monitoring and early warning systems (MEWS) at operational phase contain the decentralized data collection, scattered over multiple agencies that are dependent on different ministries. This requires collaboration across ministries through a multisectorial approach, which often cannot be effectively implemented without direct support from high-level policymakers [10]. Although most countries have foreseen the development of such monitoring systems in their legislation, it often remains underdeveloped and inappropriate for decision making.

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References

[1] United Nations. Our Common Future, Report of the World Commission on Environment and Development. United Nations; 1987

[2] UNESCO-WWAP (UNESCO World Water Assessment Programme). The United Nations World Water Development Report 3: Water in a Changing World. Paris: UNESCO, and London: Earthscan; 2009. ISBN: 978-9-23104-095-5

[3] UNESCO-WWAP (UNESCO World Water Assessment Programme). The United Nations World Water Development Report 2015: Water for a Sustainable World. Paris: UNESCO; 2015

[4] UN, GA. Transforming our world: The 2030 agenda for sustainable development. A/RES/70/1, 21 October; 2015

[5] Black R, Kniveton D, Skeldon R, Coppard D, Murata A, Schmidt-Verkerk K. Demographics and climate change: Future trends and their policy implications for migration. Working Paper. Brighton: Development Research Centre on Migration, Globalisation and Poverty, University of Sussex; 2008

[6] Bates B. Climate Change and Water: IPCC technical paper VI. World Health Organization; 2009

[7] Wohl EE. Chapter 1: Inland flood hazards. In: Wohl EE, editor. In Inland Flood Hazards: Human, Riparian, and Aquatic Communities. New York, NY, USA: Cambridge University Press; 2011. pp. 3-36

[8] IPCC. Climate Change 2014: Synthesis Report. In: Pachauri RK, Meyer LA, editors. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Geneva, Switzerland: IPCC; 2014. 151 p

[9] Turner AB, Colby JD, Csontos RM, Batten M. Flood modeling using a synthesis of multiplatform LiDAR data. Water. 2013;**5**(4):1533-1560

[10] Verbist K, Amani A, Mishra A, Jiménez B. Strengthening drought risk management and policy: UNESCO International Hydrological Programme's case studies from Africa and Latin America and the Caribbean. Water Policy. 2016;**18**(S2):245-261. DOI: 10.2166/wp.2016.223

[11] Ganoulis J, Skoulikaris C. Interactive open source information systems for fostering transboundary water cooperation. In: Free Flow—Reaching Water Security Through Cooperation. Tudor Rose: UNESCO Publishing; 2013. pp. 94-98

[12] Ganoulis J, Aureli A, Fried J. In: Ganoulis J, Aureli A, Fried J, editors. Transboundary Water Resources Management: A Multidisciplinary Approach. Weinheim: Wiley-VCH; 2011. 446 p

[13] Gerlak AK, Lautze J, Giordano M. Water resources data and information exchange in transboundary water treaties. International Environmental Agreements: Politics, Law and Economics. 2011;**11**(2):179-199

[14] Giordano M, Shah T. From IWRM back to integrated water resources management. International Journal of Water Resources Development. 2014;**30**(3):364-376

[15] Glasgow HB, Burkholder JM, Reed RE, Lewitus AJ, Kleinman JE. Real-time remote monitoring of water quality: A review of current applications, and advancements in sensor, telemetry, and computing technologies. Journal of Experimental Marine Biology and Ecology. 2004;**300**(1):409-448

[16] Anderson MC, Allen RG, Morse A, Kustas WP. Use of Landsat thermal imagery in monitoring evapotranspiration and managing water resources. Remote Sensing of Environment. 2012;**122**:50-65

[17] Adler RF et al. The version-2 global precipitation climatology project (GPCP) monthly precipitation analysis (1979–present). Journal of Hydrometeorology. 2003;**4**(6):1147-1167

[18] Jain SK, Goswami A, Saraf AK. Accuracy assessment of MODIS, NOAA and IRS data in snow cover mapping under Himalayan conditions. International Journal of Remote Sensing. 2008;**29**(20):5863-5878

