Introduction to Water Safety, Security and Sustainability

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Abstract Based on review of data and information concerning water stress, bio-physico-chemical interactions with human body and nexus of water with food, energy, safety, sustainability and energy, this chapter makes some recommendations for the future. The recommendations are consistent with the United Nations Sustainable Development Goals. A Delphi based survey identified global challenges and a correlation is drawn as how the top twenty priorities correspond to the Sustainable Development Goals. Using risk assessment modalities, the chapter presents a sustainable landscape of water going forward and how to make drinking water systems safe, secure, and sustainable to meet current and future needs. This chapter also serves as an introductory chapter to this edited book on Water Safety, Security and Sustainability with interesting chapters ranging from fundamental concepts, novel materials and their applications, regional cases studies and device modeling to enhance understanding of the subject matter.

Keywords Water · Safety · Security · Sustainability · Sustainable development goals

1 Water—Current Status and Global Challenges

At the first glance, water appears to be one of the most simple, abundant and pure substance, which in its pure state is practically colourless, odourless, and tasteless. However, from scientific standpoint, water possesses quite mysterious and complex physical and chemical characteristics, with many yet to be explored. Furthermore, water is vital for sustaining life on Earth, and in fact, where there is water, there is life and where water is scarce, sustaining life is complex. Water is considered a purifier

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A. Vaseashta and C. Maftei (eds.), *Water Safety, Security and Sustainability*,
Advanced Sciences and Technologies for Security Applications,
https://doi.org/10.1007/978-3-030-76008-3_1

in most faiths and religions, and particular sources or bodies of water are considered to be sacred or at least auspicious. Water is critical to sustaining basic functions of human body such as homeostasis, maintaining equilibrium between exogenous and endogenous water, regulating metabolism and temperature, filtering out toxins, just to name a few. Water (Hydrogen-oxide), mostly, is a chemical compound with two atoms of hydrogen and one atom of oxygen in a molecule (H_2O). The isotope ratio of deuterium and protium (D/H 150 ppm), that once formed water—a "matrix" of life, facilitated the large variety of biological species. Life on Earth became possible, due to exactly this isotope composition. A particular ratio of hydrogen and oxygen isotopes, determines physical and chemical properties of water, viz., boiling and freezing points, viscosity, density, refractive index, density, surface tension, and several other characteristics, including chemical reaction rate constants and biological processes taking place in living matter. These functions are due to some of the unique characteristics of water. However, the huge amount of water on our planet is not just simple H_2O but water complex that has anomalous properties. Among many other interesting characteristics, water has anomalous thermal expansion property which is responsible for protecting our delicate aquatic ecosystem. Water has strong solvent properties since it mixes with and dissolves a wide range of factors and is therefore easily contaminated. Hence, chemicals and industrial wastes entering the environment pollute water, thus impacting food supply-chain and forages and ambient air that impacts living organisms and human health. On the other hand, due to dilution of contaminants, unless quantities are significantly large, the solvent characteristics of water tend to protect nature. Research on eco- and aqua-toxicity and its impact on human health has accomplished significant progress and the subject is still unfolding and needs attention from a holistic viewpoint by scientific community for our survival and path forward. Due to these and several other unique characteristics, water remains an intriguing substance.

