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Use of 4IR Technologies in Water and Sanitation in Latin America and the Caribbean

Water and Sanitation Division

Authors:
Dr. Mirjana Stankovic
Dr. Ali Hasanbeigi
Mr. Nikola Neftenov
Tambourine Innovation Ventures

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Marcello Basani
Anamaría Núñez
Raphaëlle Ortiz

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USE OF 4IR TECHNOLOGIES IN WATER AND SANITATION IN LATIN AMERICA AND THE CARIBBEAN

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Contents

List of acronyms

4IR	Fourth Industrial Revolution
AI	Artificial Intelligence
IDB	Inter-American Development Bank
GDP	Gross Domestic Product
GDPR	General Data Protection Regulation
GVA	Gross Value Added
HDI	Human Development Index
ICT	Information and Communication Technologies
IoT	Internet of Things
IT	Information Technology
LAC	Latin America and the Caribbean
LTE	Long Term Evolution
NRW	Non-Revenue Water
OECD	Organisation for Economic Cooperation and Development
SDG	Sustainable Development Goals
SME	Small and Medium Sized Enterprise
UAVs	Unmanned Aerial Vehicles
US	United States
WASH	Water, Sanitation, and Hygiene
WDN	Water Distribution Networks
WEF	World Economic Forum
WIPO	World Intellectual Property Organization
WRM	Water Resource Management

1. Introduction

The United Nations' Sustainable Development Goal 6 (SDG 6) aims to ensure the availability and management of water and sanitation for all, including an end to open defecation, by 2030.[1] Lack of access to clean water and proper sanitation affect all aspects of human life across the globe, having the largest negative effects on least developed countries and marginalized communities. About 36% of the global population live in water-scarce regions, with more than two billion people having no other choice but to consume contaminated water. Water pollution is the greatest culprit in ecosystem destruction, leading to biodiversity loss with often irreversible consequences. Water scarcity is expected to displace 700 million people by 2030, while desertification will put the livelihood of one billion people living in 100 countries across the world at risk by 2050.[2] Despite these risks, our society has very few incentives to consume less water, maintain water quality, or allocate funding and resources to ecosystems or social objectives.[3]

In order to fulfill the objectives of the SDG 6, the High Level Panel on Water called for a "fundamental shift in the way the world looks at and manages water", noting that a 40% shortfall in water availability by 2030 could be expected if no action is taken.[4] An urgent need to develop innovative approaches to solve global water scarcity and quality issues has arisen, as traditional financing solutions and technologies have proven to be insufficient in addressing these challenges.

Fortunately, the remarkable technological advances that have been thrust into the limelight by the Fourth Industrial Revolution (4IR) have provided new tools to accelerate progress towards meeting the targets set in the 2030 Agenda. As an umbrella term, 4IR encompasses a range of new, emerging and disruptive technologies, such as Artificial Intelligence (AI), Big Data, the Internet of Things (IoT), Blockchain, Drones, and Virtual and Augmented Reality (VR/AR), to name a few (Table 1). The 4IR provides revolutionary methods of organization, production and distribution based on digital transformation and automatization that can erase limits between physical objects, turning them into a comprehensive complex system of interconnected and interdependent elements.[5]

1 Ryder, G. (2018) How ICTs can Ensure the Sustainable Management of Water and Sanitation, at https://news.itu.int/icts-ensure-sustainable-management-water-sanitation/

2 World Health Organization (WHO), United Nations Children's Fund (UNICEF) (2017) Progress on Drinking Water, Sanitation and Hygiene: 2017 Update and SDG Baselines, at https://www.who.int/mediacenter/news/releases/2017/launch-version-report-jmp-water-sanitation-hygiene.pdf

3 UN, World Bank (2018) Making Every Drop Count, An Agenda for Water Action, at https://sustainabledevelopment.un.org/content/documents/17825HLPW_Outcome.pdf

4 UN (2016) World Could Face Water Availability Shortfall by 2030 if Current Trends Continue, Secretary General Warns at Meeting of High-Level Panel, at https://www.un.org/press/en/2016/sgsm18114.doc.htm

5 Sukhodolov, Y. A. (2019) The Notion, Essence, and Peculiarities of Industry 4.0 as a Sphere of Industry. In Industry 4.0: Industrial Revolution of the 21st Century https://www.researchgate.net/publication/326547788_The_Notion_Essence_and_Peculiarities_of_Industry_40_as_a_Sphere_of_Industry

The goal of this report is to provide an overview of some of the current applications of key 4IR technologies (Artificial Intelligence, the Internet of Things and Big Data, Blockchain, Drones and Remote Sensing, and Virtual and Augmented Reality) in the Water, Sanitation and Hygiene sector (WASH) globally and in the Latin American and the Caribbean (LAC) region, and outline the main opportunities and challenges in deploying these technologies in the WASH sector.

Table 1. Fourth Industrial Revolution

Fourth Industrial Revolution Technologies					
AI	IoT	Blockchain	Drones and Remote Sensing	Virtual Reality	Augmented Reality
System's ability to correctly interpret external data, to learn from such data, and use those learnings to achieve specific goals and tasks via flexible adaptation.	Rapidly growing network of devices and objects connected to the Internet.	An almost incorruptible digital ledger of transactions, agreements and contracts (blocks) that is distributed across thousands of computers (chain) worldwide. Data are validated in a decentralized way.	Unmanned, flying vehicles controlled remotely using a range of sensors and GPS navigation.	Intuitive interface that allows a person to interact with a computer and data in a naturalistic fashion by generating real-time, immersive and interactive multi-sensory experiences situated in a responsive 3D computer-generated virtual environment.	Computer generated content that is overlaid on a real - world environment.

Source: Authors' elaboration

The countries of Latin America and the Caribbean have been successfully improving basic water access and sanitation infrastructure over the past couple of decades, although progress varies across countries and a disparity of service persists between urban and rural households.[6] As Figure 1 indicates, the LAC region performs above the world's average in providing basic services to its population. However, SDG 6 goes beyond the idea of ''basic services,''[7] and introduces the concept of "safely managed" services, which include the location of water sources, water availability for general consumption and water quality (see Annex 1). Figures 1 and 2 show that under this more comprehensive framework, LAC countries still have important challenges in terms of sanitation, wastewater, solid waste, water-related climate risks, such as droughts and floods, and reducing inequalities.

6 Bertomeu-Sanches, S., et al (2018) Water and Sanitation in Latin America and the Caribbean: An Update on the State of the Sector, at https://cadmus.eui.eu/handle/1814/52205

7 Basic water services are defined as "drinking water from an improved source, provided collection time is not more than 30 minutes for a round trip, including queuing". Basic sanitation can be defined as "Use of improved facilities that are not shared with other households". IADB (2017) Why Business as Usual Will Not Achieve SDG6 in LAC The Promise of Wastewater Reuse, Green Infrastructure and Small Business Around WASH Conclusions from World Water Week 2016, at https://publications.iadb.org/publications/english/document/Why-Business-as-Usual-Will-Not-Achieve-SDG6-in-LAC-The-Promise-of-Wastewater-Reuse-Green-Infrastructure-and-Small-Business-around-WASH-Conclusion-s-from-World-Water-Week-2016.pdf

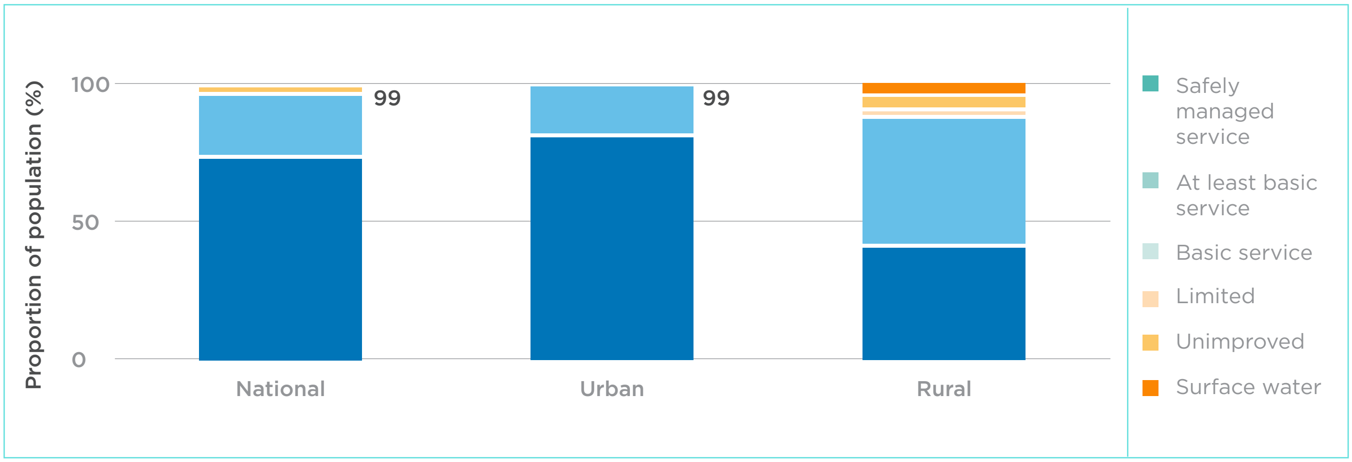


Figure 1. Proportion of population using drinking water services in LAC, by service level and location.

Source: WHO, UNICEF (2017)

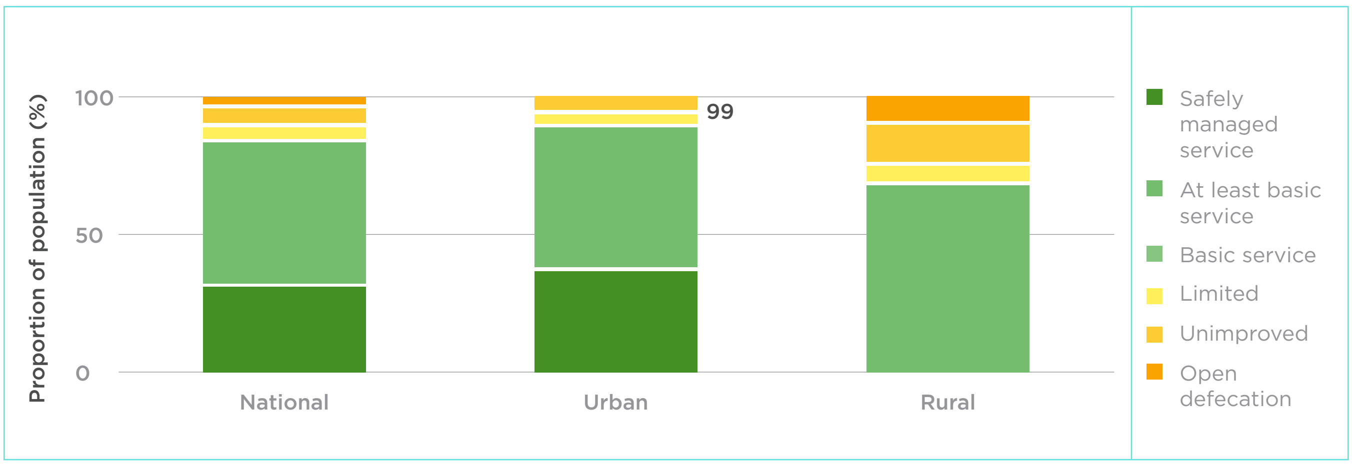


Figure 2. Proportion of population using sanitation services in LAC, by service level and location.

Source: WHO, UNICEF (2017)

Countries in LAC have acknowledged the importance of meeting the challenges set by the SDG 6, and have begun tackling two main obstacles – closing the institutional gap by adapting policies, regulatory frameworks, programs, financial strategies, and sector capacities, and closing the information gap by adapting methodologies and instruments to collect information in accordance with the SDG indicators.[8]

8 Baskovich, M., Arias Uijtewaal, B. F. (2018) Sneak Peek: A New Observatory for Water and Sanitation in Latin America and the Caribbean, at https://blogs.worldbank.org/water/sneak-peek-new-observatory-water-and-sanitation-latin-america-and-caribbean. For this reason, the regional conference 'LATINOSAN' is organized every three years with the aim of fostering policy and technology discussion among LAC region countries to promote access to quality and sustainable sanitation services in urban and rural areas. During this conference, participating countries envisaged the creation of the Latin American and Caribbean Water and Sanitation Observatory (OLAS). The Observatory, backed by the IADB and LAC governments, is intended to act as a body that will advocate for the preparation of plans to hold water, sanitation, and hygiene (WASH) efforts to new standards as required for the SDG 6, to monitor the implementation of such plans, systematize learning, and disseminate knowledge across the region and beyond.

Current water and sanitation problems cannot be solved with conventional methods. Water resources will continue to dwindle as population grows, coupled with the complexities that plague water governance and political barriers to transboundary water management. In addition, investments in technological innovations in water and sanitation infrastructure remain insufficient.[9] This is due to the fact that the water technology sector is still in its early stages of understanding the possibilities that 4IR could bring through real-life applications in aiding in the creation of smart and resilient businesses, communities, cities and nations, across the globe. Some of the possibilities offered by 4IR to address water issues are summarized as follows:

- **Access to safely managed drinking water and sanitation** (SDG 6.1 and 6.2): More than 240 million people who live mostly in rural areas are expected to remain without access to safe and clean water by 2050. In addition, it is projected that around 1.4 billion people living mostly in developing countries will not have access to basic sanitation by 2050. Hence, the need for the application of new technologies, such as IoT and AI, which could provide solutions for distribution systems to dynamically direct water to areas where demand is higher at any given moment. Similarly, blockchain-enabled peer-to-peer trading systems (currently deployed by farmers in Australia) can be used to buy and sell water directly from providers or other users, reducing the need for intermediaries, and their associated costs and attritions.
- **Wastewater treatment and water quality** (SDG 6.3): The quality of surface water in developing countries is expected to deteriorate due to nutrient flows from agricultural runoff, as well at effluents coming from ineffective wastewater treatment facilities. The consequences include increased eutrophication, biodiversity loss and an increase of waterborne diseases. AI, smart sensors and other IoT technologies have already found their application in monitoring waste treatment plants to optimize the use of resources and schedule equipment maintenance based on historical data.
- **Water use efficiency and water-stress** (SDG 6.4): It is estimated that by 2050, 3.9 billion people, representing over 40% of the world's population, are likely to be dependent on river basins under severe water stress. AI and smart sensors have been used to detect water leakages at early stages, greatly reducing potential water loss. Blockchain peer-to-peer trading systems and smart contracts could be used for excess water to be traded safely and transparently between households.
- **Water-related ecosystems** (SDG 6.6): The number of people at risk from floods is projected to rise from 1.2 billion in 2019 to around 1.6 billion in 2050, or nearly 20% of the world's population. Technologies such as AI, IoT and drones are already being used to monitor waterways and large reservoirs, collect large amounts of data in real-time and measure vast areas of water bodies with higher precision than conventional methods, at a fraction of the time and cost.[10]

9 Results for Development Institute (2017) Challenge Funds and Innovation in the Water Sector: A Report to The High-Level Panel on Water, at https://sustainabledevelopment.un.org/content/documents/153732._HLPW_Final_Report_pdf_3.pdf

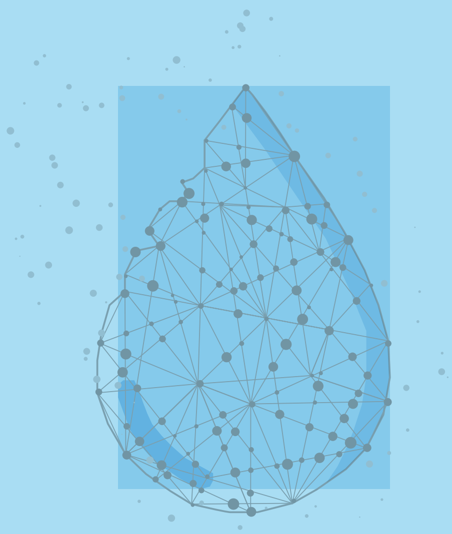
10 https://www.preventionweb.net/sendai-framework/sdg/target

Nonetheless, technology alone is incapable of solving all problems, as water crises are often associated with poor water governance. It is estimated that more than 80% of wastewater generated in developing countries is discharged without treatment into surface water bodies; 12% of the world population lacks access to drinking water services; 32% of people globally lack access to basic sanitation services; and 3.4 million people, mostly children, die annually from water-related diseases.[11] In less developed countries, poverty is multidimensional – it cuts across many sectors, WASH being one of them. In these countries, the lack of WASH services constitutes one of the greatest hardships. Dealing with inequalities in the WASH sector requires a holistic approach. Even when advanced technical solutions are available, it is difficult to use them to define the roles and responsibilities of the parties involved.