[19] Kuchment LS, Romanov P, Gelfan AN, Demidov VN. Use of satellite-derived data for characterization of snow cover and simulation of snowmelt runoff through a distributed physically based model of runoff generation. Hydrology and Earth System Sciences. 2010; **14**(2):339-350

[20] Rodell M, Velicogna I, Famiglietti JS. Satellite-based estimates of groundwater depletion in India. Nature. 2009;**460**(758):999-1002. DOI: 10.1038/nature08238

[21] Voss K, Famiglietti J, Lo M, de Linage C, Rodell M, Swenson S. Groundwater depletion in the Middle East from GRACE with implications for transboudnary water management in the Tigris-Euphrates-Western Iran region. Water Resources Research. 2013;**49**: 904-914

[22] Feng W, Zhong M, Lemoine JM, Biancale R, Hsu HT, Xia J. Evaluation of groundwater depletion in Northc China using Gravity Recovery and Climate Experiment (GRACE) data and ground-based measurements. Water Resources Research. 2013;**49**(4):2110-2118

[23] Chen Y, Li W, Deng H, Fang G, Li Z. Changes in Central Asia's water tower: Past, present and future. Scientific Reports. 2016;**6**. DOI: 10.1038/srep35458

[24] Chen J, Wilson C, Tapley B, Longuevergne L, Yang Z, Scanlon B. Recent La Plata basin drought conditions observed by satellite gravimetry. Journal of Geophysical Research. 2010;**115**:D22108. DOI: 10.1029/2010JD014689

[25] Ramillien G, Frappart F, Seoane L. Application of the regional water mass variations from GRACE satellite gravimetry to large-scale water management in Africa. Remote Sensing. 2014;**6**:7379-7405

[26] Humphrey V, Gudmundsson L, Seneviratne S. Assessing global water storage variability from GRACE: Trends, seasonal cycle, Subseasonal Anomalies and Extremes. Surveys in Geophysics. 2016;**37**:357-395

[27] Nezlin NP, Polikarpov IG, Al-Yamani FY, Subba Rao DV, Ignatov AM. Satellite monitoring of climatic factors regulating phytoplankton variability in the Arabian (Persian) Gulf. Journal of Marine Systems. 2010;**82**:47-60

[28] Cord AF, Brauman KA, Chaplin-Kramer R, Huth A, Ziv G, Seppelt R. Priorities to advance monitoring of ecosystem services using earth observation. Trends in Ecology & Evolution. 2017;**32**(6):416-428

[29] Tallis H et al. A global system for monitoring ecosystem service change. Bioscience. 2012;**62**:977-986

[30] Alexandridis TK, Monachou S, Skoulikaris C, Kalopesa E, Zalidis GC. Investigation of the temporal relation of remotely sensed coastal water quality with GIS modeled upstream soil erosion. Hydrological Processes. 2015;**29**:2373-2384

[31] Porter J et al. Wireless sensor networks for ecology. AIBS Bulletin. 2005;**55**(7):561-572

[32] Alexandridis TK et al. Combining remotely sensed surface energy fluxes and GIS analysis of groundwater parameters for irrigation system assessment. Irrigation science. 2014;**32**(2):127-140

[33] Singh R, Liu S, Tieszen L, Suyker A, Verma S. Estimating seasonal evapotranspiration from temporal satellite images. Irrigation Science. 2012;**30**(4):303-313

[34] Bastiaanssen WGM, Ali S. A new crop yield forecasting model based on satellite measurements applied across the Indus Basin, Pakistan. Agriculture, Ecosystems and Environment. 2003;**94**(3):321-340

[35] Santos C, Lorite IJ, Tasumi M, Allen RG, Fereres E. Performance assessment of an irrigation scheme using indicators determined with remote sensing techniques. Irrigation Science. 2010;**28**(6):461-477

[36] Chen C, Liu F, Li Y, Yan C, Liu G. A robust interpolation method for constructing digital elevation models from remote sensing data. Geomorphology. 2016b;**268**:275-287

