Chapter

Artificial Intelligence and Water Cycle Management

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Abstract

Artificial intelligence applications play a crucial role in improving environmental quality from all points of view. Digital technologies have revolutionized our way of life as they are permeated to a capillary level in our daily life. On the other hand, the data produced every second cannot be managed by a human mind due to a certain physical and temporal impossibility, so artificial intelligence, algorithms written by men to perform human reasoning, they can accomplish this arduous task. In this chapter we will address the potential of artificial intelligence to process important amounts of data and analyze existing relationships also through a focus on the conservation capacity of one of the most precious resources: water.

Keywords: water cycle, artificial intelligence, smart communities, collective knowledge, big data

1. Introduction

When we talk about Artificial Intelligence, we immediately think of cutting-edge technologies, robots capable of understanding and deciding the actions to be taken and a futuristic world in which machines and humans coexist. In fact, Artificial Intelligence and its use are much more real than one might imagine and are now used in various areas of daily life. In this chapter, we want to discuss the state of the art of the application of artificial intelligence for the management of water resources.

The "White Paper on Artificial Intelligence - A European Approach to Excellence and Trust", COM (2020) 65, highlights how digital technology has improved our lives allowing easier access to knowledge and content. Nowadays, Europe is called to make two transformations (green and digital) which, in the water management sector, could have common objectives: the first requires to take actions towards more sustainable solutions, the second consists in directing the social transformations in such a way that every citizen can take full and maximum benefit. In line with these objectives, the applications of artificial intelligence can contribute to preserving the environment and first of all the most precious resource: water.

Digital and AI are an engine of change that can allow companies to expand and consolidate their competitive positions in international markets in the name of sustainability [1]. The challenges faced in recent months and the Commission's guidelines [2] aim to promote a series of initiatives, both legislative and development programs, to guide our society towards a more modern, equitable model that can exploit better the power of data and AI. One focus will be on extracting hidden information from available data.

The full exploitation of the significant potential of AI in the water sector to process important amounts of data and analyze relationships allows supporting technical and political choices especially during the planning stage. The management of water resources is particularly important also for the protection of the natural biodiversity which expresses a profound complexity, which is reflected in the extraordinary numbers of animal and plant biodiversity and the environmental parameters that our territory records [3]; but also natural and anthropogenic threats touch different levels of scale and complexity, causing alterations and changes in the stability of ecosystems, reducing functionality and resilience. Mathematical and geostatistical tools for the study of environmental complexity represent a fundamental tool for understanding the complexity of processes that can impact on the quality of life, but many times they are not sufficient [4]. Understanding and analyzing the complex and often imperceptible relationships between the environment and health are fully part of the issues that require a joint scientific commitment which, starting from the in-depth examination of each environmental and anthropic component in its complexity numerical, leads to an indispensable multidisciplinary collaboration often difficult to achieve [5]. A multitude of algorithms defined by different expertise and formalized in Artificial Intelligence systems can contribute to overcoming these criticalities [6]. We collectively need integrated analysis strategies of environmental information, which take us beyond the short-term horizon of specific sectoral knowledge, albeit specialized, aiming at the harmony of knowledge to face the challenges of protecting the water resources that impact not positively on the conservation of the environment and the preservation of health. The numbers involved allow us to understand the indispensability of *Big Data* analysis with AI systems: from the 1.000 billion bacterial species that populate the planet and/or our body to the 100.000 chemical compounds that we disperse into the environment and that they reach our organs, to the complexities that each of these elements brings with it individually and in their interaction.

The aforementioned complexity makes the creation of an ecosystem of excellence based on AI extremely positive, capable of introducing scientific innovation that can be transferred to the sector of Public Administration and Companies.

The hope is that the economic support for research can stimulate and reward the excellences present in the territories, determining a distribution growth of the communities on AI. I believe it is appropriate to encourage the use of technologies based on AI in relation to the resolution of application problems in sectors based on regional strategies designed for innovation areas such as "Human health and the environment", as well as "Sustainable manufacturing" with particular attention reference to water management in production processes.

