Hydroinformatics and the Web: Analytics and Dissemination of Hydrology Data for Climate Change and Sustainability

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Climate change and global sustainability are among the most urgent concerns facing humanity. One important aspect of this is hydrology, i.e., the scientific study of the movement, distribution and management of water. In light of the pervasiveness of Web technology and more broadly of information and communication technology (ICT), this article presents an overview of recent advances in Web data analytics for hydrology and hydroinformatics, via scientific perspectives, experiments, and tools pertaining to hydrology data and its relevance to areas such as climate change. Researchers have conducted studies on hydrological problems that are spreading globally, and the role of the Web is crucial here for providing ubiquitous access to information, enabling its efficient analysis and adequately disseminating the results via websites and apps. This aids in predictive analytics and decision support. We address the management, mining, and dissemination of hydrology data with the long-term goal of global sustainability. We survey classical and state-of-the-art works in hydroinformatics and the Web, also including recent COVID-19 related issues, and discuss notable open avenues for future research both with regard to climate change as well as the future of the Web.

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1. INTRODUCTION

Scientific applications have been among the principal drivers of the growth of the World Wide Web ever since its conception at CERN in 1989. The numerous applications of the Web now span the gamut of scientific domains. Scientists often rely on the Web as a useful platform for obtaining data, conducting lab studies, performing online experiments, exchanging results, and in recent times also invoking it as a medium for communication (as opposed to in-person meetings), thereby facilitating collaborator interactions, video-conferencing for seminars and much more. Since many scientific studies today are data-driven (rather than the traditional hypothesis-driven), various tools and techniques in data mining, machine learning and web data management play a significant role in automation, analysis and dissemination [Provost and Fawcett ; Aggarwal et al. 2019; Zadeh 2003]. In fact, the realm of data science has evolved as a fairly multi-disciplinary area, spanning various fields such as biology, medicine, climate science, engineering, economics and others [Gao et al. 2018; Grossman et al. 2001; Einav and Levin 2014].

In this article, we dwell on the broad field of climate science with particular focus on hydrology, i.e., the study of water. As we know, water is one of our most vital natural resources, without which there would be no life on Earth. Hydrology is a science that has evolved in response to the necessity to comprehend the complex water systems across the globe and assist in providing solutions to water-related problems [United States Geological Survey 2019]. A related area is hydroinformatics, which considers information management and analysis with respect to hydrology [Abbott 1991]. Today, hydroinformatics leverages the advances in ICT (information and communication technology) in addition to classical methodologies in data science for storing, processing and mining data, and using the discovered knowledge in pertinent applications. We present a survey on hydroinformatics in this article with respect to Web technology, considering its overall impact on climate change and sustainability. We focus on how hydrology data is analyzed and broadcast to the masses using cutting edge tools and techniques. We delve into papers on water data management, mining and dissemination. Topics discussed in this article include precipitation studies, climate change, water quality management, cyber-infrastructure for water resources, online modeling tools and techniques in hydrology, water contamination analysis, websites and apps on hydroinformatics, and decision support in hydrology. We also discuss water-related issues associated with the recent COVID-19 pandemic.

The analytical approaches harnessed in the works surveyed in this article span various data science techniques such as regression analysis and artificial neural networks. Geospatial data management is utilized in some works, while principles from Human Computer Interaction (HCI) and Internet of Things (IoT) are deployed in others.

To the best of our knowledge, ours is one of the first surveys on Web data analytics and dissemination in hydrology and its impact on global sustainability. This survey article may be particularly relevant to multi-disciplinary researchers working across data science and climate science related areas. This includes Web development, data mining, HCI, IoT, climate change and geoinformatics.

The rest of this article is organized as follows. Section 2 addresses Web data management and mining in the realm of hydrology, focusing mainly on analytics. Section 3 describes the development of useful web systems and mobile applications in hydroinformatics, focusing on dissemination and decision support. Section 4 addresses the recent COVID-19 pandemic with respect to the theme of this article. Section 5 states the conclusions along with open issues for future work.

2. WEB DATA MANAGEMENT AND MINING IN HYDROINFORMATICS

Runoff Forecasting with Data Mining: Runoff refers to the draining away of water (and substances in it) from the surface of an area of land, building structures, etc. Runoff forecasting is a nonlinear and complex process, useful for designing canals, planning water management, predicting natural calamities such as floods and drought. Certain models have been developed for runoff forecasting with specific attention to flood and rainfall estimation [Mishra et al. 2015]. These models have been developed by using AI and data mining with techniques such as regression analysis, clustering, artificial neutral networks (ANN), support vector machines (SVM), genetic algorithms (GA), rough sets, and fuzzy logic [Russell and Norvig 2020]. Hydrology data stored on the Web has been subjected to analysis, mainly using the following methods.

- Clustering – used for grouping in order to monitor similarities between areas pertaining to rainfall, flood occurrence, and also water quality.
- Regression analysis – used for hypothesis testing, modeling the relationships between hydrological parameters, and for water quality assessment.
- Artificial Neural Networks (ANN) – used for computing models based on hydrological time series data, the advantages being that they require less data, are capable for long duration forecasting and much more.
- Support Vector Machines (SVMs) – used for robust binary classification aiming to maximize the accuracy of the different forecasting situations.