[37] Grimaldi S, Petroselli A, Tauro F, Porfiri M. Time of concentration: A paradox in modern hydrology. Hydrological Sciences Journal. 2012;**57**(2):217-228

[38] Reil A, Skoulikaris C, Alexandridis TK, Roub R. Evaluation of riverbed representation methods for 1D flood hydraulics model. Journal of Flood Risk Management. DOI: 10.1111/jfr3.12304

[39] Costabile P, Macchione F. Enhancing river model set-up for 2-D dynamic flood modelling. Environmental Modelling & Software. 2015;**67**:89-107

[40] Thomson P, Hope R, Foster T. GSM-enabled remote monitoring of rural handpumps: A proof-of-concept study. Journal of Hydroinformatics. 2012;**14**(4):829-839

[41] Muste M, Kim W, Fulford JM. Developments in hydrometric technology: New and emerging instruments for mapping river hydrodynamics. World Meteorological Organization Bulletin. 2008;**57**(3):163-169

[42] Le Coz J, Pierrefeu G, Paquier A. Evaluation of river discharges monitored by a fixed side-looking Doppler profiler. Water Resources Research. 2008;**44**:W00D09. DOI: 10.1029/2008WR006967

[43] Pasquale N. Modern comprehensive approach to monitor the morphodynamic evolution of a restored river corridor. Hydrology and Earth System Sciences. 2011;**15**(4):1197-1212

[44] Song S, Schmalz B, Hörmann G, Fohrer N. Accuracy, reproducibility and sensitivity of acoustic Doppler technology for velocity and discharge measurements in medium-sized rivers. Hydrological sciences journal. 2012;**57**(8):1626-1641

[45] Meah K, Fletcher S, Ula S. Solar photovoltaic water pumping for remote locations. Renewable and Sustainable Energy Reviews. 2008;**12**(2):472-487

[46] Hope R, Foster T, Money A, Rouse M, Money N, Thomas M. Smart Water Systems. Project report to UK DFID. Oxford: Oxford University; April 2011. 14 p

[47] Gutiérrez J, Villa-Medina JF, Nieto-Garibay A, Porta-Gándara MÁ. Automated irrigation system using a wireless sensor network and GPRS module. IEEE Transactions on Instrumentation and Measurement. 2014;**63**(1):166-176

[48] Peppler RA et al. An overview of ARM program climate research facility data quality assurance. Open Atmospheric Science Journal. 2008;**2**(1):192-216

[49] Fiebrich CA, Grimsley DL, McPherson RA, Kesler KA, Essenberg GR. The value of routine site visits in managing and maintaining quality data from the Oklahoma Mesonet. Journal of Atmospheric and Oceanic Technology. 2006;**23**(3):406-416

[50] Campbell JL et al. Quantity is nothing without quality: Automated QA/QC for streaming environmental sensor data. Bioscience. 2013;**63**(7):574-585

[51] Martins PH, LeBoeuf EJ, Dobbins JP, Daniel EB, Abkowitz MD. Interfacing GIS with water resource models: A state-of-the-art review. JAWRA Journal of the American Water Resources Association. 2005;**41**(6):1471-1487

[52] Tsihrintzis VA, Hamid R, Fuentes HR. Use of geographic information systems (GIS) in water resources: A review. Water Resources Management. 1996;**10**(4):251-277

[53] McKinney DC, Cai X. Linking GIS and water resources management models: An object-oriented method. Environmental Modelling & Software. 2002;**17**(5):413-425

[54] Olivera F, Valenzuela M, Srinivasan R, Choi J, Cho H, Koka S, Agrawal A. ArcGIS-SWAT: A geodata model and GIS interface for SWAT. JAWRA Journal of the American Water Resources Association. 2006;**42**(2):295-309

[55] Jeton AE, Smith JL. Development of watershed models for two sierra Nevada basins using a geographic information system. Water Resources Bulletin. AWRA. 1993;**29**(6): 923-932

[56] Singh P, Gupta A, Singh M. Hydrological inferences from watershed analysis for water resource management using remote sensing and GIS techniques. The Egyptian Journal of Remote Sensing and Space Science. 2014;**17**(2):111-121