1.1 Current Status and Global Challenges

Water covers ~71% of the Earth's surface and the remaining 29% consists of continents and islands. Furthermore, 96.5% of all the Earth's water is contained in the oceans as salt water, while the remaining 3.5% is freshwater in lakes and frozen, inaccessible being in glaciers and the polar ice caps—about 69% of the total freshwater, and is large enough to raise the sea levels to an altitude of approximately 2.7 m, if all of it were to melt and of course, if the surface of the Earth was perfectly smooth. Unfortunately, even with such a vast reserve of water body on Earth, there is a global shortage of clean water for public consumption. According to the WHO, over 2.1 billion people, which is 3 in 10 worldwide, do not have access to on-premise sources of water, approx. 845 million people do not have access to a water sources which are within about 30 min or less round trip and may not necessarily be always free from contamination or accessible when needed, 265 million people have to travel over 30 min just to access water that isn't even clean, and 159 million drink from untreated surface water sources [1–3]. Some additional alarming statistics show that humans play a large role in the disruption of the hydrologic cycle, irrespective of the reasons, may it be self-serving, intentional or accidental. It is further estimated that by 2025, more than half of the world population be living in water stressed areas due to formation of mega-cities and increasing world population, which is expected to rise to 9.7 billion by 2050, causing further stress on water globally [4–7]. One of the reasons of water stress due to lack of sanitation services and it is estimated that 2.3 billion people, that is 1 in 3 persons worldwide, lack access to even basic sanitation services. Those without safe systems run the risk of having their water supply become contaminated with human and animal waste.

According to WHO, 1 in 3 persons consume water from a source that is contaminated with feces, which is a major cause of deadly waterborne diseases such as *Hepatitis A*, *Norovirus*, and *E. Coli*. Hence 1.6 million people die every year from waterborne diseases [8]. Nearly 1 out of 5 deaths under the age of 5 worldwide is due to a water-related disease [9]. In developing countries, as much of 80% of illnesses are linked to poor water and sanitation conditions. Also, 443 million school days are lost each year due to water-related diseases and nearly half of the world's hospital beds are filled with people suffering from a water-related disease [10]. It is further estimated that 80% of diseases are carried by water, resulting in loss of life of about 1 child every 8 sec., i.e. approximating 5–7 million people annually and with $125 billion in economic loss due to workday losses/yr.

There are socio-economic aspects, such as, women end up taking responsibility of managing household and hence in some instances walk several miles to fetch water for family, likely contaminated, for cooking and washing. In schools, girls are more likely to drop out of schools than boys, as disproportionate consequences of lack of sanitation services [11, 12]. It is further estimated that ~75% of world population live in water stressed areas, as world continues to lose irrigated land by as much as 30% by 2025 to 50% by 2050. Interestingly, in Asia, over 75% of population live in areas where 50% of rainfall occurs for 20% times of the year.

1.2 Water-Energy-Food Nexus

Water, food and energy are closely coupled, and water is a critical common component to making food and energy systems work. Due to rapid growth in population and associated economic growth in conjunction with accelerated urbanization, the dynamics of demand for water, food and energy is quite complex and constantly changing. Since, the natural resources are limited and water scarcity affects almost one third of world population, it requires a careful planning for the three, known as the Water-Energy-Food Nexus, also known as Food-Energy-Water (FEW) nexus. To highlight its relevance, it is critical to understand their interdependencies and how they collectively impact food, water and energy security.

In order to highlight some interdependences, it should be noted that agricultural processes in the U.S. account for 80% of freshwater consumption. The Water

Footprint Network (WFN) has calculated how much water it takes—called a water footprint—for a large number of food items [13]. It is noteworthy that meats (such as pork and beef), require the highest amount of water to produce and consume [14]. Over and above this consumption, an average person requires one-gallon water per person, as a daily water requirement for proper hydration, which accounts for over 7 billion gallons of water per day for everyone globally. Just in the US alone, ~140,000 million gallons of water per day is used for irrigation and livestock, out of which ~85% is not returned to the local water source. Furthermore, 25% of all freshwater consumed in the US is associated with discarded food, which is about as much as the volume, as that of Lake Erie, New York. New technological advances, such as on-demand irrigation [15], genetically modifying seed to consume less water [16], and similar scientific breakthroughs can dramatically enhance agriculture water conservation and enhance recovery and reuse of irrigation runoff and livestock wastewater and provide much needed impact on future water consumption.