These techniques have been found particularly effective for hydrological prediction in disastrous situations such as flooding and are also useful for water resource management. While mathematical models have also been developed for this purpose, it is found that they require too much data and time involvement for forecasting and yet often only yield marginally superior results compared to more automated AI and data mining techniques. Hence, the approaches described herein are often preferred, especially given the fact that data evolves rapidly in this era of climate change, due to which rapid forecasting with efficient training is imperative. Since data is widely available on the Web today, its ubiquitous access with respect to the changing climate makes such AI-based predictive analytics a good choice.

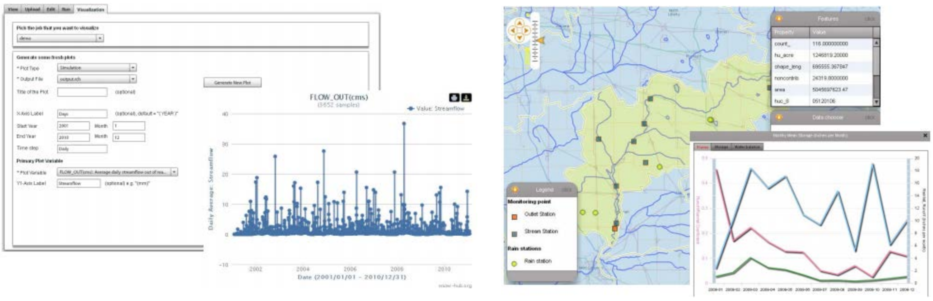
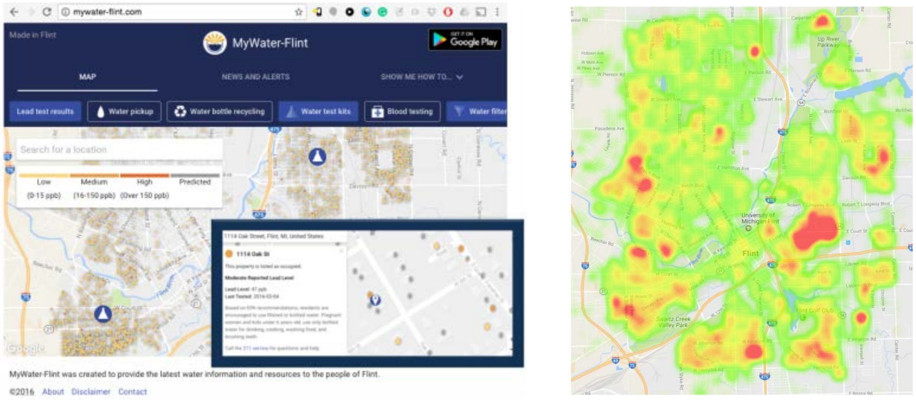


Fig. 1: SWATshare online modeling results (left), HET rainfall-runoff views (right) [Merwade et al. 2012]

Educational Resources and Knowledge Discovery: Researchers [Merwade et al. 2012] have developed a GIS-infused model sharing platform called SWATShare (Soil Water Assessment Tool Share). It endows students and educators with the ability to conduct simulations online, as well as to publish, share and visualize model results to study the impact of land use change on hydrology. The SWATShare resource constitutes an online modeling environment. In addition, it is also useful to understand the water cycle of a watershed. Accordingly, a Hydrology Exploration Toolkit (HET) has been developed to access rainfall and runoff views using web services, such that students can analyze data on specific watersheds. Both SWATshare and HET are developed based on the WaterHUB system built at Purdue University [Merwade et al. 2012]. The goal of WaterHUB is to arrange a cyber-infrastructure for education and training on water-related issues and offer guidance on how to save water. WaterHUB draws on the Structured Query Language (SQL) via MySQL [Oracle 2020] and is designed on the Purdue HUBzero framework, an open source web-based scientific gateway system that provides a turnkey platform for users to access, use, share and contribute data as well as tools. Additionally, WaterHUB facilitates online teaching and learning activities via user groups, discussion forums, project wikis, ratings and citations.

Figure 1 portrays parts of SWATshare and HET. The left side shows a visualization of online modeling results from SWATshare while the right side depicts rainfall and runoff views using HET. Systems such as SWATshare, HET and WaterHUB contribute to global sustainability by addressing land use change (related to climate change), guiding people in water-saving procedures and offering Web-based data exchange for education and training on hydrology. These systems harness technology in Web-based data management and knowledge discovery for educational resources in hydroinformatics.

Diagnosis of Water Contamination: Contamination of water resources is a vital concern. Lead contamination in water is a major problem and can be a substantial health hazard. An important case here is the well-known Flint Water Crisis, which has also received attention in the data mining community [Chojnacki et al. 2017]. Figure 2 presents a snapshot of the MyWaterFlint website for analysis and visualization along with a glimpse of the map showing locations of voluntary residential tests in Flint.



MyWater-Flint was created to provide the latest water information and resources to the people of Flint.