In particular, concerning the theme of "*Human and environmental health*", Artificial Intelligence can make a decisive contribution in terms of territorial control through automatic image classification systems (*CBIR - Content-Based Image Retrieval System*) that allow using mathematical models, computer implementations of the content of an image, to simulate the principles of the human visual system and to interpret the scenes with a semantics capable of recognizing predefined situations. Such AI applications allow to protect the privacy (as the videos are, in the first instance, analyzed by machines) and to recognize illegal acts such as *spills of wastewater, disposal of waste solids or liquids, picking activities unfair contract* *and infringements environmental of any kind* that can hurt the environment and in particular on water resources. Similar paths can be used with AI approaches through the application of *semi-automatic Change detection algorithms* functional to the evaluation of territorial transformations, enhancing the significant availability of satellite images acquired by the numerous sensors onboard satellite platforms. In this sense, the environmental and territorial applications affecting the water sector refer to the following areas: illicit disposal, illegal building, land-use change, forest fragmentation, urban growth, loss of agricultural land, availability of resources water supply in lakes and reservoirs, melting of glaciers, the evolution of watercourses, etc.

2. Materials and methods

2.1 Artificial Intelligence and integrated management of the water cycle

Water, as a primary source of life and as a natural, cultural, economic and political resource, requires *intelligent management* and the same artificial intelligence can assist in the involvement of the collective intelligence dispersed in citizenship, now evolved into a true *Smart Communities*, to ensure the protection, conservation and rational and optimal use in an *Adaptive Water Management* regime.

The management of water resources requires the formulation of new paradigms capable of combining, on the one hand, the protection of water resources, through new systems and intelligent technologies, capable of increasing the efficiency in the use of resources and the performances of networks and treatment plants present in the territory and on the other hand the development of new monitoring systems distributed and easy to access for widespread control of the quality status. In both cases, the AI plays an extraordinarily important role, especially in the presence of massive amounts of data: an increasingly recurring situation due to the strengthening of water and environmental monitoring systems. The development of interoperable technologies capable of promoting the dissemination and exchange of large volumes of information between decision-makers, managers and citizens, can lead to the creation of *widespread knowledge* capable of feeding artificial intelligence systems and aimed at supporting better environmental protection, ending with a direct impact on the educational and behavioral side. In this direction, the *ubiquity of water*, in every declination of social and productive life, constitutes a natural element to channel information and to consolidate a new culture that can combine the expressions of AI favoring growth, the sharing of structured expert knowledge and not and increasing the sense of belonging to one's territory and to the natural resources it expresses. The recognition of water, as a human right, passes through the acceptance of the sense of widespread (public) ownership and responsibility that must guide both the small daily choices and the big planning, management, political and administrative decisions.

In line with the definitions of the Water Framework Directive 2000/60/EC and the updates in progress, and in general with the articulated Community, national and regional regulatory framework, it is necessary to pursue the objectives of safeguarding, protecting and improving the environmental quality of water bodies, as well as the prudent and rational use of natural resources based on management that is not only sustainable but adaptable to the circumstances that arise also as a result of global changes: all elements of high complexity that find in AI an indispensable ally. In this vision, participatory processes that can also be activated through AI are crucial for triggering paths that lead to the construction of the economic and social vocation of smart cities.

The keyword underlying the concept of AI is "*integration*" to be achieved at various levels of knowledge: both in the management of the entire " *water supply chain* " but also with the active involvement of citizens, management bodies, research bodies and universities, companies, supervisory authorities, to achieve management of water resources capable of facing complexities, in line with the needs of environmental sustainability and reduction of impacts.

A correct understanding of the management of water resources can certainly not be limited to the simple government of only one of the components such as, procurement, distribution networks, purification, etc., but it requires a broader perspective that allows the analysis and definition of coordinated and integrated strategies that affect the entire water cycle (**Figure 1**).

Furthermore, even the potentially most efficient strategies have no chance of success if they are not supported by an "awareness" of citizens who must be directly involved as actors within a system that cannot ignore virtuous behavior at the macro level and micro-communities.

It must be emphasized that the constantly growing demographic evolutions, the consequent increased use of the intensification of crops, the effects of climate change with the increase in the frequency of extreme events, determine an extreme urgency in implementing every possible solution (including technological and "intelligent") that can make the resource management system as a whole more efficient, both in quantitative and qualitative terms.

In this context, the research activities on AI that envisage water management in the implementation of environmental policies, in close connection with the Europe 2020 strategy which has identified smart growth, sustainable growth and inclusive growth, as engines of the relaunch of the economy.