Despite the ability of emerging technologies to support and inform decision-makers from businesses, governments and non-governmental organizations, the voices of all stakeholders from relevant sectors need to be heard in order to create sound policies. Technologies must be coupled with and enabled by innovation in partnerships, business models and financing mechanisms for this to be a successful endeavor. These stakeholders can be mobilized by entrepreneurial programs, such as prize competitions and crowdsourcing.

11 https://www.2030vision.com/global-goals/clean-water-and-sanitation

Artificial Intelligence



2. Artificial Intelligence (AI)

Difficulties arise when we try to precisely define AI, as it is usually not a clearly delineated concept and it is constantly evolving. In many cases, what we have once considered AI, we now consider as something that computer systems are able to do, such as an Internet search, road navigation or spam filters. A more scientific definition of AI describes it as: "a system's ability to correctly interpret external data, to learn from such data, and to use those learnings to achieve specific goals and tasks through flexible adaptation".[12] On a more practical level, AI refers to machines (agents) that think and act like humans.[13]

For the purposes of this report, we will refer to AI as systems that typically have some degree of autonomy and are adaptive. This means that they can process external data and learn from experience. These systems often tend to imitate 'natural' intelligent human behaviour and are developed to solve specific problems better than humans. While many AI systems have the ability to operate autonomously, they often work best in tandem with human intelligence to understand certain issues, reason out questions defined by humans, and learn by drawing conclusions from data processing. This study focuses on narrow AI, i.e. purpose-driven, specific AI systems linked to solving specific problems in the water and sanitation sector. Narrow AI is to be separated from a general AI system that may evolve in the future. General AI would be able to improve itself entirely independently from humans, which is a milestone commonly referred to as 'singularity'.[14] This concept is visualized in the next page figure.

12 Kaplan, A., Haenlein, M. (2018) Siri, Siri in my Hand, who's the Fairest in the Land? On the Interpretations, Illustrations and Implications of Artificial Intelligence, at https://www.sciencedirect.com/science/article/pii/S0007681318301393

13 Elsevier (2018) Artificial Intelligence: How Knowledge is Created, Transferred, and Used. Trends in China, Europe, and the United States, at https://www.elsevier.com/?a=827872

14 Walsh T. (2018) Machines that Think: The Future of Artificial Intelligence

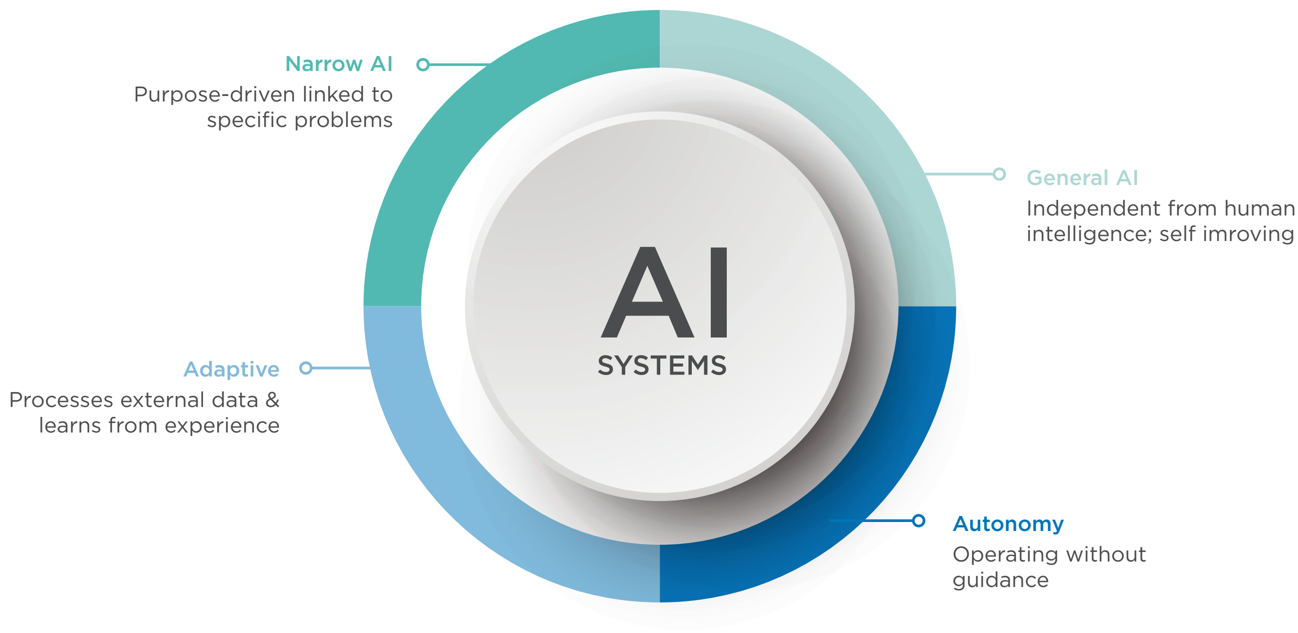


Figure 3. Key AI elements

Source: Authors' elaboration

Over the course of the last decade, AI researchers have made ground-breaking advances in long-standing problems related to machine learning, image recognition and speech recognition. As a result, AI has rapidly become an integral part of nearly all areas of our daily lives, pushing forward innovative applications in various domains. For example, AI can be used to find new construction and design solutions and enhance cooperation between humans and machines across the entire value chain. Yet, there is general agreement that what we see today is just the beginning of the AI revolution, as its anticipated advances and changes will undoubtedly represent one of the biggest technological revolutions in human history.

AI is likely to affect all parts of the economy and transform the way we work and live. It will disrupt the economy by lowering the cost of prediction in business. For decision-makers,[15] AI will enhance both capital and labor as inputs to economic activities, which in turn will provide a significant productivity boost.[16] This productivity boost may also prove disruptive, as it threatens to make many jobs redundant due to AI's ability to replicate labor activities at a much greater scale and speed, thus outperforming humans. AI's disruptive capabilities have already been felt by Amazon employees, who have been forced to keep up with production quotas fulfilled by the company's warehouse robots, sometimes at the expense of their own personal well-being and safety.[17] AI will be a true game changer in how our economies work, empowering humans by drawing on newly available vast amounts of data, helping them understand, reason, learn and predict, so that people can make better decisions.

15 McKinsey Quarterly (2018) The Economics of Artificial Intelligence, at https://www.mckinsey.com/business-functions/mckinsey-analytics/our-insights/the-economics-of-artificial-intelligence
16 https://www.accenture.com/us-en/insight-artificial-intelligence-future-growth
17 NPR (2019) Amazon Warehouse Employees Face Serious Injuries, Report Says, at https://www.npr.org/2019/11/27/783223343/amazon-warehouse-employees-face-serious-injuries-report-says

Table 2. AI's impact on the global economy

		2018 - 2030
GDP rise	Global	14%
	North America	14.5%
	Europe	9.9% - 11.5%
	Latin America and the Caribbean	3% - 4%
	South Africa	3.5% - 4.5%
Global economic activity rise		16%

Source: Authors' elaboration

As an important and fundamental technology under the 4IR, AI could be used as an important tool to address various challenges that affect the development of LAC. According to Statista, the AI market in Latin America in 2017 was estimated to be worth around $95 million, with an expected growth of $2.8 billion by 2025.[18] AI has the potential to boost national economic growth across LAC, with Brazil yielding the highest economic benefit in absolute terms, with an additional $432 billion in its gross value added (GVA) by 2035, or 0.9% growth that year.[19] Chile and Peru could experience a boost of 1% to their GVA by 2035 with the help of AI, with Colombia lagging behind at 0.8%.[20] Argentina's growth rate is expected to rise from 3% to 3.6% by 2035 with the utilization of AI, adding nearly $59 billion to its GVA.[21]

2.1. Case studies

The number of AI applications has increased in recent years, thanks to advances in computing capacity, cloud computing, and the accessibility of ever increasing amounts of data and sophisticated data analysis tools.[22] According to the World Economic Forum (WEF), AI provides opportunities to address worldwide environmental challenges.[23] Directed AI could help us meet the challenges of climate change, biodiversity and conservation, healthy oceans, water security, clean air and weather, and disaster resilience.

18 Statista Research Department (2019) Artificial Intelligence Market Revenue Latin America 2016-2025 https://www.statista.com/statistics/721751/latin-america-artificial-intelligence-market/
19 Ovanessoff, A., Plastino, E. (2017) How Artificial Intelligence can Drive South America's Growth, at https://www.accenture.com/_acnmedia/pdf-48/accenture-ai-south-america.pdfla=es-la
20 Ibid
21 Ibid
22 IQUII (2017) Artificial Intelligence: The Current Market, Technology, and the Most Promising Applications for Companies, at https://medium.com/iquii/artificial-intelligence-the-current-market-technology-and-the-most-promising-applications-for-1717e680040b
23 World Economic Forum (2018) Harnessing Artificial Intelligence for the Earth, at http://www3.weforum.org/docs/Harnessing_Artificial_Intelligence_for_the_Earth_report_2018.pdf

Increasing water utilities' process efficiency

AI can enable the creation of more efficient 'digital water' systems.[24] Many of the inefficiencies of current-generation water utility systems are being addressed through AI-based analytical systems empowered by IoT sensors, a combination powerful enough to continuously track, predict and respond to water demand levels in the most effective and sustainable manner possible.[25]

These developments, referred to as 'smart water management' or 'digital water', place AI at the heart of a new way of managing water. The system's raw processing power effectively analyzes everything that is happening across the system, while its machine learning elements allow it to continually improve its understanding of how best to respond. Smart water management enables governments and utility providers to build and deliver water infrastructure that is overseen by a management process that never gets tired and can constantly adapt its approach to any given situation or contingency.

By finally seeing every part of the bigger picture, such systems can significantly improve the cost-effectiveness and sustainability of existing water operations. Pilot projects in Finland are already showcasing the potential of this approach, as recently shown by Silo.AI and Ramboll.[26] Their pilot system was built on top of a pre-existing IoT infrastructure to optimize day-to-day water utility operations. The next step envisages the creation of human-in-the-loop AI systems, where the AI elements handle data processing and subsequently free up human operators to concentrate on more cognitive tasks, such as validating and expounding on the AI system's analysis.

This approach applies to water treatment as well as supply operations. Recently, the Australian water utility Melbourne Water revealed the success of the trial of its AI platform, which calibrates optimal usage of its pumps without the need for human intervention or oversight.

The pilot program suggests that the system can help its parent company achieve savings of more than 20% in energy costs.[27]

24 World Future Energy Summit (2019) The Power of Data: How Artificial Intelligence is Transforming Water https://www.worldfutureenergysummit.com/wfes-insights/ai-cleantech-applications-part-3-ai-in-water#/

25 Huneeus Guzmán, C. (2019) Digital Water Transformation: The Promise of Artificial Intelligence, at https://medium.com/datadriveninvestor/digital-water-transformation-the-promise-of-artificial-intelligence-7d88fb07e79b

26 Alanen, P., (2019) How Artificial Intelligence is Transforming the Water Sector: Case Ramboll, at https://silo.ai/how-artificial-intelligence-is-transforming-the-water-sector-case-ramboll/

27 Wells, H. (2018) How Melbourne, Australia Uses AI to Cut Water Treatment Costs, at https://news.itu.int/melbourne-cut-down-water-costs-using-ai/

Tackling waste at the source

AI can enable greater conservation of water from pump to tap.[28] As well as accurately assessing and supplying water demand, AI is becoming an essential tool in the fight against water waste. Preventing water waste is of particular importance in water-stressed or water-scarce countries. Every liter wasted through leaks, burst pipes and other anomalies is a liter that could save or improve lives.

Water waste prevention is not merely a regional issue; it is a global one. The US alone wastes seven billion gallons of drinking water per day. The amount of water lost before reaching households due to broken pipes is estimated to be around 15% in developed countries, and up to 50% in developing countries.[29] The same can be said about LAC, despite being home to some of the largest rivers and lakes in the world. With the imperative of reducing such drastic wastage, AI can be employed to analyze water flows in real time, sending alerts and shutting off systems automatically whenever leaks or anomalies are detected. This approach prevents water waste and saves on operational costs, as the system reacts in a fraction of the time it would take a human engineering crew to observe, find and fix the problem unaided.[30]

Water security

AI can be used to improve water security in the region.[31] An example of AI application for water security is presented in the figure below.

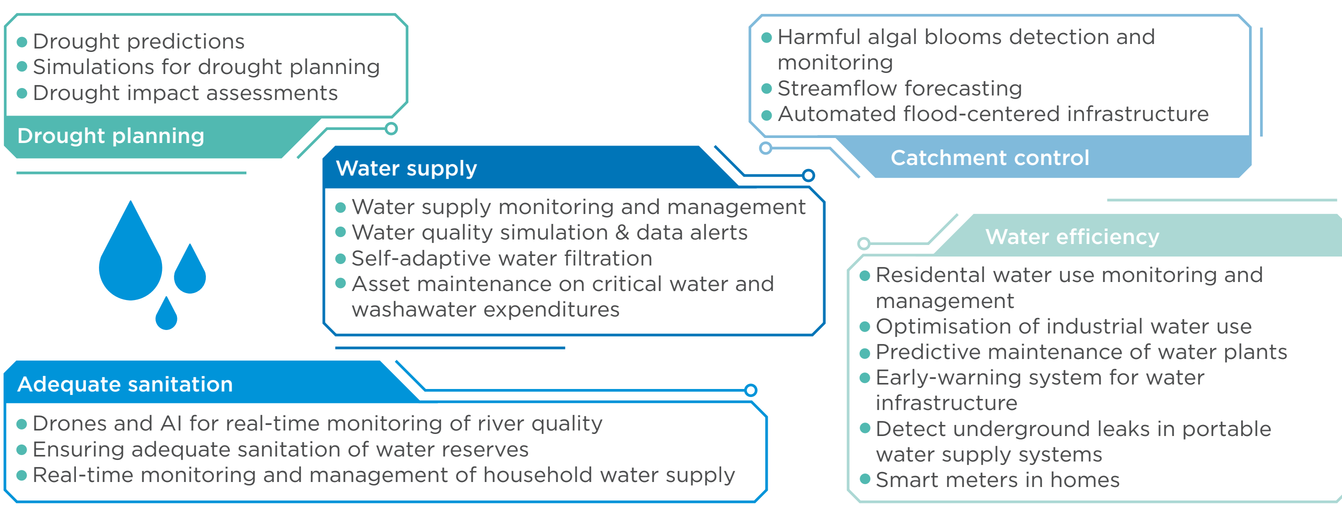


Figure 4. Water Security

Source: adapted from PwC (2018) Building block(chain)s for a better planet, at https://www.pwc.com/gx/en/sustainability/assets/blockchain-for-a-better-planet.pdf

28 World Future Energy Summit (2019) The Power of Data: How Artificial Intelligence is Transforming Water tureenergysummit.com/wfes-insights/ai-cleantech-applications-part-3-ai-in-water#/

29 World Bank (2015) Latin America: A Thirsty Region With Abundant Water Sources, at https://www.worldbank.org/en/news/feature/2015/03/20/america-latina-tener-abundantes-fuentes-de-agua-no-es-suficiente-para-calmar-su-sed

30 James, A. (2011) The U.S. Wastes 7 Billion Gallons of Drinking Water a Day: Can Innovation Help Solve the Problem? https://thinkprogress.org/the-u-s-wastes-7-billion-gallons-of-drinking-water-a-day-can-innovation-help-solve-the-problem-f7877d6e3574/

31 https://www.worldfutureenergysummit.com/wfes-insights/ai-cleantech-applications-part-3-ai-in-water#/

Given the potential of big data, several government agencies are already using data to make better decisions in the water and sanitation sector. Large tech companies, such as Microsoft, Google and Amazon, are investing in programs to apply technologies that tackle environmental challenges. Microsoft, for example, has committed $50 million between 2017-2022 to their AI for Earth programme, in which they award grants to projects that utilize Microsoft's cloud and AI tools to address climate, agriculture, biodiversity and water issues.[32]