Fig. 2: MyWaterFlint site (left) and locations of water tests in Flint (right) [Chojnacki et al. 2017]

This work [Chojnacki et al. 2017] examined the lead contamination of each household's water supply incorporating risk factors on lead contamination. Relevant assessments have been made accessible to the people of Michigan via the Web (as shown here) and through a mobile application funded by Google.org. Moreover, a survey has been conducted scrutinizing respondents on how frequently they test their water samples. This research revealed higher amounts of water lead levels in comparison to what one would expect based on the Environmental Protection Agency (EPA) guidelines. A pediatrician's report states that there has been a drastic increase of lead levels in the blood of children from Flint. Pregnant women and elderly people have also been exposed to the lead in the water. This research has evaluated pertinent datasets, including residential water testing data, sentinel water testing data, parcel data, service line data, and census block level data. These datasets have been used to further analyze the results of the lead contamination in water.

This research has aroused much attention and is still ongoing. Steps are being taken to fully eliminate the lead content in the water. Such work proves the effectiveness of data analytics with regard to crucial issues such as water contamination, which may severely affect health of the population. The related Website serves as a useful source of information dissemination to the common public.

Analysis of Precipitation Data: Climate change can influence weather trends and precipitation levels across the globe. Some areas experience excessive precipitation with the possibility of flooding and landslides, while others receive very little precipitation with the potential of drought, wildfires, agricultural problems, poor air quality and health issues. Scientists claim that rising temperatures due to global warming could increase evaporation and transpiration, causing excessive precipitation with adverse impacts [Kirschbaum and McMillan 2018]. Globally disseminating and analyzing precipitation data is useful especially in this age of ever-growing big data [Sellars et al. 2013]. Accordingly, precipitation studies have been conducted in domains spanning climate science and data science. A gauge-based global dataset called REGEN is discussed in recent work [Contractor et al. 2019]. It provides daily precipitation data on temporal land coverage for the period of 1950–2013. As per REGEN, there are notable changes in rainfall from 1950 to 2013 in well-gauged areas.

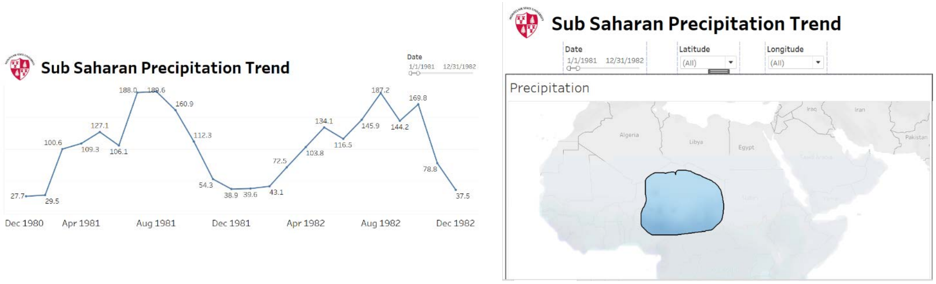


Fig. 3: Precipitation analysis tool: trendline (left), lasso selection view (right) [Karthikeyan et al. 2020]

An interactive tool for visualization and analysis of precipitation data has been developed [Karthikeyan et al. 2020] to enable ubiquitous access and facilitate conducting studies. This tool is customized for Sub-Saharan Africa since the region is among the most severely affected by climate change worldwide. This tool is designed to be particularly user-friendly, such that experts (e.g., data scientists, climate scientists) as well as the common public (farmers, local planning agencies etc.) can easily comprehend its functionality. It deploys Web-based software such as ArcGIS (Aeronautical Reconnaissance Coverage Geographic Information System) [Environmental Systems Research Institute 2020] and Tableau [Salesforce 2013]. ArcGIS is used for geoprocessing of big data of the order of terabytes to extract meaningful information. Tableau is harnessed to provide dashboards, trendlines, custom filters, zooming and panning, as well as rectangle, radial and lasso selection. Figure 3 provides a glimpse into this tool. The left side shows a precipitation trendline with a date filter, while the right side shows lasso selection (enabling users to draw freehand shapes around given regions for specific views) along with a date and latitude–longitude filter. This tool on Sub-Saharan precipitation data facilitates the identification of specific regions needing attention in hydro-climate studies. It promotes future predictions based on past data. While this tool caters to Sub-Saharan Africa, the methods and software described in this work can be applied to other world regions with adequate adaptation.

Such works in general [Contractor et al. 2019; Karthikeyan et al. 2020] exemplify the importance of data science in recent precipitation studies. They address issues such as ubiquitous information access via the Web and user-friendly analysis for the common public. They make broader impacts on climate change by providing relevant datasets and analytical features for precipitation studies.

3. WEB SYSTEMS AND MOBILE APPLICATIONS FOR HYDROINFORMATICS

DSS for Water Resource Management: Modern information systems and technologies are making efforts to find solutions and improve conditions of water resource management and the hydrological modeling of river catchments. The knowledge on how to collect, store and process information about the quantity, quality and distribution of water resources in a river catchment has been studied [Iliev et al. 2010]. In this research, a Web-based decision support system (DSS) helps in finding the best possible solutions on various problems related to water resource management and its protection. Its functionalities include:

—Calculating operations in specialized applications on hydrological data processing and economic activities
—Assisting decision-making in river basin water management via digital maps and geographic information
—Finding preventive measures for protection from catastrophes
—Searching index data, documents, video and audio information in water related knowledge bases
—Organizing seminars, briefings etc. on water management with national and international coordination

The architecture of this Web-based DSS comprises several components including Web-based services, geographic information, communication centers etc. The system is illustrated in Figure 4. This DSS has been developed in Bulgaria and is targeted towards regional water resource management, aiding in its case studies. Yet it has global impact with respect to its functionalities, and its architecture can be deployed in similar systems elsewhere. This DSS exemplifies the use of Web technology in conjunction with GIS and other features to provide a useful platform for Web-based dissemination of valuable hydrological information, helpful in achieving sustainable solutions to water management.