Water-related energy use accounts for 20% of all electricity use in the state of California and 15% of it goes toward moving water large distances for irrigation. Nearly half of all water withdrawals—both freshwater and ocean water—in the U.S. are used for cooling at thermoelectric power plants [17]. By 2030, generating capacity is expected to increase by over 20%, resulting in an expected increase of freshwater consumption by as much as 49%. As per Nuclear Energy Institute (NEI) estimates, a nuclear power reactor consumes between 1,514 and 2,725 L of water per megawatt-hour [18]. In comparison, the consumption is 1,220–2,270 L per MWh for coal and 700–1,200 L per MWh for gas [19]. As of 2016, the U.S. had 99 operating nuclear reactors and 61 plants across the country, with a capacity-weighted average age of 37 years, with additional four reactors are currently under construction. About 25% of these reactors are in water stressed areas and may face potential shutdown due to shortage of water and concerns over environmental issues. The NEI has recommended that a majority of future nuclear power plants should be built at coastal locations that can utilize ocean saltwater to minimize the probability of drought-related shutdowns and to provide the opportunity for the construction of desalination plants to offset their freshwater consumption. This trend would further improve perception of nuclear power plant water withdrawal and consumption and may render it the most viable thermal electricity generation method from a sustainability viewpoint. Yet another example is in producing corn, which is the main ethanol feedstock in the country. Using potential food supplies for energy generation can put us in direct competition and both will depend on large reserves of water.

1.2.1 Interdependence on Environment, Health, Safety

The impact of water reaches far beyond human consumption, as water supports basic pillars of our life and survival, viz. health, environment and safety. In the context of human health, it is estimated that water contents constitute between 60 and 75% of human body weight. Being a polar molecule, water interacts with other polar molecules, such as itself, leading to the cohesion of water molecules, which helps regulate body temperature. Water's capability to dissolve a variety of other molecules makes it an invaluable life-sustaining substance. On a biological level, water's role as a solvent helps cells transport substances such as oxygen or nutrients to the necessary locations within the body that has a major influence on the ability of drugs to reach their targeted location. Additionally, water buffers cells from the dangerous effects of acids and bases. Water contributes to the formation of membranes surrounding cells and these bilayers selectively allow salts and nutrients to enter and exit the cell and perform filtration functions. Furthermore, water molecules encapsulate DNA in an ordered manner to support its characteristic of double-helix conformation to follow instructions encoded in the DNA or to pass the instructions onto future cells, making human growth, reproduction, and, ultimately, survival viable. Although, we have yet to determine the physiological impacts of these properties, but it is interesting to note that such a simple molecule, is vital and universally critical for organisms with vastly diverse needs.

As per environmental considerations, aquatic ecosystems include aspects, such as biodiversity, habitat for fisheries, recreation and tourism. Unfortunately, many freshwater ecosystems and the services they provide are vulnerable to changes due to land use, environmental pollution, water diversion, overfishing and the introduction of foreign species that harm freshwater resources. Changes in temperature and precipitation patterns significantly influence the movement of water through the atmosphere and landscape. Effects associated with climate change continue to disrupt lakes, rivers and wetlands, such as increased evaporation, decreased summer precipitation, and warmer water temperatures. A combined effect of these influences can destructively impact both water quality and quantity.

Contaminants negatively impact the water quality and have direct environmental consequences. New and emerging contaminants, such as microplastics, household cleaning agents, volatile organic compounds (VOCs), returned pharmaceuticals and engineered nanomaterials have adverse health and environmental consequences which are hereto completely unknown and are subject of ongoing investigations [20]. In fact, U.S. Environmental Protection Agency (US EPA) has now listed over 90 of such contaminants on the Candidate Contaminants List (CCL), which water utilities will be required to detect and mitigate. Unfortunately, most of the water filtration facilities use conventional methods for removing sediments and salinity, followed by activated carbon technology to remove only selected contaminants. Aquifers provide reserve for clean water, however only few acquirers have been surveyed for available water reserves. Moreover, impact of water quality in aquifers due to fracking is yet unknown. Detection of new and emerging contaminants by state-of-the-art scientific methods, contamination remediation and mitigation strategies, and impact of contaminants on human health and environment, is an area that will require much more aggressive approach to increase utilization of currently available resources [21]. In addition, facilities developments of new resources of water is necessary to maintain a delicate balance of nexus of clean water with environment, human health and safety.