Currently, most AI solutions in the water and sanitation sector focus on automated and assisted intelligence to address these challenges with input from large unstructured real-time datasets, as the ability to process large and complex datasets at high-speed offers the opportunity to significantly increase both the agility and complexity of information processing. In this regard, AI has the potential to both increase the number of decisions that can be made based on relevant data and improve those decisions by facilitating new and more complex data analysis and reducing the potential for human error. This may bring significant benefits to any organization that relies on the processing and analysis of information. By using the image recognition capabilities of IBM Visual Insights to scan live video feeds from thousands of cameras, the AI system can be trained to recognize problematic conditions and activities, including illegal fishing, mining and swimming, and alert officials when necessary.[33]

AI can also be used to analyse data inputs and compare them to large databases. This principle is used by Brazilian start-up Stattus4[34] in the development of a technology called Fluid,[35] which can detect leakages in large water distribution systems. The technology utilizes sensors to record vibrations emerging from water flowing in pipes, and then compares these sounds with a database of different noises. Through learning, the AI can distinguish expected noises from those of leakages or even illegal connections, and then alert officials of possible problems.[36]

AI has been integrated into wastewater treatment by the Canadian company EMAGIN, which has developed a system called Hybrid Adaptive Real-Time Virtual Intelligence (HARVI). The product can be integrated into existing systems to optimize the management of water networks and wastewater treatment plants by providing optimal control actions based on learning from past performances, real-time data and forecasted conditions. It can optimize anaerobic digestion and aeration by adjusting energy costs based on load profiles; support nutrient control by optimizing influent-driven chemical dosing set points (ex. ferric chloride) to enhance phosphorus control; provide real-time scaling/fouling detection and membrane service life calculation; optimize conventional and membrane-driven water treatment systems, enhancing flocculation and coagulation with advanced multi-layer predictive chemical dosing control; and maximize membrane recovery based on predictions of feed water quality. It can also leverage AI to optimally manage water transmission and distribution networks with real-time water quality monitoring and advanced event detection that uses high resolution pressure transient data coupled with real-time optimization of pressure reducing valves (PRV) set points across the network.[37]

32 Microsoft (2019) AI for Earth, at https://www.microsoft.com/en-us/ai/ai-for-earth?activetab=pivot1:primaryr6
33 Dawei, F. (2018) AI and IoT Technology Help Boost Water Quality in China, at https://www.ibm.com/blogs/client-voices/ai-and-iot-help-boost-water-quality-in-china/
34 https://stattus4.com/en_US/
35 https://stattus4.com/en_US/fluid/
36 Sebrae News Agency (2018) Empresa usa inteligencia artificial para achar vazamento de agua, at https://revistapegn.globo.com/Startups/noticia/2018/03/empresa-usa-inteligencia-artificial-para-achar-vazamento-de-agua.html; https://stattus4.com/en_US/sobre/
37 https://www.emagin.ai/industries

Table 3. Start-ups that use AI and machine learning in WASH

eWaterPay	Affordable, reliable, easily deployed smart water connections for emerging market populations, increasing service reliability by over 100% and revenue collection by 175%.[a]
Fracta	Machine learning condition assessment for potable water mains, enabling significant optimization in utility maintenance and debt service spend.[b]
Intelliflux	Artificial Intelligence-guided adaptive cleaning for membrane and filtration processes, making treatment plants more efficient, reliable and economical.[c]
WatchTower Robotics	Design, manufacture and operation of small-scale robots to identify and pinpoint pipe leaks early and accurately.[d]
Water Pigeon	A fast, simple and secure alternative to existing automated meter reading without wholesale replacement of existing legacy hardware.[e]
WaterQuest	An eco-conscious social enterprise using Artificial Intelligence for locating perennial underground rivers at a depth of 300-800 meters, with quality, temperature and flowrate accuracy of 92%.[f]

Source: Authors' elaboration
a http://www.ewaterpay.com/
b http://fracta.ai/
c http://intellifluxcontrols.com/
d http://watchtowerrobotics.com/
e https://www.waterpigeon.com/
f https://waterdatachallenge.globalinnovationexchange.org/innovations/artificial-intelligence-based-prospecting-solution-locating-self-recharging-underground

2.2. Opportunities and challenges

AI prospects are thrilling for many countries, as they appear to conjure up innovation of the kind seen in science fiction. If applied well, this technology has the potential to bring myriad positive changes to LAC. However, the uptake of AI will require a systematic response by business leaders and policy makers alike to ensure this technology is used to enhance people's work and lives while making sure AI does not reinforce social, business and political inequality due to AI bias and black boxes. Governments should not only scale these pioneering innovations, but also put sustainability considerations at the center of wider AI development and usage.[38]

Opportunities

Data-driven decision making for water.

One of the greatest applications of AI in the water and sanitation sector in LAC is to provide data that can drive decision making. For example, geospatial and user data can be used to

38 World Economic Forum (2018) Harnessing Artificial Intelligence for the Earth, at http://www3.weforum.org/docs/Harnessing_Artificial_Intelligence_for_the_Earth_report_2018.pdf

decide where sanitation and drinking water facilities need to be built to address the needs of most vulnerable communities; data can be used to understand water supply and demand gaps and help provide water where it is most needed (at a regional level, at a community-level, or within a facility of a company); data can be used to advise on better water governance and water management at watershed level.

Building climate change resilience.

Technologies such as satellite imagery, IoT, Big Data and AI can also be exploited for better scenario planning and forecasting to improve resilience at all levels of society (regional, national and subnational). In an urban context, for example, remote sensing technologies for flood prediction (e.g. Cloud to Street) and comprehensive design tools for hydraulic modelling (e.g. Autodesk Storm and Sanitary Analysis) are among the various services emerging to inform infrastructure investment decisions about urban planning and preparedness.

Challenges

Data privacy, data ownership, access to data, quality of data.

The growing use of smartphones, connected devices and sensors has created a vast digital footprint in consumers' lives. Machines that generate data overload include satellites, environmental sensors, security cameras and mobile phones.

Consumers' lives can benefit greatly when decisions are informed by relevant data that uncover hidden patterns, unexpected relationships, market trends or references. However, consumers also bear many of the costs and risks of participating in data markets and, indeed, might not even be aware they are participating. The poorest face entry barriers in the data-driven economy, and can be described as the digitally deprived.

An important question is, who owns all this data: the government, user or the service provider who stores it? If the service provider owns the information, what obligation does it have to store and protect it? To what extent can data be shared with third parties? Can a service provider charge a higher price to car owners who refuse the right to share their private data, for example, and less to those willing to share their data?

With no global agreement on data protection, regulators are taking different positions on these issues. Nearly 30% of nations have no data protection laws. Those that do, often have conflicting laws. The EU's General Data Protection Regulation (GDPR), for instance, enshrines the principle of privacy, providing strict controls over cross-border data transmissions and giving citizens the right "to be forgotten."[39]

39 UNCTAD (2016) Data Protection Regulations and International Data Flows: Implications for trade and development, at https://unctad.org/en/PublicationsLibrary/dtlstict2016d1_en.pdf

As water and sanitation utilities systems continue to record improved efficiencies because of the increased reliance on digital technologies over time, one important area that needs attention is the information and cyber security of these digital systems. The increased level of automation and connectivity reduces the scope for manual operation of the water supply system. As a consequence, a hack into the digital system could endanger the functioning of the system, as well as the information and data privacy of the utility's consumers. New security frameworks will have to be devised that span the entire cyber physical stack, from device-level authentication and application security, to system-wide assurance, resiliency and incidence response models.

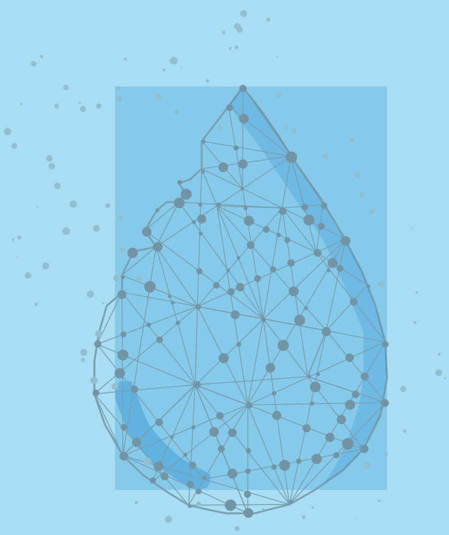
Algorithmic bias and black boxes introduce inequalities.

AI in its various forms poses some of the most difficult challenges to traditional regulation. Even today's most capable AI systems have crucial limitations. They are good only at narrowly defined tasks, and utterly clueless about the world beyond. They find correlations in data without regard for what those correlations mean, so their predictions can be dangerously unreliable. Algorithms make scores of strategic decisions, from approving loans to determining heart-attack risk. Often, these algorithms are closely held by the organizations that created them, or are so complex that even their creators can't explain how they work. This is AI's "black box"—the inability to see what's inside an algorithm. Some experts have suggested making algorithms open to public scrutiny.

In a perfect world, using algorithms should lead to unbiased and fair decisions. But some algorithms have been found to have inherent biases. While regulations in some countries explicitly prohibit discrimination in these and other areas, gray areas exist.

AI systems can reinforce what they have learned from real-world data, even amplifying familiar risks, such as racial or gender bias. Even a thoughtfully designed algorithm must make decisions based on inputs from a flawed and unpredictable real world. Systems can also make errors of judgment when confronted with unfamiliar scenarios, a condition referred to as artificial stupidity. Because many such systems are "black boxes," the reasons for their decisions are not easily accessed or understood by humans—and therefore difficult to question or probe. The fact that private commercial developers generally refuse to make their code available for scrutiny, because the software is considered proprietary intellectual property, is another form of non-transparency.

The Internet of Things (IoT) and Big Data



3. The Internet of Things (IoT) and Big Data

The Internet of Things (IoT) refers to the rapidly growing network of devices and objects connected to the Internet. These devices and objects are embedded in our everyday home and workplace equipment (kitchen appliances, machines, cars, etc.), and together they can perform specific tasks across different environments. For instance, an IoT platform designed for a private home or office space can be extended to a larger scale in factories, urban systems, or road infrastructure, and could potentially include the human body in the future. These devices are connected to powerful computers in the "cloud" that support both person-to-object and object-to-object communication. In the case of the former, sensory data is relayed to an individual to inform their decision-making process or to prompt subsequent action. In the case of the latter, interactions such as monitoring or corrective actions take place on a more automated basis without human involvement, although humans may still receive notifications. For this reason, IoT cannot strictly be considered a single technology in its own right in the conventional sense, but as a technological platform or network that combines multiple technologies, such as automation, wireless sensor networks, radio-frequency identification tags (RFIDs), microcontrollers, actuators, GPS, satellite technologies, and internet protocols, among others.[40]

40 Dlodlo, N., Mofolo, M., Kagarura, G. M. (2012) Potential applications of the Internet of Things in sustainable rural development in South Africa, at https://www.researchgate.net/publication/258446246_Potential_applications_of_the_Internet_of_Things_in_sustainable_rural_development_in_South_Africa

Figure 5. IoT Process Chain

Source : Kotze, P., Coetzee, L. (2019), Opportunities for the Internet of Things in the Water, Sanitation and Hygiene Domain, at https://link.springer.com/chapter/10.1007%2F978-3-030-15651-0_16

As a result of the large-scale adoption of IoT, vast amounts of data will be generated, which would be impractical to analyse with traditional database tools due to their size, variety and speed of creation. With the advent of Big Data, traditional data mining and handling techniques have been made redundant and have been replaced by massive parallelism on readily-available hardware to uncover the insights and meaning of underlying data.[41] A common way of characterising Big Data is by the so-called '3Vs': volume, variety and velocity. Based on the 3Vs, we can only speak of 'Big Data' when there are extreme volumes (in the order of magnitude of petabytes[42] and exabytes[43]) of data in a wide variety of types and forms, all of which are being generated at high velocity.[44] The Big Data concept is applied to the analytical solutions that deal with the capture, curation, management, processing and analysis of these large datasets, as well. Nowadays, consumers unwittingly produce most of the data being generated, and this is no different in LAC. When individuals communicate, make payments, take pictures or simply move from one place to another, they are constantly generating data that can in principle be collected and processed somewhere else, for both commercial and non-commercial purposes. To make sense of the relationship between IoT and Big Data, it may be helpful to think of IoT as a tool that contributes to the generation of Big Data. The latter, however, is a broader concept that covers more than just IoT.

The implementation of IoT and Big Data is often cited as capable of having a profound impact in a multitude of domains, as well as opening entirely new areas of opportunity and application.

41 https://www.techopedia.com/definition/27745/big-data
42 1m gigabytes (GB)
43 1b gigabytes (GB)
44 Maaroof, A. (2015). Big data and the 2030 agenda for sustainable development, at https://www.unescap.org/sites/default/files/1_Big%20Data%202030%20Agenda_stock-taking%20report_25.01.16.pdf; UN Global Pulse (May 2012) Big Data for Development: Challenges and Opportunities, at http://www.unglobalpulse.org/sites/default/files/BigDataforDevelopment-UNGlobalPulseJune2012.pdf

With respect to water management, IoT can maximize the efficient use of water through new solutions for improving water management. Water projects tend to be complex, as many cities rely on old infrastructure. Hence, the utilization of IoT can present opportunities for municipalities to reduce operational costs regarding construction and maintenance.[45] As water utilities generate significant volumes of data, Big Data can be used to harness and analyse the same data to provide insights for improved management and decision-making. By utilizing intelligent data analytics based on past usage data combined with predictive flow modelling, as well as real-time information on water levels, weather reports, water flows and pressure, significant events can be detected and alerts sent out to highlight potential issues.[46]

Reliability of data is a key consideration in deploying AI solutions in the WASH sector. Digital water technologies allow users to make informed and optimized decisions by using data. The data that is being used can come from a range of sources, such as calculated key parameter indicators (KPIs), collected KPIs, images, text and sensors.[47] Reliable sensor-generated data is critical, as faulty data can lead to faulty insights, which could in turn have detrimental implications. Despite some novel sensors, including automatic cleaning devices (e.g. using pressurized air or mechanical brushes or wipers), further development is required to increase reliability and reduce maintenance. Solutions that specialize in providing quality-checked and reconciled data for monitoring, smarter control and online simulation, such as inCTRL have appeared. Others, like Utilis, utilize satellite imaging for efficient detection. Similarly, Kando and Smart Cover Systems are placing smart remote sensing products in manholes to provide early detection and prediction of sewage conditions.

3.1. Case studies

The implementation of IoT and the advent of Big Data are often heralded as 'redefining' a broad range of sectors and industries. The use of Big Data and analytics tools to improve business results has already made a large impact by making possible some of the successful models of the internet economy, building on tools as varied as recommendation engines, sentiment analysis, fraud detection, marketing campaign and consumer analysis, among others. IoT and Big Data can also help communities build resilience in the face of environmental, political, social and economic stresses by providing useful feedback loops of information and knowledge.