Apps for Hydroclimatic Parameters: There are parameters related to hydrology data and climate such as precipitation and humidity. It is important to gain access to such data anywhere, anytime to facilitate decision-making by local government bodies and to provide

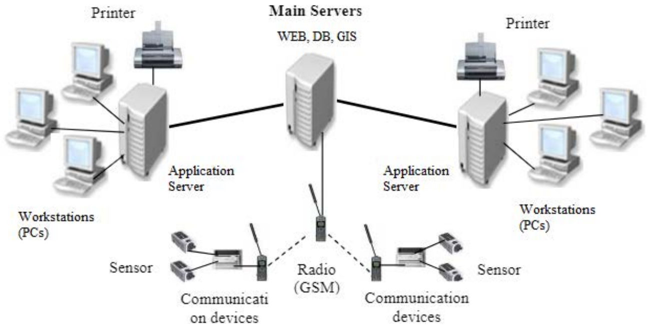


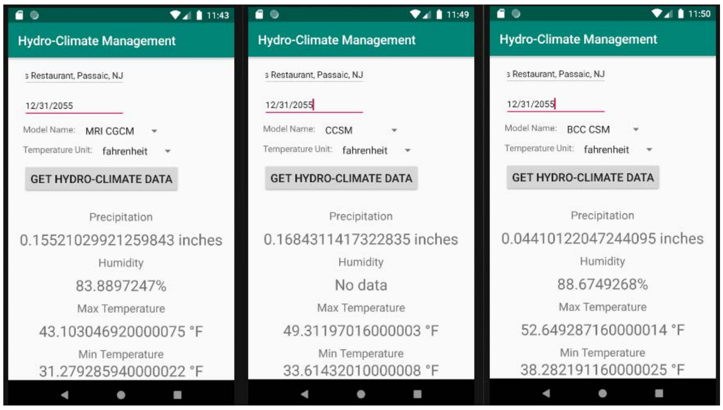
Fig. 4: Architecture of Web-based DSS for water resource management [Iliev et al. 2010]

valuable information to the common public, in addition to offering ubiquitous information retrieval and predictive analytics to scientists. This motivates the development of apps to retrieve information on hydroclimatic parameters and provide suitable predictions on their future values. Data in the respective domains as well as techniques in data science are very important in app development [Basavaraju and Varde 2016]. Such apps may be geared towards specific geolocations.

An Android app has been developed for disseminating precipitation data in Sub-Saharan Africa [Karthikeyan et al. 2020]. This app takes a particular geolocation and date as its input and displays the average, minimum, maximum and total precipitation in that location, thus providing key local data at-a-glance. This can be particularly useful for data analytics in agricultural studies. Rain-fed agriculture is a kind of farming relying on rainfall for water, and accounting for more than 95% of farmed land in Sub-Saharan Africa (also 90% in Latin America, 75% in the Near East and North Africa, 65% in East Asia and 60% in South Asia) [Serdeczny et al. 2016]. Information retrieval for precipitation data can thus benefit rain-fed agriculture by aiding in crop cultivation-related planning activities. An easily accessible Sub-Saharan African precipitation app can offer localized information to farmers and other residents to plan daily activities and make key decisions, thereby enhancing global sustainability. This Sub-Saharan precipitation app leverages the Network Common Data Format (NetCDF) [Rew and Davis 1990] to collect precipitation data from climate science sources, and ArcGIS [Environmental Systems Research Institute 2020] for mapping and conversion of the data into a SQLite (Structured Query Language lightweight) format [Bentley et al. 2019] in order to proceed with KB (Knowledge Base) development. It has a geocoder mapping API (Application Programming Interface) to map the respective geolocation to a latitude–longitude value, climatic modeling to connect the latitude–longitude values to precipitation values, and an app user interface to serve the output to the user on different kinds of devices, including IoT ones.

Principles from Human-Computer Interaction [Rogers et al. 2015] are important in designing such apps. For instance, this Sub-Saharan precipitation app draws on *metaphors* as illustrative descriptions of a concept, e.g., clouds and droplets to depict rainfall. The design follows Fitt's Law [Boritz and Cowan 1991], which states that the time to retrieve an object is directly proportional to its size and inversely proportional to its distance from the opening screen. This entails striving to render objects (metaphors, buttons, entry fields etc.)

sufficiently large for users to spot them easily, yet sufficiently small to fit on a single screen. It is also advisable to maintain simple navigation such that all objects are easily reachable from the opening screen for the users to find them quickly. Additionally, its design has been based on ethnographic studies [Rogers et al. 2015] to obtain thorough knowledge of the concerned domain via observation and analysis. For this app, Sub-Saharan Africa has been studied with regard to its geography, the bare necessities of people etc., in addition to the knowledge of climate scientists to guide app development.