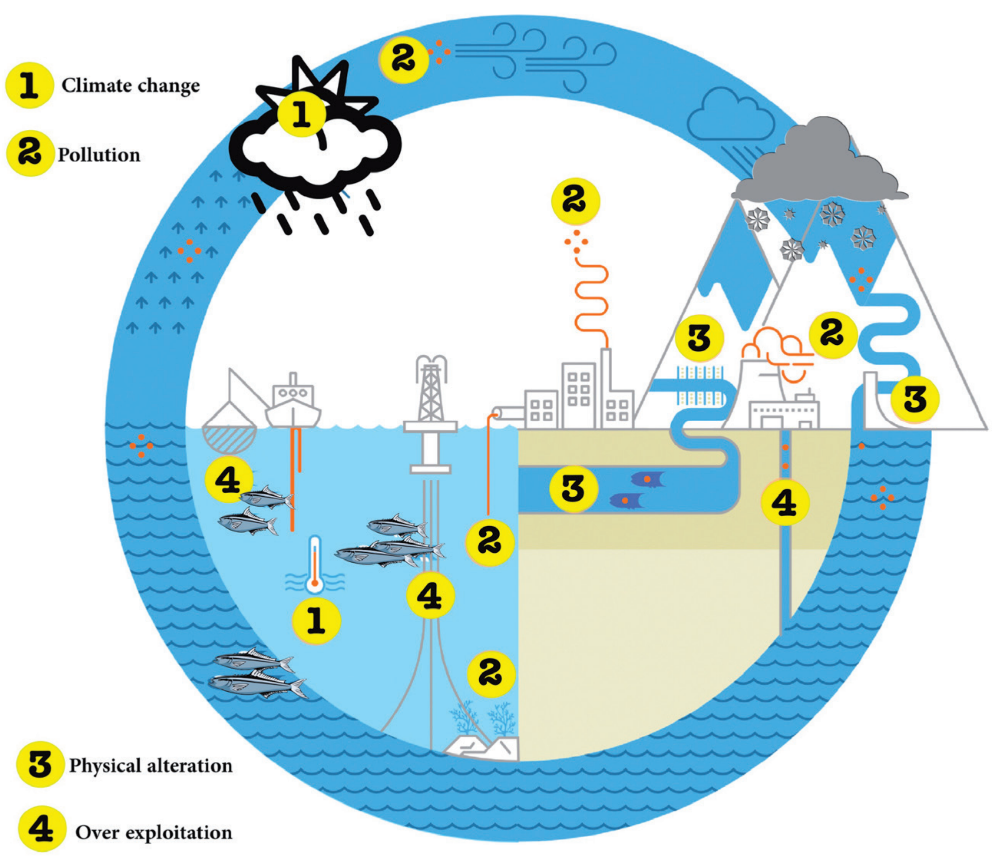

Figure 1.
Water cycle and pressure factors and areas of application of AI [7]. Legend: 1) climatic change, 2) pollution, 3) physical alterations, 4) over exploitation.

The applications of AI in the water management sector, operating on huge amounts of data, concern the monitoring and management of extreme events also interface with the "*Territory security*" area, while others concern the collection and storage of data, their dissemination and their interoperable using interfaces with the "*Home automation and Smart Grids*" area, in particular concerning aspects relating to the improvement of the quality of life in domestic environments, the reduction of management costs and the transmission of information through *Power Line Communication* (PLC) and their storage using Cloud technology [8].

By way of example, a monitoring system based on AI technologies makes it possible to more effectively target control actions on diffused loads generated as a result of an overflow of the network and on production ones, in order to reduce the presence of metal contaminants and organic and maximize nutrient recovery. The AI itself, combined with innovative devices for controlling the efficiency of urban sewers, allows immediate intervention, reducing the risk of contamination of the unsaturated and groundwater [9]. Precisely for these reasons, these technologies are particularly functional for achieving *good ecological and chemical status* in water bodies, envisaged by the European Directive 2000/60/EC. In response to what is strongly desired by administrators, managers and citizens, the AI itself uses *early warning indicators* that make it possible to identify and suggest mitigation strategies on a local scale of extreme events attributable to natural factors (e.g. climate change and consequent changes in the regime rainfall) or anthropogenic (eg illicit disposal or accidental spills).