IoT technologies have been deployed to support environmental monitoring as well as utility management. Specifically, they have enabled the remote monitoring of forest fires, as well as potential earthquakes, floods and pollution.[48]

45 Bellias, M. (2017) IoT for Water Utilities, at https://www.ibm.com/blogs/internet-of-things/iot-for-water-utilities/
46 Frankson, L. (2015) Big Data Analytics for Better Management of Water Networks, at https://infrastructurenews.co.za/2015/09/07/big-data-analytics-for-better-management-of-water-networks/
47 Karmous-Edwards, G., Sarni, W. (2018) How Digital Technology Can Be the Fundamental Agent of Change in the Modernization of Global Water Infrastructure, at https://waterfm.com/water-utility-digital-world/
48 Dlodlo, N., et al. (2012). Potential applications of the Internet of Things in sustainable rural development in South Africa, at https://www.researchgate.net/publication/258446246_Potential_applications_of_the_Internet_of_Things_in_sustainable_rural_development_in_South_Africa

Environmental monitoring

A practical application of IoT in environmental monitoring can be found in Brazil. Alerta Rio is an alert system for landslides caused by strong rains; the system provides real-time integrated data from 30 agencies, allowing for excellent coordination and timely responses.[49] This alert system is coordinated by Rio de Janeiro's Center of Operations, which is the first center of intelligent cities in the world, whose effective rainfall network and meteorological radar make possible the prevention of natural disasters.[50] Using IoT smart meters to reduce loss of electricity in distribution and sensors to detect water leaks could be worth as much as $69 billion per year globally.[51] GSMA Intelligence forecasts that there will be more than 1.3 billion IoT connections in Latin America by 2025.[52]

Smart meters

IoT applications allow for real-time monitoring of water usage in private homes, which not only improves data communication with service providers, thus resulting in more accurate billing, but also raises awareness of usage patterns.[53] While a smart meter of its own would not qualify as an IoT system, it can certainly be regarded as a step in said direction. Furthermore, domestic energy usage can be optimized by the automation and promotion of sustainable practices like running applications during off-peak times.[54] One such promoter of sustainable practices is Opower, a US company that combines a cloud-based platform, Big Data and behavioral science to aid utilities around the world to reduce energy consumption and improve provider-customer relationships.[55] The company is transforming the way the world approaches household energy conservation by offering cost-effective means of engagement, which include energy efficiency, behavioral demand response and smart thermostats.[56]

In the management of water resources, river basin operations can be optimised and pollution in underground water can be measured, as can levels of sewage and wastewater. Moreover, water pipe management is optimised using GPS sensors, allowing the monitoring of hydraulics and chemical parameters as well as locating leaks.[57] Optimised water management can therefore address issues related to water scarcity as well. GHydro is one example of a Brazilian company that offers water management services, artesian well[58] monitoring and liquid telemetry.[59]

49 Mastrangelo, P. (2018) Water and Sanitation: Innovations You Didn't Know Were from Latin America and the Caribbean, at https://publications.iadb.org/en/water-and-sanitation-innovations-you-didnt-know-where-latin-america-and-caribbean
50 Ibid
51 McKinsey Global Institute (2015) The Internet of Things: Mapping the Value Beyond the Hype, at https://www.mckinsey.com/~/media/McKinsey/Industries/Technology%20Media%20and%20Telecommunications/High%20Tech/Our%20Insights/The%20Internet%20of%20Things%20The%20value%20of%20digitizing%20the%20physical%20world/Unlocking_the_potential_of_the_Internet_of_Things_Executive_summary.ashx
52 Moura, P., Nicoletti, S. (2018) Making Smart Cities and IoT a Reality in Latin America: A Quick Guide For Decision-Makers, at https://www.gsma.com/latinamerica/wp-content/uploads/2018/11/IoTGuide-ENG.pdf
53 Ibid
54 Miazi, M. N. S., et al (2016) Enabling the Internet of Things in developing countries: Opportunities and challenges, at https://www.researchgate.net/publication/311757185_Enabling_the_Internet_of_Things_in_developing_countries_Opportunities_and_challenges
55 https://energypost.eu/opower/
56 Ibid
57 Dlodlo, N., et al. (2012). Potential applications of the Internet of Things in sustainable rural development in South Africa, at https://www.researchgate.net/publication/258446246_Potential_applications_of_the_Internet_of_Things_in_sustainable_rural_development_in_South_Africa
58 A well from which water flows under natural pressure without pumping. It is dug or drilled wherever a gently dipping, permeable rock layer (such as sandstone) receives water along its outcrop at a level higher than the level of the surface of the ground at the well site. Source: Encyclopaedia Britannica, at https://www.britannica.com/topic/artesian-well
59 A wireless system for controlling liquid container data in remote unstaffed areas where it is too difficult or expensive to connect data lines.

The company operates on the hardware front by providing compact sensors that communicate through GPRS technology and measure water pressure, volume, conductivity and temperature, among other variables. On the software front, clients can access data and receive notifications through GHydro's proprietary application, "Hydroview"[60]. Another example can be found in Uruguay's CTAgua foundation, which is the first technological center of its type in Latin America.[61] CTAgua integrates IoT and Big Data to tackle the country's daunting water and sanitation problems. Other applications of IoT in environmental monitoring would allow for predictions of climate change consequences, such as cyclones, floods and droughts.[62]

With water resource management and planning being among the biggest challenges many countries face, the Inter-American Bank has created HydroBID, a simulation tool to support water resource planning and management in the LAC region. HydroBID is an integrated quantitative system that simulates hydrology and water resource management using different scenarios (such as climate, land use and population) to evaluate the quantity of water, infrastructure needs, and the design of strategies and adaptive projects in response to those scenarios.[63] It does this by using an Analytical Hydrography Dataset (AHD) that represents over 230,000 catchments in the LAC region and their corresponding topography, river and stream segments.[64] This system covers the entire LAC region, organizing and aggregating scarce data, which are used for planning and designing water resource infrastructure, as well as stimulating basin hydrology driven by climate in a modular, flexible and scalable way.[65] This allows this robust hydrologic model formation to interact with any type of climate model or data source.

Smart water

Managing water supply is becoming a critical task for cities and their water utilities around the world, particularly as they try to create sustainable businesses and deal with the effects of climate change, which increases the propensity of drought in many parts of the world. At the same time, the IoT is being adapted more widely to fit the unique needs of monitoring water networks.[66]

Global Market Insights expects the IoT smart water metering market size to surpass $24 billion by 2024, and is set to reach an annual installation of over 35 million units by the same year. [67]

60 https://www.ghidro.com.br/
61 Mastrangelo, P. (2018) Water and Sanitation: Innovations You Didn't Know Were from Latin America and the Caribbean, at https://publications.iadb.org/en/water-and-sanitation-innovations-you-didnt-know-where-latin-america-and-caribbean
62 Onyalo, N., et al. (2015) The Internet of Things, Progress Report for Africa: A Survey, at http://ijcsse.org/published/volume4/issue9/p2-V4I9.pdf
63 https://www.iadb.org/en/water-and-sanitation/about-hydro-bid
64 Ibid
65 Ibid
66 GSMA (2017) Smart Water, A Guide to Ensuring a Successful Mobile IoT Deployment, at https://www.gsma.com/iot/wp-content/uploads/2018/01/miot_smart_water_01_18.pdf
67 Gupta, A., et al (2015) Smart Metering Systems Market to Exceed $21bn by 2024, at https://www.gminsights.com/pressrelease/smart-metering-systems-market

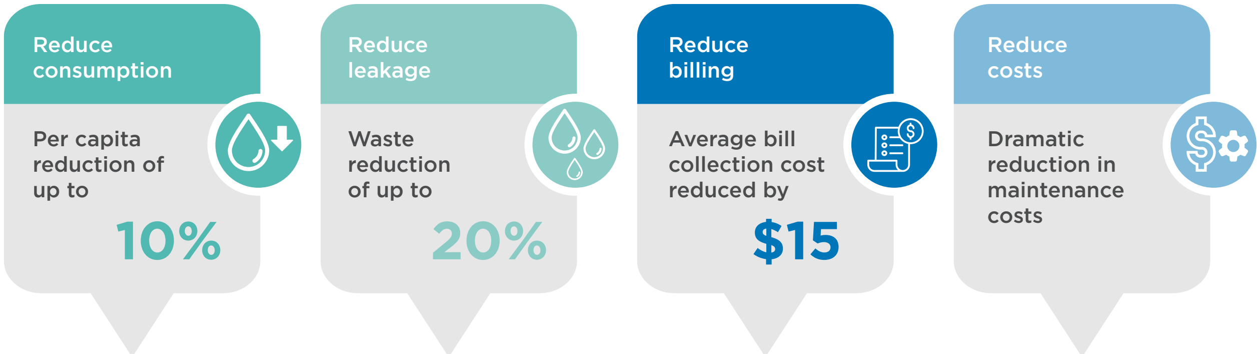


Figure 6. Benefits of Smart Water

Sources: adapted from GSMA (2017) Smart Water A Guide to Ensuring a Successful Mobile IoT Deployment, at https://www.gsma.com/iot/wp-content/uploads/2018/01/miot_smart_water_01_18.pdf

Water utilities across the globe are plagued by the generation of non-revenue water (NRW), which is a result of water loss through leakages and pipe bursts, as well as manual meter readings that can lead to errors. The average global level of NRW is between 30% and 35%, although in some networks it is as high as 50% to 60%.[68] The introduction of smart meters has the capacity to solve many problems on many levels, as they help data collection frequency. This enables better customer engagement, billing and visibility into network performance, and hence increased revenue. This type of infrastructure allows water utilities to conduct regular meter reads of customers throughout the day, provide customers with real-time water consumption data, as well as quickly detect water losses in the system.[69] Additionally, smart meters are particularly useful for water utilities as they improve efficiency by virtually eliminating the need for onsite meter readings, thus reducing manpower, fuel and vehicle maintenance costs.[70]

Another way in which these smart services can lower costs for utilities is through remotely disconnecting or restricting the flow of meters. Remotely disconnected meters reduce the costs of sending field crews to the homes of customers who have either requested to be disconnected or are being disconnected. In addition, these smart meters can ensure that bills are based on accurate meter reads rather than estimates. This in turn may lead to improved customer satisfaction and more efficient operations management.[71]

SUEZ, a private water company providing services to over 7.5 million people in the United States and Canada, is an example of a utility that has found smart meters to be highly beneficial.[72] SUEZ completed a smart water meter case study in Bayonne, New Jersey. After installing over 10,500 new smart meters (which covered 90% of the city's residents and businesses), SUEZ found over 1,000 leaks on customer properties in the first few months. These customers were unaware of the water leaks on their own properties, and two years after installing the new meters, the water consumption throughout the utility had decreased by 7%.[73]

68 Smart Water Magazine (2019) Winning the Non-Revenue Water Challenge, at https://smartwatermagazine.com/news/kampstrup/winning-non-revenue-water-challenge
69 Brears, R. (2019) Smart Water, Smart Metering, at https://smartwatermagazine.com/blogs/robert-brears/smart-water-smart-metering
70 Sigfox (2018) Utility Companies Save Time and Lower Costs With Smart Water Meters, at https://www.sigfox.com/en/news/utility-companies-save-time-and-lower-costs-smart-water-meters
71 Harvell, E. (2018) The Internet of Things and the Water World, at http://efc.web.unc.edu/2018/08/24/the-internet-of-things-and-the-water-world/
72 https://www.mysuezwater.com/community-environment/water-resource-management
73 Harvell, E. (2018) The Internet of Things and the Water World, at http://efc.web.unc.edu/2018/08/24/the-internet-of-things-and-the-water-world/

Miami-Dade County's parks system has a similar story.[74] As the third largest park system in the United States, it includes 263 parks, spanning 12,845 acres of land, containing Zoo Miami, beaches, marinas, pools, golf courses, educational nature centers and preserves. Like other areas, the system was plagued with aging infrastructure that had to be manually inspected for leaks and other problems, weighing heavily on department resources. However, after installing new IoT smart meter devices, employees could remotely monitor water consumption, detect leaks and quickly manage problems. The department estimates that there was a 20% reduction in water use, with savings of $860,000 per year following the implementation of the smart meters.[75]

Founded in 1890, Global Ominum/Aguas de Valencia manages all aspects of the collection, treatment and distribution of water in the Spanish city of Valencia and the surrounding areas (more than 300 cities). It supplies water to around three million people in the region. It already uses automated meter readings in more than 60% of its fleet of over one million water meters, and its goal is to keep improving this service to make it more agile, and provide customers with more benefits. Currently, water meters are read once per hour across the region. Global Ominum/Aguas de Valencia's goal is to implement a more efficient water meter reading service using a more standard communications system that will permit its Innovative solution to grow in a more scalable way.[76]

Vodafone and Global Ominum/Aguas de Valencia have been working together to put in place an operating model for the future, based around the use of NB[77]-IoT to connect their water meters. To better understand NB-IoT, they have been conducting a trial with around 220 meters from a range of six different manufacturers to assess the properties, performance and battery life of both water meters and local gateway connectors powered by NB-IoT, with a view to use a standard communication solution across the region, whilst retaining the existing requirement to take 24 meter readings per day from each meter. By using NB-IoT, Global Ominum/Aguas de Valencia is able to take advantage of standardized data gathering and platforms, where the whole end-to-end management of network operations can be conducted centrally by either the water company or Vodafone itself.[78]

These examples show how the IoT can nearly instantly provide utilities with information about water usage, location of leaks, and save money in the long run, but this does not happen without roadblocks. Budget restrictions are the biggest challenge utilities face when installing smart meters. Smart meters are more expensive than traditional mechanical meters and can be difficult for utilities to include in budgets. A Bloomberg Environment and Energy Report[79] notes that out of 700 utilities surveyed, two-thirds of utilities cite upfront capital costs as the barrier to implementing smart meters. More specifically, a smart meter may cost up to seven times more than a regular meter. But the large upfront costs come with the potential for high-level, long-term benefits, as implementing a smart water system can help utilities recover up to 75% of water loss.[80]

74 https://www-03.ibm.com/press/us/en/attachment/40497.wss?fileId=ATTACH_FILE1&fileName=Miami-Dade%20County%20Final%20Fact%20Sheet.pdf
75 Harvell, E. (2018) The Internet of Things and the Water World, at http://efc.web.unc.edu/2018/08/24/the-internet-of-things-and-the-water-world/
76 GSMA (2017) Valencia – Internet of Things Case Study, at https://www.gsma.com/iot/wp-content/uploads/2017/10/iot_omnium_10_17.pdf
77 NB - narrowband
78 GSMA (2017) Valencia – Internet of Things Case Study, at https://www.gsma.com/iot/wp-content/uploads/2017/10/iot_omnium_10_17.pdf
79 https://www.bna.com/high-cost-smart-n73014451587/
80 https://sensus.com/solutions/non-revenue-water-infographic/

Wireless mobile sensors in underground pipes

iXLEM Labs, in collaboration with Qatar University, Qatar National Research Fund, Acquedotto del Monferrato, Smat and Karamaa, created a solution to monitor and manage issues related to urban water distribution systems (Figure 15). Their solution comes in the form of "Watermole," which is a wireless mobile sensor that can be placed in pipes for monitoring. When the sensor intercepts a ground station, its position is identified and the acquired spectra are correlated to leakage positions (iXYLEM 2011). [81]

Remote monitoring solutions to urban wastewater management

Holon municipality's old sewage system, located in the center of Israel, was plagued with problems, such as frequent blockages and overflows. By installing several Solid Applied Technologies' (SolidAT) SmartScan 50 non-contact gauging devices equipped with sensors, the municipality was able to better control and manage its sewer systems. Additional improvements were achieved due to the high resistance of the devices to the methane environment, and to the municipality's ability to receive reliable information and monitor its sewer system using a web platform, and sending alerts via short message service (SMS) messages when the level reaches low/high limits. SolidAT offers a variety of level sensors and remote monitoring solutions for sewer level monitoring and water level monitoring.[82]

The Toilet Board Coalition is pioneering exciting work around "the digitization of sanitation" in places such as Pune, India.[83] Efforts to integrate sensors and Wi-Fi into toilet networks in such areas can generate valuable data and information on public health and consumer behavior, as well as the quality of maintenance systems and need to optimize routes for waste collection and transport.[84]

Telefónica and Huawei are partnering with Essbio, the Chilean water utility, and Kamstrup, a Danish metering company, on a smart meter project. Essbio services the Libertador Bernardo O'Higgins, Bío Bío, and Maule regions of Chile. The aim of the project is to increase network efficiency, reduce freshwater loss, and improve service quality for the end user. The group has tested various systems in an effort to improve device connectivity so that customers can monitor their daily water use; estimates can be replaced by accurate invoicing; and leaks and abnormal conditions can be detected, while allowing the water network operator to learn customers' needs. Essbio uses data to improve the design of its intelligent water network. Six thousand ultrasonic water meters were installed in diverse urban and rural areas across the three regions to determine the rate of flow to an accuracy of two litres an hour. A narrowband IoT network, developed by Telefónica, Huawei and the Government of Chile, is used by utility companies and regions to provide a two-way communication for the IoT devices, which

81 http://www.ixem.polito.it/projects/qnrf_2009/index_e.htm
82 http://solidat.com/
83 Anzilotti, E. (2017) The Quest To Use Big Data and Community Toilets to Create a Model for Building Urban Sanitation, at https://www.fastcompany.com/40466766/the-quest-to-use-big-data-and-community-toilets-to-create-a-model-for-building-urban-sanitation
84 http://www.toiletboard.org/

include smart meters and smart water applications.[85] Collaboration among the various actors should lead to service improvements for the end customer as well as the utility operator. This project showcases the viable business opportunities from which the ICT sector can benefit when project revenue is scaled up nationally.[86]

Cloud to Street is a global high-resolution flood mapping and monitoring system that is designed to protect the most vulnerable and enable resilience worldwide.[87] Utilizing satellites circling the Earth every day, the company's remote sensing dashboard provides a dynamic map of floods and flood risks across the world. The generated data helps protect over 10 million people by enabling everyone at risk access to the flood disaster information they need.[88] Cloud to Street's data provides flood insurance for the 90% of customers in emerging markets who are currently uninsured against catastrophes.