s Restaurant, Passaic, NJ
12/31/2055
Model Name: MRI CGCM
Temperature Unit: fahrenheit
Precipitation
0.15521029921259843 inches
Humidity
83.8897247%
Max Temperature
43.103046920000075 °F
Min Temperature
31.279285940000022 °F

s Restaurant, Passaic, NJ
12/31/2055
Model Name: CCSM
Temperature Unit: fahrenheit
Precipitation
0.1684311417322835 inches
Humidity
No data
Max Temperature
49.31197016000003 °F
Min Temperature
33.61432010000008 °F

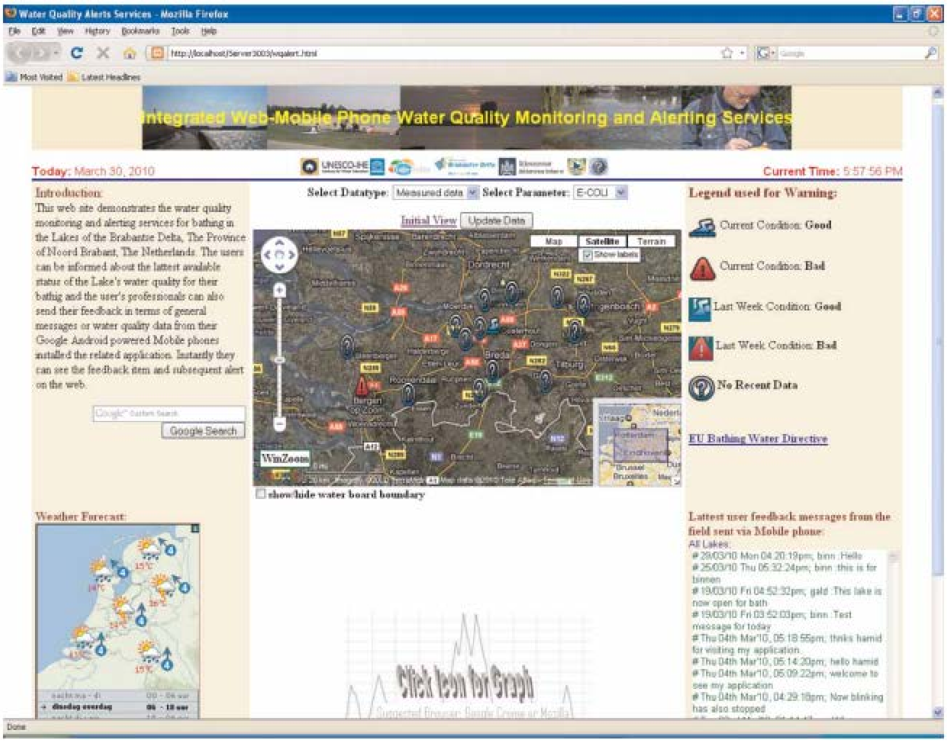
s Restaurant, Passaic, NJ
12/31/2055
Model Name: BCC CSM
Temperature Unit: fahrenheit
Precipitation
0.04410122047244095 inches
Humidity
88.6749268%
Max Temperature
52.649287160000014 °F
Min Temperature
38.282191160000025 °F

Fig. 5: Snapshot of prediction with hydro-climate data app in NJ Passaic [Pathak et al. 2019]

Another mobile app for hydro-climate data in the NJ Passaic region [Pathak et al. 2019] goes beyond information retrieval. A snapshot of the input and output displayed by this app is depicted in Figure 5. The app provides predictions of future hydroclimatic parameter values in addition to retrieving those from the past, pertaining to specific locations. It targets climate scientists, government bodies, small business owners as well as general residents. The input to the app is the name of a given geolocation (which is mapped to latitude–longitude geo-coordinates), a date (past or future up to 2075), temperature unit (Celsius / Fahrenheit) and a preferred climatic model for prediction with a link to the description of each model (default used if no selection). The output constitutes recorded or estimated values for average precipitation, average humidity as well as maximum and minimum temperatures for that geolocation and date. HCI and IoT considerations similar to those for the Sub-Saharan precipitation app are used in the design and development of this hydro-climate data app for NJ Passaic. The climatic models used for prediction in this app are CCSM (Community Climate System Model) [Gent et al. 2011], MRI CCGM (Meteorological Research Institute model of Japan) [Yukimoto et al. 2012], and BCC CSM (Beijing Climate Center Climate System Model) [Beijing Climate Center 2012], which are widely studied in climate science. The default model is MRI CCGM [Yukimoto et al. 2012], since it is the most feasible model with the highest global acceptance as found from ethnographic studies, interviews with stakeholders and particularly the inputs of domain experts in climate science involved with this work.

Apps for Water Quality Information: The quality of water is critical, not only for drinking and cooking, but also for additional purposes such as bathing. This motivates the development of mobile applications (apps) for ubiquitous access to water quality information.

In an interesting piece of work [Jonoski et al. 2013] that is part of an EU (European Union) research project in hydroinformatics, apps are made available to people for adequate water quality information management. The focus is on outdoor recreational activities, e.g., swimming and bathing. These mobile phone apps are integrated with Web applications.