[57] Skoulikaris C, Ganoulis J. Assessing climate change impacts at River Basin scale by integrating global circulation models with regional hydrological simulations. European Water. 2011;**34**:53-60

[58] Ledoux E, Girard G, de Marsily G, Deschenes J. Spatially distributed modeling: Conceptual approach, coupling surface water and ground water. In: Unsaturated Flow Hydrologic Modeling—Theory and Practice. NATO ASI Series S 275. 1989. pp. 435-454

[59] Skoulikaris C et al. Cooperative WebGIS interactive information systems for water resources data management. In: Daniell T et al., editors. Hydrology in a Changing World: Environmental and Human Dimensions. IAHS Publ. 363 Ed. Wallingford, UK: IAHS; 2014. pp. 342-347

[60] Dragicevic S. The potential of web-based GIS. Journal of Geographical Systems. 2004;**6**:79-81

[61] Kiehle C, Greve K, Heier C. Requirements for next generation spatial data infrastructures-standardized web based geoprocessing and web service orchestration. Transactions in GIS. 2007;**11**(6):819-834

[62] Yue P, Baumann P, Bugbee K, Jiang L. Towards intelligent GIServices. Earth Science Informatics. 2015;**8**(3):463-481

[63] EU INSPIRE Directive. 2007. Available from: http://inspire.jrc.ec.europa.eu/ [Accessed: 20 September 2017]

[64] Peng ZR, Zhang C. The roles of geography markup language (GML), scalable vector graphics (SVG), and Web feature service (WFS) specifications in the development of Internet geographic information systems (GIS). Journal of Geographical Systems. 2004;**6**(2):95-116

[65] Bradley ES et al. Google earth and Google fusion tables in support of time-critical collaboration: Mapping the deepwater horizon oil spill with the AVIRIS airborne spectrometer. Earth Science Informatics. 2011;**4**(4):169-179

[66] Yue P, Jiang L, Hu L. Google fusion tables for managing soil moisture sensor observations. IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing. 2014;**7**(11):4414-4421

[67] Liang X et al. A simple hydrologically based model of land surface water and energy fluxes for general circulation models. Journal of Geophysical Research. 1994;**99**(D17): 14415-14428

[68] Hsu K, Behrangi A, Iman B Sorooshian S. Extreme precipitation estimation using satellite-based PERSIANNCCS algorithm. In: Gebremichael M, Hossain, F, editors. Satellite Rainfall Applications for Surface Hydrology. New York, USA: Springer; 2010. pp. 49-67

[69] UNESCO. Water, People and Cooperation—50 Years of Water Programmes for Sustainable Development at UNESCO. Paris, France: UNESCO; 2015. ISBN 978-92-3-100128-4

[70] UNEP-MAP, UNESCO-IHP. Final Report on Mediterranean Coastal Aquifers and Groundwater Including the Coastal Aquifer Supplement to the TDA-MED and the Subregional Action Plans. Paris: Strategic Partnership for the Mediterranean Sea Large Marine Ecosystem (MedPartnership). UNESCO; 2015

[71] Hewitt C, Mason S, Walland D. The global framework for climate services. Nature Climate Change. 2012;**2**:831-832

[72] UNESCO. HOPE Initiative: Hydro Free and Open-source Platform of Experts. 2017a. Available from: http://en.unesco.org/hope [Accessed: 12 October 2017]

[73] FREEWAT. Free and open source software tools for. Water Resource Management. 2017. Available from: http://www.freewat.eu/ [Accessed: 12 October 2017]

[74] UNESCO. Water Information Network System (IHP-WINS). 2017. Available from: http://en.unesco.org/ihp-wins [Accessed: 12 October 2017]

[75] UNESCO. ICT in Education. 2017. Available from: http://en.unesco.org/themes/ict-education [Accessed: 12 September 2017]

[76] Harmancioglu NB, Ozkul SD, Fistikoglu O, Geerders P, editors. Integrated Technologies for Environmental Monitoring and Information Production. Nato Science Series: IV: 23. Netherlands: Springer, Kluwer Academic Publishers; 2003