Island Water Technologies is a wastewater treatment company that combines cutting edge systems with engineering, automation, precision manufacturing and next generation wastewater treatment technologies.[89] Their team developed SENTRY-AD, a bio-electrode sensor technology designed to be easily added to wastewater treatment facilities, with the goal of providing real-time monitoring capability of the resident microbial communities.[90] This sensor provides drop-in, low-cost, real-time monitoring of microbial activity and other parameters in the anaerobic digestion process.

Osmo Systems helps fish and shrimp farmers monitoring their water quality online. This is done through their OsmoBot, which is the world's first aquaculture monitor. The OsmoBot is a proprietary, low-cost water quality sensor that enables continuous monitoring in shrimp farms to drive higher, more predictable yields.[91]

Upepo is the leading provider of IoT network software and IoT objects in Africa, working in the water sector. Their Narrow-Band IoT solutions improve water management, reduce leakage and encourage conservation to Kenyan water agencies.[92]

3.2. Opportunities and challenges

Implementing IoT on a large scale will have a profound impact on the water sector, as it will maximize the efficient use of water, improving water management, and thereby reducing operational costs of water utilities. The benefits of utilizing this technology do not end there, especially for LAC. IoT can ensure water quality and build climate change resilience, both issues that have been plaguing the region in recent years. However, the implementation of this technology has its challenges in the LAC context.

85 Smart Energy International (2017) Metering and Smart Energy International Edition 4, at https://www.smart-energy.com/issues/metering-smart-energy-international-edition-4-2017/
86 Jorisch, D., et al (2018) Technology for Climate Action in Latin America and the Caribbean: How ICT Mobile Solutions Contribute to a Sustainable, Low-Carbon Future, at https://globalewaste.org/wp-content/uploads/2018/11/Technology-for-Climate-Action-in-Latin-America-and-the-Caribbean.pdf
87 https://www.cloudtostreet.info/about
88 Ibid
89 https://www.islandwatertech.com/regen/
90 IWT (2017) Innovative Wastewater Sensor for Improved Monitoring of Anaerobic Digestion Systems, at https://www.islandwatertech.com/real-time-sensor-for-improved-anaerobic-digestion-performance/
91 https://www.osmobot.com/
92 https://www.upepo.io/

Opportunities

Ensuring water quality. Sensors can be deployed into water bodies to collect data pertaining to water flow, quality and quantity. That information can be communicated through IoT devices. IoT-enabling sensors allow decision-makers to detect issues such as how and where waterways become contaminated from wastewater treatment plants or eutrophication from agricultural run-off, and prioritize remediation strategies accordingly.

Building climate change resilience. Droughts have become more frequent and intense in the so-called "Dry Corridor" of Latin America and the Caribbean, with Central America and the Dominican Republic being most affected.93 This has forced national and local governments to implement a series of measures in order to respond to drought-provoked impacts.94 Technologies such as satellite imagery, IoT, Big Data and AI can be exploited for better scenario planning and forecasting to improve resilience at all levels of society (regional, national and subnational). In an urban context, for example, remote sensing technologies for flood prediction (e.g. Cloud to Street) and comprehensive design tools for hydraulic modelling (e.g. Autodesk Storm and Sanitary Analysis) are among the various services emerging to inform infrastructure investment decisions about urban planning and preparedness.

Challenges

The collection and use of massive datasets can create new vulnerabilities and risks, enabling discrimination against individuals, skewing evidence and creating dependencies on centralised infrastructures. For example, people with lower levels of income and education are not accessing or creating online content nearly as much as the more educated middle-class population, reinforcing the "digital divide". If journalists, academics and policy makers rely on Big Data analytics in the future, they risk ignoring issues that are important to many poor and working-class people. Proposing actions that aim to tackle these barriers and failures is a good way for governments to get involved in ensuring that Big Data analytics and related innovation reach all sectors of the population and the economy.
The IoT system is composed of multiple underlying wireless technologies such as GPS, GSM, and Mesh networks, and it is worth noting that the development of infrastructure, particularly with the emergence of 5G, will also create a spectrum of needs. Specifically, regulators will have to ensure that the necessary frequency bands can be provided.[95] Second, there are challenges associated with the requirements for the individual components and devices that make up an IoT system. In particular, IoT devices need to be robust, modular, energy-efficient, and in the case of developing countries, need to run on batteries for prolonged periods of time, as well as use solar energy for (re)charging.[96] On a higher level, challenges can be foreseen in terms of the interoperability of IoT platforms, the use of different Commercial Off-The Shelf (COTS) products, and more general requirements in terms of technological standards and scalability.[97]

93 http://www.un-spider.org/projects/SEWS-D-project-caribbean
94 Ibid
95 Kotzé, P., Coetzee, L., Opportunities for the Internet of Things in the Water, Sanitation and Hygiene Domain, at https://link.springer.com/chapter/10.1007%2F978-3-030-15651-0_16
96 Miazi, M. N. S., et al (2016) Enabling the Internet of Things in developing countries: Opportunities and challenges, at https://www.researchgate.net/publication/311757185_Enabling_the_Internet_of_Things_in_developing_countries_Opportunities_and_challenges
97 Onyalo, N., et al. (2015) The Internet of Things, Progress Report for Africa: A Survey, at http://ijcsse.org/published/volume4/issue9/p2-V4I9.pdf.

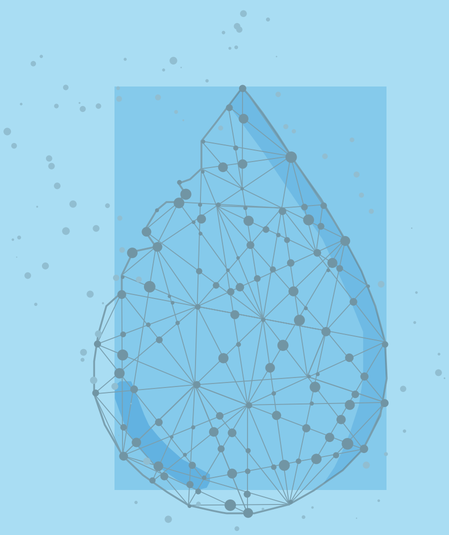
Constraints in terms of network capacity stand in the way of large-scale IoT adoption. There is a general lack of dedicated data centers and connections between them that are able to collect, store, transmit and receive large volumes of data. As the number of interconnected IoT devices expands, this type of infrastructure will become a necessity. These data centers as well as the number of IoT devices will also create significant power demands, which can be addressed in a variety of ways, such as relying on a combination of battery technology, remote power sources, and solar energy. The extent to which individual countries can meet these energy demands is completely dependent on their specific context and cannot be generalised. A third condition that will eventually have to be met is the need for data protection frameworks within countries as well as for their neighbours. Other challenges include comparatively low internet penetration rates, interoperability and standards, human capital requirements, and platforms for (open) data sharing.

In terms of data, the question of access and sharing also creates technical challenges. Primarily, the inter-comparability and inter-operability of (data) systems is a key technological precondition.[98] In the case of LAC, additional challenges associated with the use of Big Data include uneven coverage, accessibility, and usage (of data) across regions and population segments, as well as the mismatch between demand and supply as data is often not available for the issues and areas where they are needed most. In addition there is a general lack of disaggregation and harmonisation, meaning that in cases where data is open and, in principle, accessible, it is often not in a form that is directly useable by stakeholders.

Finally, due to the large yet distributed nature of IoT as well as Big Data, it is extremely challenging to provide meaningful cost estimations. Indeed, the lack of clarity on specific use cases and return on investment figures is creating considerable commercial obstacles.[99] For instance, sensors are part of the primary components of an IoT system, yet, these can be expensive because they are commonly manufactured by companies located in developed economies and must therefore be shipped.[100] A second financial challenge stems from the fact that many of the available IoT devices are proprietary and come with their own software. Updating this may be associated with additional operation and maintenance costs, although these could be mitigated by prioritising open-source software.[101] The costs of Big Data are equally hard to estimate, but will undoubtedly be non-trivial. To provide an indication, collecting global data for the Sustainable Development Goals has been estimated to cost some $245 billion. A big issue in terms of water and gender diversity is the difficulty of obtaining gender disaggregated data. Since the scale of the required investments is larger than a government would be able to provide, implementation will be challenging with regards to providing the conditions needed to facilitate the investments to deal with broadband demands.[102] These conditions include credible commitments, a predictable regulatory environment, a delivery strategy for infrastructure, demand-creation strategies for education and e-literacy, entry-level prices for devices and services and tax reductions for internet-enabled devices.[103]

98 UN Global Pulse (2012) Big Data for Development: Challenges and Opportunities, at http://www.unglobalpulse.org/sites/default/files/BigDataforDevelopment-UNGlobalPulseJune2012.pdf
99 Oehly, J. (n.d.). Unlocking the IoT Opportunity in LAC
100 Miazi, M. N. S., et al (2016) Enabling the Internet of Things in developing countries: Opportunities and challenges, at https://www.researchgate.net/publication/311757185_Enabling_the_Internet_of_Things_in_developing_countries_Opportunities_and_challenges
101 Ibid
102 Ibid
103 Coetzee, W., et al (2013) Making 5G a Reality for Africa, at Lockwood, D. (2010) Virtual Reality in Africa, at https://www.tandfonline.com/doi/abs/10.1076/digc.13.1.3.3214

Blockchain



4. Blockchain

Blockchain is a technology used to create a shared database, which can record and track both transactions and assets. In theory, any database or ledger could be created and maintained using a blockchain. It is not governed by one single user, so no centralised version of a ledger exists. Instead, it can be widely accessible to the public or to large groups (depending on permissions granted). The chain is updated with each transaction, so users can see the chronological activity for that particular blockchain. Once something is on the database, it cannot be removed. Proponents have praised the technology for its resilience to fraud, its transparency and relatively low maintenance cost. Blockchain technology is often heralded as a solution to many of the world's grand challenges. It can be deployed in diverse areas, ranging from reducing inefficiencies in financial systems (with attendant cost-reduction and improved user-friendliness), to improving the transparency of fair trade via tracking and aiding the (re-) distribution of end user-generated energy on local grids.[104]

Blockchain is an almost incorruptible digital ledger of transactions, agreements and contracts (blocks) that is distributed across thousands of computers (chain), worldwide. Data on a blockchain are validated in a decentralised way, i.e. by the wider community, rather than by a central authority. In other words, blockchain is a form of distributed ledger[105] because, in contrast to traditional centralised ledgers, it records and synchronises transactions across a network of independent nodes (computers) and their respective ledgers.[106]

Three principle technologies underpin blockchain:

- **Cryptographic keys**, which create a digital identity between transacting partners;
- A distributed, **peer-to-peer (P2P) network**, which provides a means to approve and authorise transactions;
- **A network protocol**, i.e. rules by which nodes in a network collectively apply an agreed rule.

104 Daussa et al., IDB (2019) Blockchain for Microfinance, A Study & Pilot in the Water and Sanitation Sector
105 Mainelli, M., Smith, M. (2015) Sharing Ledgers for Sharing Economies: An Exploration of Mutual Distributed Ledgers (Aka Blockchain Technology), at https://papers.ssrn.com/sol3/papers.cfm?abstract_id=3083963
106 World Bank (2018) Blockchain & Distributed Ledger Technology (DLT), at https://www.worldbank.org/en/topic/financialsector/brief/blockchain-dlt

The use of cryptography provides authentication, proving identity and ownership in transactions. However, authentication must also be paired with authorisation, which relies on consensus among nodes on a peer-to-peer network.[107] Every data modification is subject to this consensus, i.e. nodes may agree to or reject modifications according to agreed rules. Once a majority of nodes reach a consensus, modifications are combined into a 'block' with other modifications from the same time period and appended to a 'chain' of previously agreed blocks. The nodes serving the P2P network solve computationally intense proof-of-work mathematical problems to produce an open record of all data modifications that have taken place,[108] thus allowing all participants to see all the transactions that have taken place.

The combination of cryptography and the actions of the P2P network ensure that verified data modifications are not tampered with by individuals or groups, and that no new un-detected modifications are made. This means that – without knowing one another or relying on a central authority – users can trust data held on a blockchain.[109] This is the essence of a blockchain – the production of 'trustable' data and records without a central authority. In addition to digital currency, blockchain technology can handle any other transactions that can be expressed as computer code, principles that could be applied in: i) creative industry; ii) electoral processes; iii) land management and management of other property rights; iv) ID; and v) management of intellectual property rights.

Smart contracts are a practical example beyond cryptocurrencies; they are applications that allow automatic contract enforcement if certain conditions are met. For example, if a good is unloaded in a port, then the payment for it will be executed.[110] This has the potential to mitigate issues of corruption, contract enforceability, information asymmetry, or principal-agent conflicts.[111] Moreover, trust issues concerning third-party intermediaries such as banks or government institutions can be circumvented, and having a secure and enforceable contract reduces credit risks for financial institutions, thus having the potential to efficiently lower the costs of capital.

By providing a secure, transparent and distributed ledger to record transactions between parties, blockchain-based technology could fundamentally transform the way water resources are managed and traded.

Blockchain could enable everyone from households, industry consumers, water managers and policymakers to access the same data on water quality and quantity and make more informed decisions. Such transparency would help inform consumer decisions around when to conserve or use water. In turn, it could help prevent corrupt behavior in situations where there may be an incentive for local authorities to tamper with or withhold water quality data.

Blockchain technology also could support peer-to-peer trading of water rights, empowering water users who have enough or are willing to share their excess resources with others in the area to do so 24/7. Imagine a scenario where farmers in the same water basin could make the decision to trade their allocations based on the latest weather data, crop prices, market trends and longer-term climate trends — much of which is already accessible via their mobile devices.[112]

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107 Citi GPS, Digital Disruption (2016) How FinTech is Forcing Banking to a Tipping Point, at http://www.disruptivefinance.co.uk/2016/04/01/how-fintech-is-forcing-banking-to-a-tipping-point-citi-report/

108 Pisa, M. and Juden, M., (2017) Blockchain and Economic Development: Hype vs. Reality. CGD Policy Paper, at: https://www.cgdev.org/publication/ blockchain-and-economic-development-hype-vs-reality

109 Ibid

110 https://www.wto.org/english/res_e/booksp_e/blockchainrev18_e.pdf

111 Sharda, S. (2018) How India can Lead the World Into the Fourth Industrial Revolution, at https://www.weforum.org/agenda/2018/11/india-can-be-the-laboratory-that-leads-the-world-into-the-fourth-industrial-revolution/?fbclid=IwAR0ZC-5Ru6w5YfmBHdPCaeL4e5Tc4hjaTM5sAhiWms6FVP1fphfQu5eP518

112 Stinson, C. (2018) How Blockchain, AI and Other Emerging Technologies Could End Water Insecurity, at https://www.greenbiz.com/article/how-blockchain-ai-and-other-emerging-technologies-could-end-water-insecurity

This type of transparent, real-time approach to water management could mitigate tensions within and across certain localities by democratizing access to information and preventing data tampering.

For instance, Power Ledger is among the companies pioneering blockchain applications for the water sector, as evidenced by its current work with the city of Fremantle in Australia to create a blockchain-backed trading system that leverages smart water metering data.[113]

4.1. Case studies

Blockchain has the potential to be both a foundation and a springboard for a new developmental infrastructure. Early internet-based innovations, such as Kenya's M-PESA, have clearly demonstrated the appetite for accessible, Internet-financial services, and South African start-up Bankymoon is already offering products to facilitate the payment of water and energy services through cryptocurrencies. As explained by Bankymoon's CEO: "Unlike bank accounts, Bitcoin addresses can be monitored by predefined processes which can trigger automated actions. These actions can form part of a workflow, which will only proceed once Bitcoin transaction has been detected".[114] This could in effect enable those in the developing world who are still out of the banking system to pay more easily for water consumption.