Introduction:
This web site demonstrates the water quality monitoring and alerting services for bathing in the Lakes of the Brabantse Delta, The Province of Noord Brabant, The Netherlands. The users can be informed about the lattest available status of the Lake's water quality for their bathig and the user's professionals can also send their feedback in terms of general messages or water quality data from their Google Android powered Mobile phones installed the related application. Instantly they can see the feedback item and subsequent alert on the web.

Latest user feedback messages from the field sent via Mobile phone:
All Lakes:
28/03/10 Mon 04:20:19pm; binn :Hello
25/03/10 Thu 05:32:24pm; binn :this is for binnen
19/03/10 Fri 04:52:32pm; gald :This lake is now open for bath
19/03/10 Fri 03:52:03pm; binn :Test message for today
Thu 04th Mar'10, 05:18:55pm; thnks hamid for visiting my application
Thu 04th Mar'10, 05:14:20pm; hello hamid
Thu 04th Mar'10, 05:09:22pm; welcome to see my application
Thu 04th Mar'10, 04:29:18pm; Now blinking has also stopped

Fig. 6: Feedback messages from water quality app users [Jonoski et al. 2013]

The water quality model here employs the open source MOHID modeling package[1] based on the MOHID system [Viegas et al. 2009]. This is a nonlinear 3D hydrological modeling system with object-oriented programming, combining various mathematical models and providing GUIs (graphical user interfaces) for pre-processing and post-processing. The apps rely on the Google Maps API for location-tracking. These apps foster bidirectional communication on water quality between water management authorities and end-users, i.e., the common public. Water quality alerts are provided to end users for giving them updates from the management authorities using simple terms such as “swimming allowed”, “swimming not advisable” etc. The end-users in turn can provide any feedback for assistance needed via the apps. Figure 6 depicts mobile phone feedback messages incorporated into the Website within which the apps are integrated.

In two case studies conducted using these apps on regions in the Netherlands, it has been found that the apps are very effective. Overall, this work [Jonoski et al. 2013] indicates the

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[1] Available at the site `http://www.mohid.com`

importance of hydroinformatics in applications pertaining to sports and recreation. While these may be of secondary importance compared to potable water and crisis management, they are examples of advances in sustainable living, especially beneficial to smart cities.

Cloud-based Water Quality Monitoring: Since water is indispensable, it should be monitored and maintained very carefully, and waste should be avoided. In order to ascertain a high potable water quality and also to prevent contamination, methods for water quality monitoring (WQM) with the help of wireless sensor networks (WSNs) and the cloud have been proposed [Adu-Manu et al. 2017]. The authors of the study emphasize that while around 71% of the world is filled with water, only 2.5% of this is fresh water; and that in some African countries, approximately 3/4 of the drinking water is derived from underground sources. Hence, the monitoring of water quality is highly critical. The presented WQM, as illustrated in Figure 7, uses online Web-based storage via the cloud along with remote monitoring stations. As found in recent surveys, e.g., [Chandra et al. 2019; Pawlish and Varde 2018] spanning several works, cloud-based systems offer adequate services in such large scale applications. Likewise in this WQM system, information retrieval, analysis and reporting are all conducted using cloud services. The system deploys WSNs for data acquisition and transfer. The standard use case is to check the quality of water with regard to any chemical, physical and biological properties, while also analyzing water conditions. The WQM system ensures that there is a freshwater source in rivers, lakes, ponds, streams and much more.

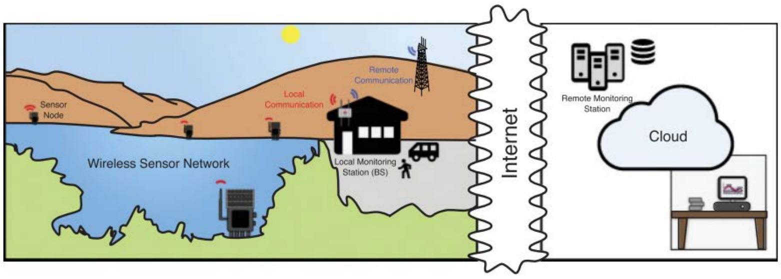

Fig. 7: Water quality monitoring system using cloud technology [Adu-Manu et al. 2017]

This cloud-based WQM deploying WSNs overcomes the drawbacks of manual WQM systems, mainly for the following reasons:

- Sensors and cloud services enable collection of consistent hydrology data
- Frequent sampling of water quality is easily achievable
- Measurements of water quality can be conveyed to targeted users for real-time analysis
- User feedback can be applied to alter sampling frequencies for enhanced performance

Systems of this sort in the realm of hydroinformatics have substantial potential for impact on global sustainability, particularly in regions with water scarcity or in times of crisis.

4. COVID-19 AND HYDROLOGY

The recent coronavirus global pandemic has caused substantial hardship and concern. While this has led to doctors and other healthcare professionals rush to the need of the hour, it has also made numerous researchers from multiple domains focus their efforts on contributing towards the analysis, diagnosis, prevention of spread as well as investigation of potential treatments and vaccines for COVID-19. This accounts for health, social, economic and other issues. Data science has played a crucial role in much of this research providing techniques for analysis and dissemination. This also applies to hydrology-related investigations. Not all observations are negative. Some water sources have become cleaner due to the COVID-19 lockdown, as e.g. depicted in Figure 8. The image from 2020 (right) is clear enough to show what lies beneath the surface of the water in the Venice canals.