AI can be decisive in identifying and managing adaptation guidelines in relation to the climate changes underway. In particular, it can be useful for:

- water supply management sector:
  - **control of leaks,** orienting measurement strategies and priorities and the most effective types of intervention to reduce water dispersion;
  - the definition of **investments in water networks and infrastructures**, supporting a holistic water policy that takes into account an extremely large number of technical, managerial, social and economic variables;
- water resources management sector:
  - the promotion of the **natural conservation of water** by orienting the areas in which to favor it both for employment opportunities and for the reduction of hydraulic risk;
  - **the aggregation** of fragmented **surveillance activities** between the different management and control bodies, also in order to improve the quality and use of information;
  - support **capacities in adapting to extreme climatic events**, in particular as regards the control of floods and drought;
- transversal sectors for example in relation to climate change:
  - **the efficiency of water use in all sectors** and guaranteeing sustainable withdrawal and supply of freshwater also to reduce conflicts of use and to address water scarcity in the short, medium and long term;

- ○ support and promote **inter-sectoral, regional, national and sub-national policies** on water management and quality to increase the resilience of water supply, treatment, storage and transport systems as well as hygiene systems, ensuring adequate knowledge and implementation of hygiene practices;

- ○ support the adoption and implementation of a **risk-based approach in the water** and sanitation sector (ie water safety plans, sanitation safety plans), including management of data on diseases, the design of early warning systems based on projections of distributions pathogens, emerging chemical contaminants and/or subject to ordinary control;

- ○ support the modeling and monitoring of hazards, including algae blooms and the production of toxins in the aquatic environment;

- ○ avoid the effects on water quality due to floods, etc.

As better specified below, in urban and semi-urban areas, AI can also intervene effectively in the urban wastewater purification sector, orienting technological applications to improve the efficiency and versatility of plants and favoring low environmental impact technologies, in terms of occupied surfaces, production of sludge and odor emissions, aimed at maximizing energy recovery and the recovery of raw materials and in particular nutrients and biofuels [10].

2.2 Smart devices in the home: data source for AI applications

The availability of sensors in the home, interfaced via Wi-Fi network to routers or smartphones and computers, allows to acquire important amounts of data that can be used both for the benefit of the individual user, but also and above all for the benefit of the manager, allowing responsible management of consumption, maintenance of the plants and networks as well as the operating pressures in the different time bands.

In addition, the *intelligent* management of water distribution systems allows ample space for the introduction of innovations in the name of water-saving and environmental sustainability, obtaining useful advantages in terms of monitoring and optimization of resources.

Technologies based on microelectronic applications make it possible to create multiple systems of specialized micro and nanosensors, capable of monitoring in real-time the main physic-chemical parameters that establish the characteristics of the water.

Among the many types of sensors available or in advanced development we remember in particular:

- selective ion field-effect transistors (ISFET) and enzyme-modified field-effect transistors (ENFET) for the measurement of pH, concentration of nitrates and ions of alkali metals and halides such as Ca and Cl, of surfactants anionic and cationic, pesticides and for monitoring the level of fertilizers in the soil;

- potentiometric sensors with a polymeric membrane with selective ionic planar electrodes used for the determination of the presence of organic ionic pollutants;

- potentiometric sensors based on amorphous chalcogenides for the detection of the presence of heavy metals, including Cu, Pb, Cd, Ag, Cr and Fe, even at very low concentrations of the order of nanomoles;

- semiconductor/graphene/metal (SGM) thin-film devices for the detection of traces of organic contaminants;

- laser interferometry sensors that measure the change in the refractive index of water with respect to the reference value determined by the presence of chemical contaminants, capable of detecting the main chemical contamination agents at the level of one part per million and acting as localized *early warning* systems;

- MEMS (Micro- Electro - Mechanical Systems) acceleration sensors consisting of micrometric mechanical transducers to measure the variations in water flow with an integrated wireless data transmission system with very low consumption;

- arrays of MEMS sensors (Micro- Electro - Mechanical Systems) with enzymatic amplification for the detection of bacterial agents by means of amperometric techniques.

The dimensions of these sensors, all of the order of more than a few millimeters, allow them to be installed in smart meters and, in perspective, directly in the flow limiters of the taps according to advantages (water conservation, energy saving) and disadvantages (initial investments, reflective surfaces and extremely bright colors for infrared sensors) [11] also from the point of view of the loss of transmission signals [12].