Smart contracts

Smart contracts are another application of blockchain technology that could greatly improve access to basic services. For example, allocation of water for agriculture often requires contracts between farmers and water providers that can be time-consuming and uncertain, often requiring consumers to guess how much water they would need, weeks in advance.[115] Australian company 'Civic Ledger' has been working directly with the government at the local and national level to use blockchain technology to address this issue. One of its products, WATERLEDGER, improves the transparency and reliability of water markets and increases the efficiency of resource allocation by establishing an Ethereum-based market platform where consumers and service providers could trade water contracts without intermediaries. This market can be easily accessed online and has advantages such as low cost of transactions, high-degree of trust and

113 Power Ledger (2018) Project Update: Fremantle Smart City Development, at https://medium.com/power-ledger/project-update-fremantle-smart-city-development-b16ccce2eb8f
114 Smart Energy International (2015) Smart Meters Prepaid: Bankymoon Develops Bitcoin Solution, at https://www.smart-energy.com/top-stories/smart-meters-payment-bankymoon-develops-bitcoin-solution/
115 Calver, O. (2019) Water Trading in Minutes with Blockchain, at https://www.theland.com.au/story/6274260/blockchain-in-the-pipeline/

simultaneous register to state records.[116] Based on its trial results, the technology could potentially save up to USD$61.5 million by unifying in one system what is currently done by four platforms, minimizing trade frictions, saving USD$34-68.4 million to farmers and reducing transaction times from nine weeks to near real time.[117]

Rainwater capture for vertical farming and urban greenhouse projects

Pilot studies have been launched in Hong Kong by the company WATERIG[118]. They are developing collection points that capture rainwater. These hubs are connected to water processing systems and then directed into applications like vertical farming (growing food on the sides of skyscrapers) and urban greenhouse projects. Because the system is decentralized, different communities can decide what works best for them and then use the blockchain to crowd-fund their own water hubs. WATERIG's decentralized water collection points are trying to reduce the strain on existing government water collection and treatment infrastructures. This is vital with urban populations skyrocketing and infrastructures deteriorating.[119]

Planned rollouts in Nigeria, China and Mexico

BanQu is the world's first non-cryptocurrency blockchain platform that helps lift people out of extreme poverty. The company operates in Brazil, Costa Rica, India, Indonesia, Jordan, Malawi, Somalia, South Africa, Syria, Uganda, United States, and Zambia, with rollouts in Nigeria, China and Mexico slated for late 2019. BanQu connects people in extreme poverty to the global supply chains in which they participate through a secure, immutable and distributed ledger of financial and personal records. BanQu does this by building a recognizable, vetted economic identity for the world's poorest people, allowing them to maintain a free and secure online profile that permits them to begin tracking their relationships and transactions.[120] Through this process, the company has been able to lower the cost of access to finance for small farmholders in Latin America by connecting their land ownership rights to their economic identity on BanQu. Farmers thus have direct access to tailored crop insurance, soil and irrigation management, and crop rotation.

116 https://waterledger.com/
117 Ibid
118 https://www.waterig.com/
119 Russell, O. (2018) Blockchain and Water: Everything You Need to Know, at https://hackernoon.com/blockchain-and-water-everything-you-need-to-know-b7e753108715
120 https://banqu.co/

Water treatment

The application of blockchain technology can be leveraged further to develop and deploy water treatment. OriginClear is a water treatment technology provider that has created a blockchain protocol called WaterChain. Its aim is to create a platform that will improve water quality worldwide, thus reducing the number of deaths caused by unsanitary water conditions. As a platform, WaterChain allows investors to buy tokens to fund water recycling projects and to receive a return. In this way, OriginClear is attempting to create new funding opportunities for water treatment facilities.[121]

4.2. Opportunities and challenges

Blockchain technology has the potential to improve how the public and private sectors function. However, blockchain and its applications, including Bitcoin, blockchain's most famous application, are young - only a decade old at the time of writing. As such, the precise prediction of potential impacts of blockchain technology are difficult. The adoption of most technological innovations is dependent upon essential infrastructure, specialist personnel and appropriate governance. In some ways, blockchain technology deviates from the dependence on infrastructure, though the dependence on electricity and stable internet connectivity remains key. We see that greater use of blockchain requires changes to regulation for P2P trading. In many countries, current regulation does not contemplate this, with the majority set up for centralised or hierarchical systems.[122]

The larger the P2P network, the better blockchain solutions operate, due to increased computing power. This means that there must be stable access to electricity, suitably fast broadband, a motivated community of users (nodes) and the political will to adapt regulations and develop suitable governance models.

Opportunities

Water Transparency

Blockchain is a secure, transparent and distributed public ledger that records transactions between parties. If a public blockchain is used for water quantity and quality data, the information can't be hidden or changed by corrupt governments, corporations or powerful individuals. This technology and its characteristics have ushered in a new level of access to information and real-time approach to water management. The data on water quality and quantity can now be used to make better decisions in times of increasing water scarcity.[123]

121 https://www.originclear.com/
122 Pisa, M. and Juden, M. (2017) Blockchain and Economic Development: Hype vs. Reality. CGD Policy Paper, at https://www.cgdev.org/publication/ blockchain-and-economic-development-hype-vs-reality
123 Russell, O. (2018) Blockchain and Water: Everything You Need to Know, at https://hackernoon.com/blockchain-and-water-everything-you-need-to-know-b7e753108715

Co-operation for Smarter Water Management

Blockchain is co-operating with the Internet of Things (IoT) to make cities' water systems smarter, safer and more efficient. For example, nearly half of Mexico City's water is wasted in their network due to leaky pipes. With an IoT based water management system, things would look very different. The city's water distribution network would have smart sensors collecting data on water pressure and quality. Using the Internet, these sensors send each other data to monitor for leaks, pipe bursts and contamination. They then rapidly send out alerts to notify water managers and modify water pressure to avoid further damage. Put simply, IoT allows complete insight, automation and control over every part of a city's water network.[124]

Challenges

Blockchain is an exciting technology that has received a lot of hype in recent years. Its sceptics highlight existing challenges related to its performance and scalability. Most of the existing blockchain systems are in pilot stage, and serious challenges have also been noted in the area of blockchain systems' interoperability. Blockchain systems have been under greater regulatory scrutiny in the past few years, and this trend is likely to continue until all legal and regulatory conundrums have been solved.

Much is written about the cost-saving potential of blockchain, vis-a-vis the reduction of system inefficiencies and frictions. However, the operation of a blockchain platform is energy-intensive due to computational requirements, namely, a larger P2P network to improve operation. An example of this is evident in the Bitcoin blockchain, which over its first 10 years of existence has amassed more computing power than the 10,000 largest banks in the world combined (3.5m TH/s).[125] Even a much younger cryptocurrency – Ethereum – quickly amassed more computing power than Google via its P2P network.[126] This also implies that the costs of running blockchain can be significant. One estimate of running costs on the Bitcoin blockchain – associated with validating and sharing transactions on the public ledger – is $600 million USD per year.[127] Furthermore, the cost of ever-expanding storage requirements should be considered. An estimate reported by Forbes of the long-term storage cost per gigabyte for a Bitcoin node was to exceed $22 million, based upon current transaction costs.[128]

124 Ibid
125 Bauerle, N. (2019) How Does Blockchain Technology Work?, at https://www.coindesk.com/information/how-does-blockchain-technology-work
126 Ibid
127 Deloitte (2016) Blockchain Enigma. Paradox. Opportunity, at: https://www2.deloitte.com/content/dam/Deloitte/uk/Documents/Innovation/deloitte-uk-blockchain-key-challenges.pdf
128 Bloomberg, J. (2018) Don't Let Blockchain Cost Savings Hype Fool You, at https://www.forbes.com/sites/jasonbloomberg/2018/02/24/dont-let-blockchain-cost-savings-hype-fool-you/

Drones and Remote Sensing

5. Drones and remote sensing

Drones, or unmanned aerial vehicles (UAV), are umbrella terms for unmanned, flying vehicles controlled remotely using sensors and GPS navigation. Originally designed for the military, the technology was used for intelligence, surveillance, and reconnaissance. However, while the military uses of UAVs go back to the latter half of the 20th century,[129] today the technology has been increasingly applied in a civilian context for commercial and recreational purposes.[130]

In general, drones are relatively cheap and easy to deploy in mapping and data-collection missions. They can be programmed, which facilitates their use. As long as weather conditions are favourable, the deployment of drones is possible at any time, presenting a significant advantage over satellites that can only monitor on a regular basis. Moreover, they can collect imaging data below the clouds and often at higher resolutions than satellites.[131] Due to these advantages, drones are increasingly being used in non-military settings, such as in emergency response efforts following natural disasters for data collection, situation assessment, victim identification and search and rescue.[132] Haiti has deployed drones for humanitarian purposes since 2012, as the country is prone to hurricanes. The International Organization for Migration (IOM) has used drone images from before and after hurricanes to quickly calculate how many homes were destroyed, as well as how many people were displaced and in need of immediate shelter. These images were also used in Haiti to plan a flood barrier that could protect the community against future hurricanes.[133]

Drone production is growing extremely fast. By 2030, the dominating purpose of drones is expected to be industrial inspection in oil and gas, energy, infrastructure and transportation worldwide. Other important markets are military and agriculture. Delivery drones are expected to play a smaller role in the future compared to these industrial applications.[134]

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129 Sandvik, K. (2017) African Drone Stories, Behemoth A Journal on Civilization, 2015, Volume 8, Issue 2, at https://ssrn.com/abstract=3060768

130 Washington, A. N (2018) A Survey of Drone Use for Socially Relevant Problems: Lessons from Africa, at https://www.researchgate.net/profile/Alicia_Washington/publication/330988826_A_Survey_of_Drone_Use_for_Socially_Relevant_Problems_Lessons_from_Africa/links/5c5f380d299bf1d14cb7e75b/A-Survey-of-Drone-Use-for-Socially-Relevant-Problems-Lessons-from-Africa.pdf

131 NEPAD (2018) Drones on the Horizon: Transforming Africa's Agriculture, at https://www.nepad.org/publication/drones-horizon-transforming-africas-agriculture

132 Washington, A. N (2018) A Survey of Drone Use for Socially Relevant Problems: Lessons from Africa, at https://www.researchgate.net/profile/Alicia_Washington/publication/330988826_A_Survey_of_Drone_Use_for_Socially_Relevant_Problems_Lessons_from_Africa/links/5c5f380d299bf1d14cb7e75b/A-Survey-of-Drone-Use-for-Socially-Relevant-Problems-Lessons-from-Africa.pdf

133 https://ec.europa.eu/echo/field-blogs/stories/how-drones-can-help-humanitarian-crises_en

134 Stamford, C. (2017) Gartner Says Almost 3 Million Personal and Commercial Drones Will be Shipped in 2017, at https://www.gartner.com/en/newsroom/press-releases/2017-02-09-gartner-says-almost-3-million-personal-and-commercial-drones-will-be-shipped-in-2017

Table 4. Trends in drone production

	Commercial Drones	Total number of drones
2016	110.000	2.160.000
2017	174.000 (60% increase from 2016)	3.000.000 (39% increase from 2016)
2020	Total market for commercial and personal drones expected to reach $11.2 billion	

Source: Gartner (2017) Gartner Says Almost 3 Million Personal and Commercial Drones Will Be Shipped in 2017, at https://www.gartner.com/en/newsroom/press-releases/2017-02-09-gartner-says-almost-3-million-personal-and-commercial-drones-will-be-shipped-in-2017

In the context of the 4IR, the development of drones and associated operating systems provides a good example of the fusion of technologies. Rapid developments of drone technologies will ultimately determine their future capacities. This is especially true for technological progress in the fields of engineering and manufacturing that could lead to improved simulation models, new materials, dispersed battery storage, 3D printing of metal components, biomimetic 4D printing methods for optimised elastic surfaces and novel software tools, as well as ICT technologies including AI, wireless 5G communication, and miniaturised electronics.[135] All of these will have very direct implications for both current and future drone capabilities.

Several complementary technologies are associated with the operation and usage of drones. Notable technologies relevant to agricultural applications are GPS, GIS (geographic information system), variable rate technology and remote sensing data. The availability of accurate GPS and GNSS (Global Navigation Satellite Systems) is crucial for any operator to determine locations and conduct precise measurements.

In a similar vein, GIS is an important software precondition to analyse and display all kinds of geographical data. Leading technology companies, such as Sony have begun to diversify their business models, tapping into new areas of business by leveraging their expertise in technology solutions. Sony's Smart Agriculture provides advanced real-time vegetation analytics through the use of their drone-mounted Multispectral Camera, which captures 12MP RGB and 2MP NDVI maps and geolocation data simultaneously to give an instant view of crop density.[136] As drone technology has matured steadily, farmers have begun to utilize it beyond just mapping and analysing geographical data. For effective drone-based precision agriculture, variable rate technology is essential as it can apply fertilisers or pesticides in specific quantities at specific sites.

Drones can be further used to increase watering efficiency and to detect possible pools or leaks in irrigation.[137] Skyx, an agricultural-robotics technology company from Canada, has created an innovative solution called Skyx Precision Agriculture Spraying Swarm (PASS), which can be used to water crops uniformly over an entire farmland.[138] Lastly, the availability of remote sensing data is an important precondition, as it yields soil and crop data that are used in higher-level analyses such as biophysical crop parameters and vegetation indices.[139] This data is typically included in GIS databases as well, and up-to-date satellite imaging is an important input needed for pre-flight operations, including planning, flight range determination, and minimum elevation setting.

135 Ibid
136 https://pro.sony/ue_US/solutions/agriculture/smart-agriculture-solution
137 https://halorobotics.co.id/agriculture/irrigation-management-drones/
138 https://www.skyx.solutions/
139 Ibid.

Remote sensing on the other hand, can help meet many of the challenges of information asymmetry and data gaps in developing countries. The capabilities and techniques which remote sensing possesses are well-suited for monitoring regional-scale precipitation, water budgets, soil moisture and some measures of water quality. By marrying remote sensing and satellite imaging, catchment characterization, water quality monitoring, soil moisture assessment, water extent and level monitoring, irrigation service monitoring, urban and agricultural water demand modelling, ground water management, hydrological modelling, and flood mapping and forecasting have been made possible.[140] This technology has been used by the European satellite Sentinel-1, which was used to estimate water volumes retained by small reservoirs to assess the feasibility of small water supply systems in low-income countries.[141]

5.1. Case studies

Drones are technological 'game-changers' by virtue of the many possibilities they offer across sectors. Indeed, drones offer multiple benefits as compared to manned aircrafts. For instance, they provide easy access to remote areas that would otherwise be inaccessible.[142] They also offer more versatile and affordable surveillance capacities and enable new ways of information gathering. Due to their link with digitalization and robotics, drones can solve a wealth of different problems where physical access is a challenge.

The application of drones is expected to have a profound economic impact in multiple domains. This is also why drones have been discussed in relation to the idea of 'leapfrogging' in terms of economic development.[143] UAVs will partly address future mobility needs by replacing services on ground, rail, water and in the air.[144] The level of integration between drones and manned counterparts still remains to be seen, but at least some degree of integration is expected. One example is the use of drones in freight transportation. Economic impacts are not limited to new technological possibilities, but will also include effects on employment. The proliferation of drones and their integration into airspace, for instance, will have impacts on workforce in the aviation industry by generating new jobs in manufacturing and service sectors.

The application of UAV technology in the water sector has begun to gain traction due to its transformational properties in the monitoring and maintenance regimes, adding commercial value and engineering accuracy. Drones allow for the inspection of pipelines, sewer crossings, joints, pipework and beams, thus avoiding disruption and costs incurred in time-consuming and expensive manual access solutions.[145] Mounting LiDAR scanners to UAVs to create 3D models of assets and landscapes provides companies with quick and highly reliable surveys of entire assets and topographies. Anglian Water recently used drones with thermal imaging to address leakage issues, which are easily picked up by thermal cameras that indicate temperature difference between escaping water and the surrounding earth.