Fig. 8: Venice canals 2019 (left), 2020 (right); cleared in COVID-19 lockdown [European Space Agency 2020]

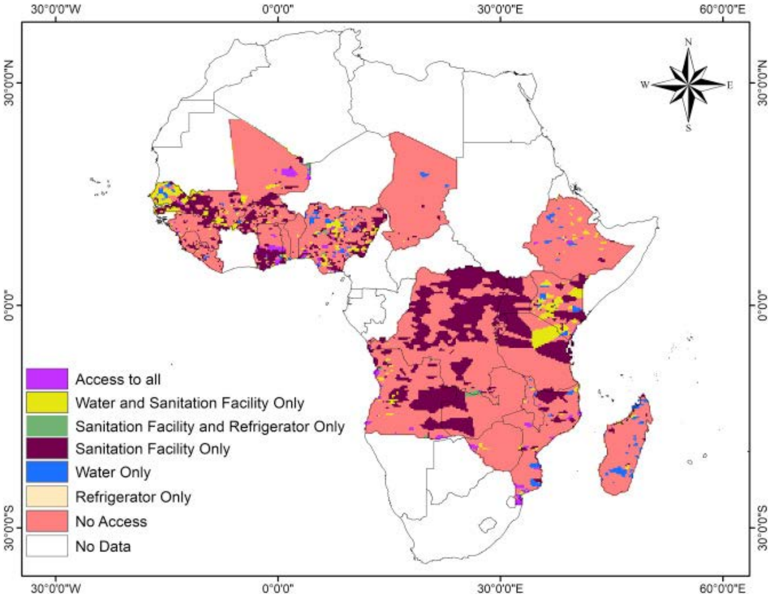

Fig. 9: Spatial variation of in-house access to basic needs in Sub-Saharan Africa [Ekumah et al. 2020]

COVID-19 and Water-Related Amenities: Some researchers [Ekumah et al. 2020] address the issue of how the COVID-19 pandemic has extensively affected humanity overall in the Sub-Saharan African region. Clearly, basic amenities such as water, food and sanitation are essential, and hence some people who are not able to easily access these needs may have to leave their homes during the lockdown. In such cases, the risk of them getting affected by COVID-19 and also causing further spread of the disease may increase. Therefore certain preventive measures are taken by governmental organizations in the respective regions, such as to infuse innovative gender and age sensitive support services. These include water supply and portable sanitation in order to facilitate adherence to the preventive measures recommended by healthcare experts, i.e., maintaining social distancing, hand-washing, and partial or total lockdowns.

Figure 9 depicts a map of Sub-Saharan Africa with spatial variations of in-house access to bare necessities, including water and other amenities [Ekumah et al. 2020]. This enables at-a-glance views of the proactive measures taken by the organizations in the respective regions. These views are useful to healthcare professionals and others aiming to provide immediate help, and to data scientists and environmental researchers conducting further studies in these areas. Such views assist analysis for scientific and economic purposes.

Correlation of Climatic Parameters and COVID-19: A recent article [Wu et al. 2020] addresses the global crisis of COVID-19 with respect to the greatest challenges encountered based on climatic parameters such as humidity. It analyzes the effects of temperature and relative humidity on daily new cases and daily new deaths due to COVID-19. It also reemphasizes the fact that elderly people and patients with pre-existing medical problems are at higher risk if infected by COVID-19. Their findings suggest that temperature and relative humidity are both negatively correlated with daily new COVID-19 cases and deaths. This is illustrated in Figure 10, which presents a graphical plot of these parameters versus COVID-19 case counts [Wu et al. 2020].

Such data may be useful in epidemiological and medical studies on COVID-19, as it reveals interesting information on the relationships between climatic conditions and COVID-19. Findings of this sort have the potential to ultimately provide guidance regarding recommended preventive measures for COVID-19 from a climate standpoint.

Impacts of COVID-19 on Water Consumption: Studies based on water consumption and COVID-19 proffer interesting experiments and results. A notable study [Kalbusch et al. 2020] focuses on the preventive measures being taken on water consumption in Joinville, Southern Brazil due to COVID-19. Certain analyses have been conducted on the water consumption of different categories of users, i.e., those in commercial, industrial, public, and residential buildings. Water consumption data has been gathered by remote telemetry, via the deployment of IoT sensors attached to consumption meters of the water distribution systems in the respective types of buildings. The results suggest that the COVID-19 spread prevention measures have had a significant impact on urban water consumption.