For data collection, industrial research has already developed numerous types of computational models [13], which, however, are susceptible to important innovations related to the measurement of consumption with quantitative assessments. Sensors installed in the same meters have to transmit data wirelessly to second-level data collection systems, similar to the cells of the cellular telephone network, in turn, connected directly to the data collection and processing network of the water network operator. Similarly, techniques borrowed from artificial intelligence are mature that can allow data to be collected from smart meters to transmit them (after appropriate processing) directly to the network manager, transparently using the decentralized network made up of the smartphones of users who are nearby. This could avoid the implementation of second-level data collection systems, with significant benefits at the level of complexity and overall cost of the system. Such projects, but on a much smaller scale, have already been developed and implemented both in the Netherlands and in Singapore. A Dutch water distributor, has implemented a "*smart grid*" of sensors for real-time monitoring of water quality at a chemical and bacteriological level, considering, in particular, the presence of pesticides, hormones and pharmaceutical products. The sensors are developed are mounted in flow cells crossed by the distribution water. But research continues with the development of increasingly innovative technological solutions and increasingly providing useful information to artificial intelligence systems [14].

The chemical-bacteriological characteristics are monitored in real-time by measuring the change in the refractive index of the water using a laser beam and comparing it with the seasonal reference values for pure water. All this makes it possible to build an "*early warning*" system capable of dealing with water contamination events in real-time within the macroscopic grid made up of the installed sensors. The system incorporates wireless transmission modules that allow to automatically transmit the measured data to the operator. In Singapore, the local water manager, the Public Utility Board (PUB), has also implemented a similar *smart grid* using the same sensors [14].

Ultimately, these low-cost *smart devices* make it possible [12] to achieve significant water savings through the active involvement of citizens. These devices, suitably miniaturized and customized, allow total integration with the innovative information transmission systems as well as capturing the energy necessary for self-supply.

These low-cost sensors are born with the aim of connecting element between the *Smart Communities* and the *intelligent government of resources*, allowing each citizen to be an active part in the acquisition of distributed information can be used both directly (through specific *apps*) and both with the mediation of interoperable Artificial Intelligence systems that make it possible to return the information with high added value to managers and citizens.

The implementation of low-cost sensors that can be marketed through distribution channels of simple access, allows reaching citizens in a widespread manner, supporting mechanisms for acquiring information useful both to users/citizens and to public decision-makers. In this direction, AI systems capable of reading and interpreting large amounts of data from individual users allows *for precision water management* that can be commensurate with each individual user or even aggregated by the district.

The AI System, acquiring information from individual users on a daily basis, is able to identify any anomalies in real-time, signaling possible malfunctions and providing alarm signals. In this direction, AI can be profitably aimed at implementing efficient systems for controlling and reducing water losses both in distribution networks and in the home, favoring technological convergences between the scientific fields of electronics and hydraulics.

2.3 AI in the monitoring of urban waste

The monitoring of discharges assumes particular importance in the context of water management, both because it is allowed to obtain useful information along the pipeline in order to evaluate the presence of any illegal connections and illegal discharges and both because it allows modulating the management of the plant's purification as a function of the monitored polluting load and other ancillary parameters. The monitoring of the hydraulic efficiency of the drainage system, the