140 Andres, L., et al (2018) A Review of In-Situ and Remote Sensing Technologies to Monitor Water and Sanitation Interventions, at https://www.mdpi.com/2073-4441/10/6/756/pdf
141 Ibid
142 Washington, A. N (2018) A Survey of Drone Use for Socially Relevant Problems: Lessons from Africa, at https://www.researchgate.net/profile/Alicia_Washington/publication/330988826_A_Survey_of_Drone_Use_for_Socially_Relevant_Problems_Lessons_from_Africa/links/5c5f380d299bf1d14cb7e75b/A-Survey-of-Drone-Use-for-Socially-Relevant-Problems-Lessons-from-Africa.pdf
143 Sandvik, K. (2017) African Drone Stories, Behemoth A Journal on Civilization, 2015, Volume 8, Issue 2, at https://ssrn.com/abstract=3060768
144 Schechtner, K., et al. (2018) (Un)certain Skies? Drones in the World of Tomorrow, at https://www.itf-oecd.org/uncertain-skies-drones
145 Williams, D. (2018) The Power of Drones for the Water Sector, at https://wwtonline.co.uk/features/the-power-of-drones-for-the-water-sector

Drones have the capabilities to precisely locate even the smallest leaks, thus minimising excavation works and service disruption. Coupling this technology with GPS tracking means that the drone can revisit areas of concern in a matter of minutes and deliver real-time, high-definition footage and thermographic data to an inspection team.[146] Furthermore, drones have found their application in humanitarian aid and disaster relief purposes, such as sanitation needs in refugee camps, as well as monitoring acid mine drainage from abandoned mines and tailings.[147]

With the advent of drones, advances in the methodology of using remote sensing techniques for managing water in agricultural systems have been made. For example, Indian state governments have been faced with the worst water crisis in the country's history, with more than 600 million Indians facing acute water shortage, and more than 80% of the total water in India being used for irrigation purposes. This is particularly alarming as the country's water table is quickly vanishing. A critical bottleneck that most of these state governments face comes from the unbilled water consumption on agricultural farms. This lowers revenue collection necessary for the optimal maintenance of a well-designed canal network. As state governments were using outdated and obsolete agriculture maps, they needed updated and accurate information about the types of crops and irrigation methods. For this reason, Indian state governments hired Terra Drone India to map an area of around 4,200 sq. km of agricultural land parcels in a limited timeframe to streamline its revenue generation process, as well as provide data with the highest precision and accuracy to better plan future water supply.[148]

Drone technology can improve the accuracy of water quality predictions and reduce manpower necessary to physically collect samples. The Auckland Council teamed up with Pattle Delamore Partners, an engineering and environmental consulting firm from New Zealand, to develop a methodology that carries out a water sampling process. Samples are collected by drones at various sites up to 1km offshore by lowering a sample bag into the waters. After a lab analysis is carried out, the results are fed into the council's water quality monitoring system. This not only improves the accuracy of water quality predictions, but also lowers operating costs for the city of Auckland.[149]

Economic inequality is on the rise across all of LAC, with more and more families being driven into poverty. As a result, many people live in informal human settlements (or favelas) which have limited or no access to adequate housing, education, clean water, sanitation and other basic services. The metropolitan area of Sao Paulo houses over 2 million people in favelas. To combat this, a Brazilian non-profit called Techo has taken up the task to build a fair and integrated poverty-free society, which would give families living in these areas access to basic services, such as water, electricity, and sewage. By partnering with DroneDeploy, Techo correctly mapped and counted the total number of families living in these areas in order to launch an urban upgrade project that will bring fresh water to these settlements.[150]

146 Ibid

147 Matthews, S. (2018) Water and Technology: The Age of the Drone – Keeping an Eye on the Nation's Water, at http://www.wrc.org.za/wp-content/uploads/mdocs/WW%20July_Aug%202018%20WATER%20AND%20TECHNOLOGY.pdf

148 Terra Drone India (2019) Water Management Made Easy With Drones – A Case Study, at https://medium.com/@info_16773/water-management-made-easy-with-drones-a-case-study-4db4cfcc600e

149 Aquatech (2019) Drones Reduce Water Quality Sampling Costs in Auckland, New Zealand, at https://smartwatermagazine.com/news/aquatech/drones-reduce-water-quality-sampling-costs-auckland-new-zealand

150 https://www.dronedeploy.com/resources/stories/drone-mapping-impoverished-neighborhoods/

Plant modelling

Water and wastewater treatment facilities often lack complete documentation and drawings. Drones can quickly capture an "accurate, engineering-ready 3D model of a plant" to help asset management teams better understand the state of existing facilities.[151] More complete models help maintenance teams inspect and plan maintenance with fewer site visits, and engineering teams plan repairs and modifications more efficiently.

In a study funded by the European Regional Development Fund, drones have been tested for topo-bathymetric monitoring of the reservoirs of the Segura River Basin in Spain. In this project, the team utilized UAVs for photogrammetry, Surface Water Vehicles (USVs) for bathymetric surveys and Remote Operated Vehicle (ROVs) for bathymetric surveys and water quality measurements to test the potential and costs of sensorized drones to "provide digital models of reservoir surfaces with a high spatial and altimetric resolution".[152] The price of design and manufacture of the probes and their integration with the different drones varied between USD$10,500-16,000; considering the quality of results and time reductions, it was estimated that the costs of these bathymetric techniques using drones were 75% lower than for traditional bathymetry.[153]

Sewer inspection

There are also some indications that drones could be useful for the inspection of sewer networks and collector pipes. One example is the EU-backed ARSI (Aerial Robot for Sewer Inspection) initiative, a groundbreaking project that tests the use of a Micro Aerial Vehicle (MAV) for sewer inspection[154].

ARSI keeps the operator in mind and includes a platform design based on multiple state-of-the-art sensors. Currently, the work is mainly focused on developing inspection tasks to support on-site workers, but in the near future the work will focus on automatic structural inspection, replacing the human eye, and also on hazardous gas detection and sample collection.[155]

151 Williams, A. (2018) Flying High: How Water is Adopting Drones, at https://www.waterworld.com/international/utilities/article/16201296/flying-high-how-water-is-adopting-drones
152 Erena, M., et al (2019) Use of Drones for the Topo-Bathymetric Monitoring of the Reservoirs of the Segura River Basin, at https://www.mdpi.com/2073-4441/11/3/445
153 Ibid
154 Echord (2019) ARSI – Aerial Robot for Sewer Inspection, at http://echord.eu/essential_grid/arsi-aerial-robot-for-sewer-inspection/index.html
155 Williams, A. (2018) Flying High : How Water Is Adopting Drones, at https://www.waterworld.com/international/utilities/article/16201296/flying-high-how-water-is-adopting-drones

Remotely sensed data from satellite imagery

As water resource management (WRM) is a key global challenge, a move towards satellite imagery would be a more scalable solution. Drones lack scalability for certain applications, such as covering large farm acreages of water reservoirs; whereas, satellite remote sensing instruments provide a unique perspective on the direct and indirect measurements of nearly all components of the hydrological cycle. With the number of satellites launched steadily increasing over the past decade, satellite-based information provides unprecedented opportunities to support and improve WRM worldwide. This can be seen in the benefits remote sensing provides, as satellite imagery can be used as a tool that can provide continuously monitored water quality information, thus identifying and minimizing the sources of pollutants that have been proven harmful to both human and aquatic life.[156] The sensors used in satellite remote sensing are capable of providing critical information in support of water management and monitoring the evolution of hazards and their potential impact. Even though these sensors are in their nascent stage and face many limitations and challenges in the context of WRM, the large spatial coverage and temporal resolution they deliver means that they can provide near-global information in near real-time.[157]

5.2. Opportunities and challenges

While drones open myriad opportunities and potential applications, they are likely to have a disruptive impact as well. On the one hand, the technology can be regarded as mature in the sense that multiple commercial models exist today for which there is a relatively clear and growing market. On the other hand, the wide adoption of these is simultaneously held back by the lack or restrictiveness of legal and regulatory frameworks. [158]

Widespread drone adoption will bring with it many challenges with regards to national responsibility concerns, operator training, equipment loss or damage, distance and weight capacity limits, government regulations, privacy concerns, and time-to-deployment limits. Especially from a governance perspective, challenges in terms of drone safety, security maintenance, technological reliability, resilience to cyber threats, and enforcement of regulation will have to be addressed.

The impact drones will have on the environment is somewhat debated. Concerns are primarily related to increased levels of noise pollution and vibrations, as well as light pollution and the impact this will have on both humans and wildlife[159]. In urban areas, noise volumes are likely to exceed desired or even legal limits, a variable that will have bearing upon civilians' acceptance of the technology.

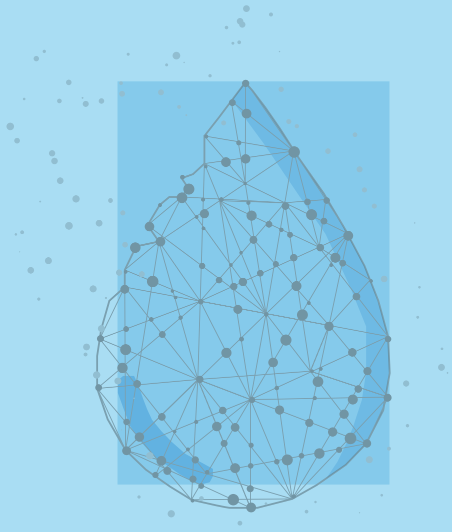
156 Saad, H., (2016) Water Quality Assessment Using Satellite Remote Sensing, at https://ui.adsabs.harvard.edu/abs/2016cosp...41E.801H/abstract
157 Sheffield, J., et al (2018) Satellite Remote Sensing for Water Resources Management: Potential for Supporting Sustainable Development in Data-Poor Regions, at https://agupubs.onlinelibrary.wiley.com/doi/10.1029/2017WR022437
158 Sandvik, K. (2017) African Drone Stories, Behemoth A Journal on Civilization, 2015, Volume 8, Issue 2, at https://ssrn.com/abstract=3060768
159 Ibid.

Similarly, there are also worries regarding energy consumption, emissions, and overall sustainability of drone-based transport.[160] The aviation sector in general is currently a major contributor to global CO2 emissions. Therefore, the question is whether drones are more energy-efficient than existing modes of transportation used in, for instance, freight delivery. The increased use of drones will also increase the demand for electricity. Studies argue that the energy-efficiency of drone delivery is limited to short-distance transportation of light-weight payloads.[161] In addition, energy will also be needed for supporting infrastructure, such as distribution centers, warehouses, and battery charging facilities. Researchers are still studying efficient set-ups for drones to minimise environmental impact.

Finally, regarding enabling conditions for developing countries, more basic technological requirements may also represent barriers to adoption. These requirements include access to electrical power for charging, access to replacement parts, as well as the computing power needed to process the data in order to generate maps, models, and other outputs.[162]

160 Ibid.
161 Ibid.
162 Technical Centre for Agricultural and Rural Cooperation (2016) Drones for Agriculture. ICT Update, Issue 82, at https://cgspace.cgiar.org/handle/10568/89779

Virtual and Augmented Reality



6. Virtual and augmented reality

Virtual reality (VR) and augmented reality (AR) have the potential to become the next big computing platform, with new markets to be created and existing markets to be disrupted. There is no shortage of examples of how VR and AR can reshape existing ways of doing things as the technology progresses and prices decline.[163] "Virtuality" is defined as a media's ability to show virtual elements or worlds created by computer graphics or visual elements adopting an experience-based perspective and experienced by the user through immersion or telepresence in the environment.[164] While both VR and AR facilitate immersive and interactive experiences, it is important to distinguish between them as they have different use cases, technologies and market opportunities.

Virtual reality is an 'intuitive interface' paired with advanced input and output devices that allows a person to interact with a computer and data in a naturalistic fashion by generating real-time, immersive and interactive multi-sensory experiences situated in, and artificially induced by, a responsive three-dimensional computer-generated virtual environment.[165] It can immerse a user in an imagined or replicated world (videogames, movies or flight simulation) or simulate presence in the real world (watching a sporting event live). Once immersed, the user can interact with objects in the virtual environment and have the displayed images updated to match the user's perspective. The three-dimensional (3D) virtual environments can facilitate conceptual design and understanding by enabling preliminary design to be previewed and experienced at full scale from a first-person perspective. VR technology has been widely used for many applications across multiple fields, such as military and medical training, health, education and engineering applications.[166]

Augmented reality (AR) is a well-established research topic within the human-computer interaction field, which has recently attracted new attention due to the announcement by major hardware vendors of low-cost, mass-market AR devices, improved standardization, increased computational power and sensor precision.[167] As opposed to the complete immersion of VR, AR applications are based on a camera's capabilities to capture real-world data and combine information from real and virtual sources, thus providing an enhanced version of our existing reality with an additional layer of digital information in such a way they appear as one environment.[168]

163 Goldman Sachs Group (2016) Profiles in Innovation: Virtual & Augmented Reality, Understanding the Race for the Next Computing Platform, at https://www.goldmansachs.com/insights/pages/technology-driving-innovation-folder/virtual-and-augmented-reality/report.pdf

164 Tom Dieck, M. C., Jung, T. (2019) Augmented Reality and Virtual Reality, at https://link.springer.com/book/10.1007%2F978-3-030-06246-0

165 Ibid

166 Wu, W., Gao, J. and Chang, K. (2012) 'Virtual reality simulation system for water supply and distribution network', Int. J. Computer Applications in Technology, Vol. 45, No. 4, pp.205–213. https://www.researchgate.net/publication/262312728_Virtual_reality_simulation_system_for_water_supply_and_distribution_network

167 Chen, J. Y. C., Fragomeni, G. (2019) Virtual, Augmented and Mixed Reality. Multimodal Interaction, at https://link.springer.com/book/10.1007%2F978-3-030-21607-8

168 Tom Dieck, M. C., Jung, T. (2019) Augmented Reality and Virtual Reality, at https://link.springer.com/book/10.10072F978-3-030-06246-0

The maturation of VR and AR technologies heralds a fundamental shift in moving from the internet of information towards the internet of experiences, in which experiences replace information as the basic unit of currency.[169] In its 2016 report, Goldman Sachs predicted the industry reaching a value of US$80 billion a year (US$35 billion software and US$45 billion hardware) by 2025. Most of its current applications have been associated with consumer good markets, as product simulation, sound, GPS data and media richness contribute to experiential value, enabling consumers to interact with virtual products. However, the potential of VR and AR is extremely diverse and extends far beyond consumer space. According to Goldman Sachs, almost half the industry's revenue will be generated in the business and public sector, with healthcare and engineering as the most promising areas of use.[170]

AR's immersive properties have found their application in the water industry as well. This can be seen by the Augmented Facility Management project developed by the O&M Department of ACCIONA Agua at the La Almunia de Doña Godina water treatment plant in Zaragoza, Spain. By combining virtual and augmented realities, this project has been applying technologies previously unheard of in the water treatment process. AR and VR have become ideal tools for learning and training of employees who are involved in the operation and maintenance of water treatment plants. Training environments allow employees to be virtually immersed in these facilities, allowing them to become familiar with a plant's daily operating tasks and to learn about its features without having to physically visit it.[171]

6.1. Case studies

Data availability is continuously growing in many parts of the world. At the same time, 'Big Data' can become so complex that it is difficult to process and analyse, pointing to the need for visualization methods that integrate complex information while filtering data of significance for a specific need.[172] VR and AR can be used as user-friendly interfaces to enable workers and specialists to understand data and make better decisions.