Figure 11 provides box-plots symbolizing water consumption before and after the deployment of measures to avoid contagion by COVID-19 [Kalbusch et al. 2020]. One of the observations is a decrease in commercial, industrial and public usage of water, and a slight increase in the residential consumption of water. This accords with the idea of people spending less time at their workplaces and in public areas and more time at home. Such

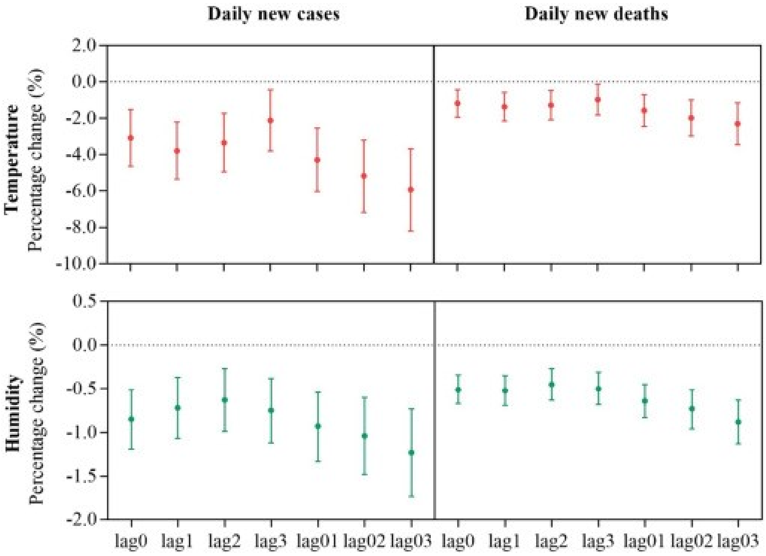

Fig. 10: Effects of temperature, relative humidity on daily new COVID-19 cases/deaths [Wu et al. 2020]

analyses are useful to comprehend the diverse effects of the pandemic on water consumption and provide useful inputs for related studies.

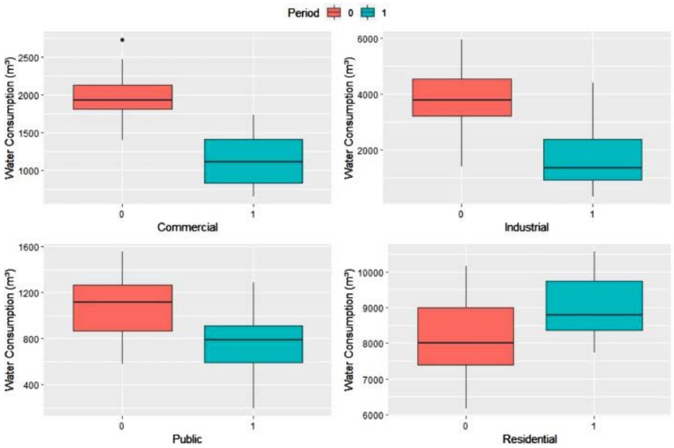

Fig. 11: Box-plots before (0) and after (1) COVID-19 preventive measures [Kalbusch et al. 2020]

All the works surveyed in this section indicate how significant data science related techniques are in addressing the recent global pandemic. Statistical metrics, geo-maps, graphical plots and various analytical methods help in understanding relationships between parameters, while Web technology aids in broadcasting the relevant data and the experimental results to the concerned audience. We have only focused on hydrological information pertinent to COVID-19 in this section, since the theme of this survey article is hydroinformatics. In general, data science has a played a remarkable role in dealing with this pandemic.

5. CONCLUSIONS AND OPEN ISSUES

In this survey article, we delve into the realm of hydroinformatics, with particular reference to the role of Web technology and data science. To the best of our knowledge, this is among the first few surveys in the area of hydroinformatics and the Web. We address Web data management and mining in hydrology with respect to analytics, and Web-based systems along with mobile applications with respect to dissemination. We also briefly cover research pertaining to the COVID-19 pandemic relevant to hydroinformatics.

The theme of this article sparks much interest, proffering the scope for further research. A few open avenues based on the works surveyed herein are as follows.

(1) Investigating deep learning techniques in detail for issues such as runoff forecasting

(2) Evaluating traditional mathematical models in hydrology and heuristic models in hydroinformatics with comparative studies

(3) Building more educational tools in pertinent areas such as climate science and environmental management based on the advances in data science, especially Web and cloud technologies

(4) Deploying transfer learning on big data in hydroinformatics, urban studies and COVID-19 analysis to achieve efficient and accurate results in targeted applications

(5) Implementing more apps on both Android as well as iOS platforms to further enhance ubiquitous access of information in hydroinformatics and related areas, thus contributing to smart living and smart mobility

(6) Learning from the results of some studies herewith to solve water-related problems such as contamination, thus contributing to smart environment and healthcare

(7) Conducting opinion mining on social media posts of the public in various regions to gauge their reactions on water-related policies via sentiment analysis, and conveying feedback to urban agencies in line with transparency for smart governance

(8) Contributing further to the diagnosis, prevention and cure of COVID-19 with data science related research and development, relevant to hydrology as well as other areas

We ourselves are considering further work on mining hydrological data from social media posts, based on the success of some of our earlier projects in relevant areas [Puri et al. 2018; Gandhe et al. 2018; Varghese et al. 2020], along with the fact that social media mining is of remarkable interest today in domain-specific applications as found from many studies [Du et al. 2019; Dahal et al. 2019; Sachdeva et al. 2016; Wang et al. 2017]. The paradigm of the geo-social web [Scellato 2011], entailing aspects such as socio-spatial features and location-as-a-service, provides challenging opportunities for further research as well. This is especially with reference to geo-informatics that constitutes a broader realm, encompassing hydroinformatics and related areas. Overall, we conclude that there is ample opportunity for impact in the area of hydrology and the Web, including analytics and dissemination of data. Such impact may benefit climate change and global sustainability, which clearly merit substantial consideration and effort.

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