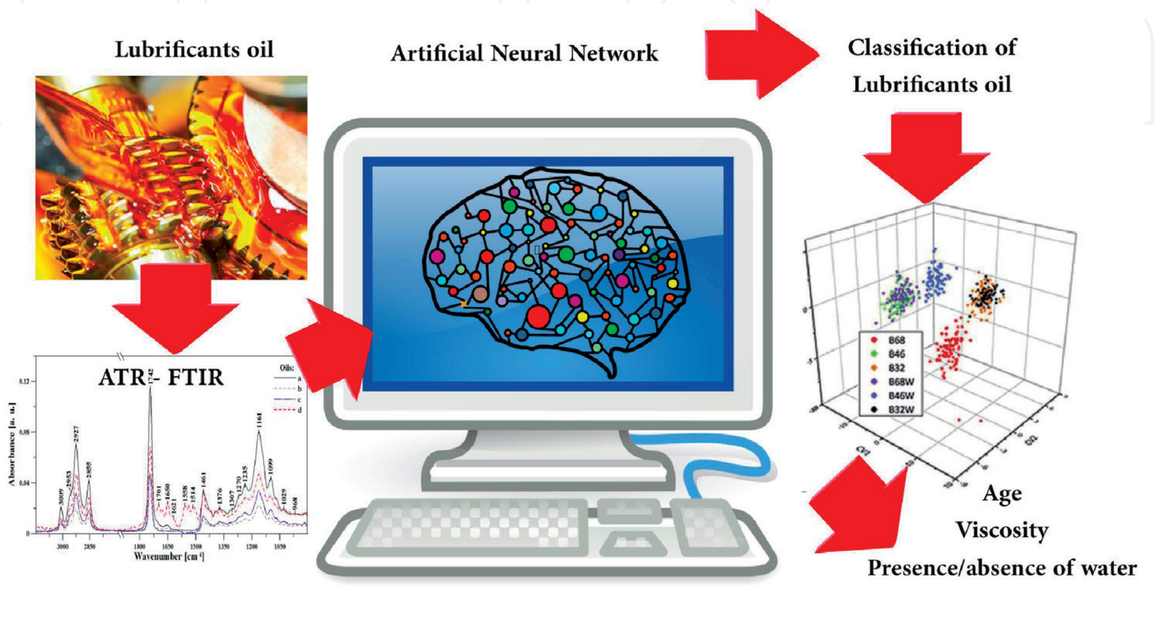

Figure 2.
Artificial intelligence applications for the expeditious characterization of oils in water [15].

chemical and physical parameters and the functionality of wastewater treatment plants is an important prerequisite for ensuring the smooth operation on environmental, health, a city economic and social.

In this field too, the main applications of AI derive from the presence of sensors and the progress of research. Engineers and chemists have made it possible to develop devices capable of evaluating pollutants present in water such as oils, hydrocarbons and/or derivatives from a qualitative and quantitative point of view (**Figure 2**) [15].

In particular, starting from the acquisition of detailed information on the quality and quantity of wastewater that passes through a sewer section, it is possible to obtain useful data referring to events that characterize the functioning of a wastewater collection system (variations in flow rates and load, anomalous discharges, exceptional meteorological events). On the basis of the data collected from chemical/physical monitoring, with the help of AI, it is possible to develop useful knowledge to build a complete picture on the composition of wastewater, also identifying the presence of inter-correlation between the different parameters and users (private, artisanal or industrial) that contribute to the composition of the wastewater. Elements of innovations and which contribute to confer added value to Artificial Intelligence applications mainly relate to:

- optimization processes of qualitative-quantitative monitoring of the wastewater collected in the sewer pipes;

- determination of primary parameters (directly measured by existing sensors) and secondary (recognizable through specific patterns) and the definition of their weight on the analysis of the wastewater collected in the sewer pipes;

- progressive refinement of typical artificial intelligence methodologies and numerical resolution of complex and approximate systems of equations to study the correlation between the data acquired by sensors and the data derived from chemical/physical analytical monitoring;

- definition of a model the applicability on a sliding scale to the continuous monitoring and in real-time of the wastewater in the sewage pipelines collected;

- system realization of the alert and who cannot afford to intervene rapidly and in a targeted manner by providing timely, useful information both on-site and on the modalities and intervention issues.

The monitoring of sewage discharges and the intelligent management of data with the consequent construction of scenarios, also allows the optimization of biological purification processes also for the purpose of subsequent reuse of the effluent of the purification plants. For example in the agricultural sector, within a broader framework of guaranteeing food safety (ensuring quality agricultural production), reducing hydrological stress in the summer (characterized by scarcity of irrigation water of natural origin), reducing pollution of surface and groundwater (reducing the excess of nutritional elements that flow into the surface water network and decreasing the pollution of the groundwater by nitrates).

The possibility that non-authorized industrial and/or artisanal discharges occur in the sewerage network, with high concentrations of chemical substances, represents a criticality that often occurs and that can affect subsequent purification processes but also of circular economy (both with reference to waters than mud).

In relation to the type, to the masses and concentrations of quests and chemicals, in fact, such recovery processes may be more or less efficient or even be inhibited. The identification and subsequent elimination of unauthorized discharges are therefore essential for the success of nutrient recovery processes and can be carried out through the combination of modeling and qualitative-quantitative monitoring of the sewer network. It should be noted that these discharges have the characteristic of being intermittent and irregular over time and can also occur in points other than those of the production activities that generated them. Their identification is therefore complex and is difficult to detect through ordinary sampling and analysis methods. However, the availability of smart sensors interfaced with AI systems can gradually refine their localization and therefore selectively organize and improve the control activity (also by modifying the location of the sensors) until the exact identification (even in flagrant) of the unloading operations.