Water Distribution Networks (WDN) could benefit greatly from these innovations. WDN are complex networks of multiple water sources and treatment plants that include pipe segments, nodes, water sources, water tanks and pump stations and valves.[173] As pointed out by Loucks (2012), anyone associated with water resource planning and management today is surely exposed to, and possibly assisted by, computer models. Water supply and distribution simulation are used to visualize all information of water distribution systems and to model hydraulic operational scenarios from water sources to end-users. Modellers need to provide planners and managers with meaningful, understandable, useful, accurate and timely information that helps them better understand their system, its problems and alternative ways to address them.[174]

169 Ibid
170 Goldman Sachs Group (2016) Profiles in Innovation: Virtual & Augmented Reality, Understanding the Race for the Next Computing Platform, at https://www.goldmansachs.com/insights/pages/technology-driving-innovation-folder/virtual-and-augmented-reality/report.pdf
171 Acciona (2017) Augmented Reality, An Ally in Water Treatment Processes, at https://www.acciona-agua.com/pressroom/in-depth/2017/july/augmented-reality-an-ally-in-water-treatment-processes/
172 Mannschatz, T., et al (2015) Visualization of Water Services in Africa: Data Applications for Nexus Governance, at https://www.researchgate.net/publication/268515148_Visualization_of_Water_Services_in_Africa_Data_Applications_for_Nexus_Governance
173 Wu, W., et al (2012) Virtual Reality Simulation System for Water Supply and Distribution Network, at https://www.researchgate.net/publication/262312728_Virtual_reality_simulation_system_for_water_supply_and_distribution_network
174 Loucks, D. P. (2019) Water Resource Management Modeling in 2050, at https://ascelibrary.org/doi/pdf/10.1061/9780784412077.ch36

However, traditional simulation systems of WDN visualize results by using two-dimensional platforms, text and tables, which are not easy to understand, requiring professional knowledge and experience in water distribution systems. Our modelling methods and skills remain limited in comparison to the multiple interdependent physical, biochemical, ecological, social, legal and political processes that govern the performance of water resource systems.[175] Since pure data is meaningless without context, an appropriate visualization technique is needed to support water management and decision-makers.[176]

VR and AR technologies can thus be combined with advanced simulations to determine recommended actions, expected consequences, responsible personnel and estimated costs. Modern geospatial visualization techniques that are appropriate for decision-makers should make use of the completely automated infrastructure that can link data to interactive visualization. Therefore, such a framework should allow for the display of data, whether historic, obtained from environmental sensors, or the results of models to be continuously added manually or automatically by sensors or mobile phone data.[177] Furthermore, it can also gather knowledge from other online sources of information, all compiled in a massive amount of spatially and temporally indexed physical, environmental, ecological, economic and social data needed for practically anyone's analyses.[178] For example, a crowdsourcing application from Brazil called Sem Dengue – Sin Zika creates a virtual map that helps relevant authorities combat Zika more efficiently and informs users of the health centers they can go to. This application also allows citizens to report potential reproduction areas of the Aedes aegypti mosquito with pictures and geolocalization, allowing town halls and relevant government entities to act quickly.[179]

Wu, Gao and Chang (2012) have developed a VR scene simulation system for Water Distribution Networks with an integrated EPANET[180] toolkit to enhance performance and services of water utilities while also reducing operational cost. Their case study integrated a VR simulation system with hydraulic and water quality models, enabling real-time operational scenarios of WDN. Through the system, users could visualize updating dynamic hydraulic scenario in three-dimensional virtual environments and perform operations such as modifying the schedule of the pumps, running an extended period simulation and collecting information of energy consumption of pumps, tank levels, pipe flow rate, velocity and pressure values. The concept could also potentially be extended to combine with other models related to urban water systems, such as leakage or rehabilitation models to help water utilities understand the complexity of urban water systems and guide their routine operations, as well as provide staff training.[181]

175 Ibid

176 Chai, C. (2009) X3D-Based Virtual Reality Experiences in Water Museum Exhibitions, at https://ieeexplore.ieee.org/document/5166858

177 Mastrangelo, P. (2018) Water and Sanitation: Innovations You Didn't Know Were From Latin America and the Caribbean, at https://publications.iadb.org/en/water-and-sanitation-innovations-you-didnt-know-where-latin-america-and-caribbean;
Mannschatz, T., et al (2015) Visualization of Water Services in Africa: Data Applications for Nexus Governance, at https://www.researchgate.net/publication/268515148_Visualization_of_Water_Services_in_Africa_Data_Applications_for_Nexus_Governance

178 https://ieeexplore.ieee.org/document/5166858

179 IADB (2016) Beating Zika Through Crowdsourcing, at https://blogs.iadb.org/agua/en/3953/

180 "EPANET is a software application used throughout the world to model water distribution systems. It was developed by the United States Environmental Protection Agency's (EPA) as a tool for understanding the movement and fate of drinking water constituents within distribution systems, and can be used for many different types of applications in distribution systems analysis." Source: https://www.epa.gov/water-research/epanet

181 Wu, W., et al (2012) Virtual Reality Simulation System for Water Supply and Distribution Network, at https://www.researchgate.net/publication/262312728_Virtual_reality_simulation_system_for_water_supply_and_distribution_network

A similar idea has been applied by the French company Schneider Electric for its ‘EcoStruxure Augmented Operator Advisor’ product. They use AR to put contextual information and insights at the fingertips of maintenance workers, blending physical, real-life objects with virtual objects.[182] The objects are linked to databases containing digitized manuals, process data, troubleshooting guides and other information that can help increase efficiency and reduce maintenance costs. By using this software, technicians in water treatment plants can point a smart phone or tablet at a specific area, asset or pump, and get real-time data, such as volume, flow rate and other information critical for effective maintenance. Such instant access to critical information shortens response time by enabling a specialist, on-site or even remotely, to diagnose issues immediately based on information displayed on the mobile device. This, in turn, also reduces energy consumption (by highlighting inefficiencies), limits human error and cuts overall maintenance costs.[183]

VR and AR can also be used to enhance modern geospatial visualization techniques to support decision-makers. The choice of visualization type has a strong influence on the viewer and needs to be selected carefully. The same data can produce different types of visualizations that, in turn, convey different information to the viewer. Modern virtual geographic information systems should allow for data to be continuously added manually or automatically by sensors or mobile phones.[184] In this regard, citizens can also help gathering data: social media combined with mobile devices favour the collection of geo-located user-generated content in applications related to spatial information, so-called Volunteer Geographical Information Systems (VGIS), in which citizens help enhance, update or complement existing geo-spatial databases.[185]

This principle has been applied by SnowWatch, an outdoor mobile AR application for the automatic annotation of in-view mountain peaks with geographical meta-data (peak name, altitude, distance from viewer, etc). SnowWatch exploits a content-based reality augmentation algorithm, which takes in input from both the position and orientation of the user’s device and the content of the view on the screen. The meta-data employed for reality augmentation derive from a Digital Elevation Model (DEM), which is a 3D representation of the Earth’s surface. While its primary goal is attracting tourists, the project also aims to produce a repository of annotated mountain images to support environmental research. Through the platform, researchers have used mountain images from users or touristic webcams and extracted snow information to address a water management problem in which snow is a determinant factor. The concept has been tested in Lake Como, a regulated lake in Northern Italy with an Alpine hydro-meteorological regime characterized by water abundance in late spring and autumn due to rainfall and snow melt. Preliminary experiments show that the snow information extracted from a single webcam stream in the lake catchment can be used to identify action points with performance comparable to those conditioned on the official snow bulletin data.[186]

182 https://www.se.com/th/en/work/services/field-services/industrial-automation/performance-optimization-services/ecostruxure-augmented-operator-advisor.jsp

183 Schneider Electric (2019) New Perspectives on IT and OT System Integration for the Water Industry, at https://www.schneider-electric.com/en/download/document/998-20619554/

184 Mannschatz, T., et al (2015) Visualization of Water Services in Africa: Data Applications for Nexus Governance, at https://www.researchgate.net/publication/268515148_Visualization_of_Water_Services_in_Africa_Data_Applications_for_Nexus_Governance

185 Mongelli, A., et al (2016) Augmented Reality, Virtual Reality, and Computer Graphics, at https://link.springer.com/book/10.1007/978-3-319-40621-3

186 Ibid

VR and AR have an important role to play in local communities, offering ways to visually communicate ideas, skills and knowledge in a way that overcomes literacy barriers so often experienced in education and training programs.[187] Vivid messages that utilize strong imagery related to the senses can enable the brain to assimilate and process information more effectively, making abstract representations concrete, and influencing people's ability or motivation to carefully review the information, allowing for greater cognitive elaboration.[188] In a recent pilot project, a VR training application was developed to address rural water sanitation for a Multipurpose Community Telecenter in Nakaseke, Uganda. In Nakaseke, 60% of the community are functionally illiterate and therefore traditionally barred from modern tools and facilities such as computers and libraries, which primarily offer text-based information and applications. A VR model was built using the local community's environment to address basic issues that lead to water-borne diseases with an emphasis on visual and audio cues to transfer the message.[189]

Similarly, the Instituto Trata Brasil in partnership with the Companhia de Saneamento do Paraná (SANPAR) used AR to teach children about access to water services and sanitation during a three month exhibit in Curitiba, Brazil.[190] Elsewhere, The Hidden Dangers marketing campaign was created by WATERisLIFE, Ntropic+ Tactic and Ray Tintor of Mssngpeces to educate children in Thailand about the unseen dangers of polluted water, as well as to show them through the use of a VR platform how they can safely filter their water.[191]

A growing demand for skilled professionals with expertise in water and wastewater management has raised concerns that a traditional classroom or a learning by doing approach is not sufficient. These insufficiencies stem from the amount of subject matter needed to be covered, the risks of training in a live environment, and the time needed to gain required expertise. To help alleviate these growing concerns, Festo Didactic and EON Reality created a Virtual Reality Water and Wastewater simulator, which features several scenarios allowing users to interact with a virtual water treatment plant, operate machinery, and perform emergency procedures.[192]

A new Clean Seas augmented reality experience created by MeshMinds, a Singaporean creative technology studio, now allows audiences to immerse themselves in the challenge of tackling the marine litter problem. Working with the UN Environment Programme (UNEP) and Singaporean artist, André Wee, MeshMinds created a virtual ocean teeming with sea creatures made from plastic waste. Through a simple interaction, people are able to "clean" the sea and make a social pledge that they can easily share online.[193]

187 Lockwood, D. (2010) Virtual Reality in Africa, at https://www.tandfonline.com/doi/abs/10.1076/digc.13.1.3.3214
188 Bailey, J., et al (2014) The Impact of Vivid Messages on Reducing Energy Consumption Related to Hot Water Use, at https://www.researchgate.net/publication/276089761_The_Impact_of_Vivid_Messages_on_Reducing_Energy_Consumption_Related_to_Hot_Water_Use
189 Lockwood, D. (2010) Virtual Reality in Africa, at https://www.tandfonline.com/doi/abs/10.1076/digc.13.1.3.3214
190 http://www.tratabrasil.org.br/comunicacao/acoes-do-trata-brasil/exposicao-pastoral-da-crianca
191 Singletary, C. (2017) Hidden Dangers Uses VR to Raise Awareness on Clean Water Shortage, at https://uploadvr.com/hidden-dangers-uses-vr-raise-awareness-clean-water-shortage/
192 https://www.eonreality.com/portfolio-items/virtual-reality-training-platform/
193 UN Environment Programme (2019) New #CleanSeas Augmented Reality Experience Merges the Real World and the Virtual, at https://www.unenvironment.org/news-and-stories/story/new-cleanseas-augmented-reality-experience-merges-real-world-and-virtual

6.2. Opportunities and challenges

Opportunities

The use of VR has been demonstrated to be reliable for: early engagement of stakeholders with meaningful project information; reduced costs by not requiring 'real world' versions of modelled assets to be constructed or used; increased availability compared to limited physical resources, allowing more, and more frequent, opportunities to experience and interact with the simulated environment; increased safety by providing highly realistic environments and interactions with none of the physical risks; and providing consistency of simulation and training to all users.

Challenges

A major roadblock in the implementation of VR is the technology's high cost. This is due to the hefty price tag that comes with the production of VR gear, and the fact that many companies basically have a monopoly, as market competition is very slim. In terms of the water sector, VR has proven to be an even more costly affair, as the visualization and simulation of water plants require an extensive use of integrated software, such as GIS, computer-aided designs, multimedia data, and World Wide Web-based VR techniques.[194]

Cost is not the only challenge that VR has to overcome in order for it to be available for widespread use. We still do not know what health effects of using this technology long term could be. However, what we do know, is that there have been temporary side effects, such as blurred vision, nausea, headaches and queasiness, which stem from the overuse of VR gear.[195]

194 Jamei, E., et al (2017) Investigating the Role of Virtual Reality in Planning for Sustainable Smart Cities, at https://www.researchgate.net/publication/320788938_Investigating_the_Role_of_Virtual_Reality_in_Planning_for_Sustainable_Smart_Cities

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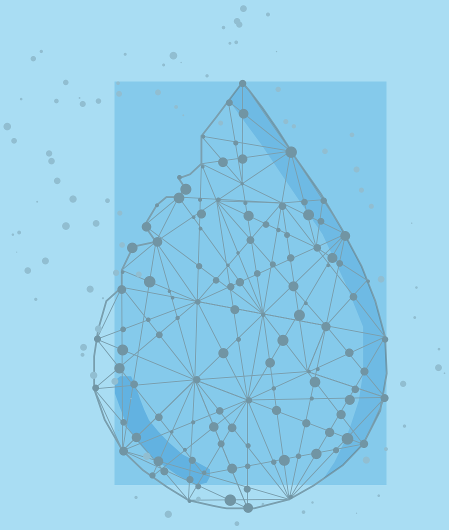
Annex



ANNEX 1: SDG 6 Targets and Indicators

SDG 6: Ensure availability and sustainable management of water and sanitation for all		
Targets		Indicators
6.1	By 2030, achieve universal and equitable access to safe and affordable drinking water for all.	Drinking water (6.1.1): A safely managed drinking water service is defined as an improved drinking water source that is located on the premises and available when needed, and free of fecal and priority chemical contamination. Improved water sources include piped water, boreholes or tube wells, protected dug wells, protected springs and packaged or delivered water.
6.2	By 2030, achieve access to adequate and equitable sanitation and hygiene for all and end open defecation, paying special attention to the needs of women and girls and those in vulnerable situations.	Sanitation (6.2.1a): A safely managed sanitation service is defined as an improved sanitation facility which is not shared with other households and where excreta are safely disposed in situ or transported and treated off-site. Improved sanitation facilities include flush/pour flush to piped sewer system, septic tank or pit latrine, ventilated improved pit latrine, composting toilet or pit latrine with slab.
		Hygiene (6.2.1b)*: A basic handwashing facility is defined as a facility with soap and water available on premises. Handwashing facilities may be fixed or mobile and include a sink with tap water, buckets with taps, tippy-taps, and jugs or basins designated for handwashing. Soap includes bar soap, liquid soap, powder detergent, and soapy water but does not include ash, soil, sand or other handwashing agents.
6.3	By 2030, improve water quality by reducing pollution, eliminating dumping and minimizing release of hazardous chemicals and materials, halving the proportion of untreated wastewater and substantially increasing recycling and safe reuse globally.	Wastewater treatment (6.3.1): Wastewater is generated by households, both as sewage and as fecal sludge, and by economic activities. Safely treated means that the wastewater has undergone sufficient treatment for its intended recipient (e.g. lake, river, ocean or soil) or further use (e.g. in agriculture).
		Water quality (6.3.2): Overall ambient water quality is estimated based on a core set of five parameters for surface water bodies and three for groundwater bodies, which inform on major water quality impairments present in many parts of the world. For surface water, these parameters are dissolved oxygen, electrical conductivity, nitrogen, phosphorus and pH, and for groundwater they are electrical conductivity, nitrate and pH.

6.4	By 2030, substantially increase water-use efficiency across all sectors and ensure sustainable withdrawals and supply of freshwater to address water scarcity and substantially reduce the number of people suffering from water scarcity.	Water use efficiency (6.4.1): Water-use efficiency is defined as the value added in US dollars per volume of water withdrawn in cubic meters, by a given economic activity. Some sectors, for example, agriculture, industry, energy and municipal water supply, are particularly relevant due to their high-water use.
		Water stress (6.4.2): The level of water stress is defined as the ratio between total freshwater withdrawals by all economic activities and total available freshwater resources, after taking into account environmental flow requirements. Environmental flow requirements are essential to maintaining ecosystem health and resilience.
6.5	By 2030, implement integrated water resources management at all levels, including through transboundary cooperation as appropriate.	Integrated water resources management (6.5.1): The degree to which integrated water resources management (IWRM) is implemented is assessed by four key components of IWRM: enabling environment, institutions and participation, management instruments and financing.
		Transboundary water cooperation (6.5.2): An arrangement for water cooperation is a bilateral or multilateral treaty, convention, agreement or other formal arrangement between riparian countries that provides a framework for cooperation on transboundary water management. Criteria for an "operational" arrangement include: the existence of a joint body, regular, formal communication between riparian countries, joint or coordinated management plans or objectives and a regular exchange of data and information.
6.6	By 2020, protect and restore water-related ecosystems, including mountains, forests, wetlands, rivers, aquifers and lakes.	Water-related ecosystems (6.6.1): Relating to changes in the extent of water-related ecosystems over time and including data on the spatial extent of water-related ecosystems and the quantity and quality of water within them. Currently, information on the spatial extent of water-related ecosystems, more specifically lakes, rivers and estuaries, is available from satellite data.
6.A	By 2030, expand international cooperation and capacity-building support to developing countries in water- and sanitation-related activities and programmes, including water harvesting, desalination, water efficiency, wastewater treatment, recycling and reuse technologies.	International cooperation (6.a.1): This indicator tracks the amount of water and sanitation-related official development assistance (ODA) included in a government-coordinated spending plan. A government-coordinated spending plan is defined as a financing plan/budget at the national or subnational level, clearly assessing the financial resources available and strategies for financing future requirements.
6.B	Support and strengthen the participation of local communities in improving water and sanitation management.	Stakeholder participation (6.b.1): This term refers to the existence of procedures defined in law or policy for participation of local communities in water and sanitation planning, as well as the extent of this participation.

Source: Authors' elaboration, based on https://sustainabledevelopmentun.org/sdg6 and http://dataportal.unwater2.rw1.co.za/)

* This appears in this UN data portal but not other UN sources

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