Further monitoring element concerns the sediments into the sewer, which is a very important problem because of the considerable hydraulic and environmental uncertainties associated with the deposits. The accumulation of sediments in the sewer can, in fact, cause considerable hydraulic problems connected to the reduction of the flow capacity of the canals and, consequently, to the increase in the risk of flooding in urban areas; it can also be the cause of significant environmental and health problems, due for example to the resuspension from the bottom of the channels of solids and associated pollutants with consequent discharge through the overflow devices during the most intense meteoric events. In addition, phenomena of anaerobic transformation may occur, linked to the establishment of septic conditions within the accumulations of solid material, with the development of corrosive phenomena, but also with the formation and release of toxic substances and bad smells. Furthermore, the development of management methods of sewage sediments that guarantee a regular solid flow to the treatment allows to optimize the management of purification processes and, at the same time, to act on some of the criticalities that are typically induced by the provision of rainwater on the functionality of urban purification plants. Even with reference to these critical issues, AI support can be strategic.

3. Results and discussion

3.1 The perspectives of AI in the water sector

The AI accelerate the design of systems procurement, distribution, treatment and reuse of water, using an increasingly widespread use of computer technology and equipment monitoring. Advanced diagnostic tools make water management more customized and intelligent in the water sector. In addition the, in fact, a raised will allow you to overlay information and animations on real-world images with model projections arising from AI applications to help in activities on an daily management and planning and to manage the resource more efficiently. The *Virtual reality* (VR) can make "viewable" projections and modeling predictions on the trend basis and patterns of use of water resources or on climatic scenarios assumed, the *augmented reality* (AR), however, superimposes information generated by a computer to the real world, in quick time. The AI facilitates the integration of these worlds, analyses the incoming data stream, managing large information relating to the scene and superimposes to do it with big data, images or animations relevant, also in 3D. In the near future, we will be able to visualize the system we are imagining to design with the possibility of visualizing the efficiency of use of the different scenarios. Engineers, chemists, biologists, *designers,* etc. they will have new tools to develop collaborative projects, involving expert technicians and young professionals and evaluating the results of design choices in different scenarios of use.

In the coming years, the offer of AI directed to researchers and companies will be able to expand further thanks to programs that are simple to use, to be used in the design, promoting the so-called "fourth industrial revolution": a systemic transformation that can have direct impacts also in the management of the waters.

The AI can determine the output of the information correct exactly at the moment when it is needed, such as when it is necessary to make choices, reducing the chances of error and, increases efficiency and improves the productivity.

Contextualizing to the water sector, the intervention of the AI will be able to optimize the distribution or disposal of water, make the removal of polluted substances more efficient [16], facilitate the reuse of purified wastewater [17], providing real-time images of the areas in which criticalities occur.

In addition, in the last years, artificial intelligence has started to increase the efficiency of the design and synthesis phases of new materials that can also be used in the water sector, making applications faster, easier and more economical, for example, by reducing the use of chemicals or sludge.

In AI, evolutionary machine learning algorithms analyze all relevant experiments; both those that worked and those that failed, effectively preventing further possibilities for error. On the basis of the experiments carried out and the consequent success, the algorithms foresee potentially useful paths. There is no machine learning tool capable of doing all this alone, but AI-based technologies are also spreading in the design of systems and structures for water management such as reservoirs, adductors, lifting systems, distribution, sewer networks, purification plants, etc.

The management of the integrated water cycle is transversal to numerous scientific fields and artificial intelligence is also expanding in all life sciences because it helps to identify *patterns* in complex data sets [18]. The water sector, in particular, allows for huge amounts of data with which to train algorithms, offering significant development opportunities. In fact, artificial intelligence is very successful when there is the possibility of a *training set* of particularly relevant dimensions. The *deep learning* and artificial intelligence tools are amazingly powerful that will provide important answers, especially when interfaced to *smart Technologies* able to acquire data in multiple areas of the integrated water cycle [19].

Even more promising prospects derive from quantum computer applications, which in a few years could greatly exceed the performance of the classical ones, thanks to the significant work on specific hardware and algorithms, exploiting quantum mechanics to perform the calculations and returning greater and further the force on AI.

4. Conclusions

The AI may soon create a new form of superintelligence life. Nevertheless also in the field of water management is useful to plan a close relationship synergy between human and artificial intelligence so that it becomes a useful ally, using a shared ethical approach, transparency of governance of innovation processes and the possibility to citizens to exercise their rights and express their opinions by contributing to the growth of artificial consciousness and collective knowledge.

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