1.2.2 Transdisciplinarity in Water Research

> Water is a basic human requirement and a matter of sheer survival, it is a natural raw material and an economic commodity, it is a matter of course and a lifestyle product, it is an instrument of power and a scarce good—too much or too little of it may lead to disaster.
> Anne Dombrowski.

Etymology of transdisciplinarity is the understanding of the present world and goes beyond the compartmentalization among disciplines. According to Nicolescu [22], the prefix trans-indicates that, transdisciplinarity concerns both, between disciplines (transition or transformation) and across different disciplines, and beyond. According to Barbier [23], transdisciplinarity is not accumulation of disciplinary mandates and, in fact, it is an epistemological posture, for which the purpose is the understanding of the present world, and the imperatives being the harmony of knowledge. It also indicates its characteristics of transversality and transcendence, believing that the synergistic encounter among disciplines is an activity, that is both transformative and formative of a new field of research. In a progression from monodisciplinary to transdisciplinary, as defined by Piaget [24], the latter represents an extreme stage of what a discipline can represent, which in the context of water, using the predominant notion of transdisciplinarity, interdisciplinary and participatory research, can be developed further by disciplinary experts, stakeholders and regular citizens.

The term 'transdisciplinarity' was originally coined by Piaget [24], during his lecture: 'The epistemology of interdisciplinary relations at the colloquium L'interdisciplinarité - Problèmes d'enseignement et de recherche'. In his section, he states that "… *we can hope to see a higher stage which would be 'transdisciplinary', which would not be satisfied with achieving interactions or reciprocities between specialized research, but would situate these links within a total system, without stable borders between disciplines*". He wanted to indicate the need to go beyond the interdisciplinary logic towards a more encompassing and integrated vision of knowledge, as transdisciplinarity attempts to respond to a new vision of human and nature, by going beyond the current paradigm in an integrative way. It is not usual to use the term transdisciplinarity in the context of water, however, transdisciplinary research is drawn from a variety of concepts that parallels those found in water research. The motivation for transdisciplinary water research is commonly socially relevant issues where facts are uncertain, values are in dispute, stakes are high, and decisions are urgent. In response to these types of problems, participatory methods have been developed to foster coproduction of knowledge and social learning among different players. Although a detailed discussion of transdisciplinarity and it's societal impact is beyond the scope of this chapter, it is worth noting that using transdisciplinarity, it is possible to cover a broad range of water research from different perspectives for a balanced conceptualization and study of human–water relations in this and other scientific contexts.

1.3 Sustainable Development Goals

Over past couple of decades, water has transitioned from "taken for granted" to "fundamental human right" status. Water also appears among the top ten challenges of the twenty-first century [25]. The United Nations has proposed a series of sustainable development goals for a brighter, self-sustaining future plan for the earth and water is listed in the Sustainable Development Goals (SDG) 6, which focuses on ensuring a clean and stable water supply and effective water sanitation for all people by the year 2030. The goal is a reaction to the fact that many people throughout the world lack these basic services. Some of the poorest countries in the world are affected by drought, resulting in famine and malnutrition. Throughout the world, approx. 2 billion people live in a watershed where water is used faster than the replenishment rate. According to some estimates, if such trends continue, one in four people, or more, might experience water shortages on a regular basis by the year 2050. SDG6 also calls for adequate sanitation and water services available to all people by the year 2030. Almost a billion people, or more, would require the construction of such facilities to provide routine clean water and waste removal facilities. For such missions to succeed, the U.N. has developed a series of targets that include restoring and protecting river ecosystems throughout the world, eliminating sources of water pollution, and increasing international cooperation to bring services throughout the world. In fact, Millennium Development Goals (MDGs), preceded the SDGs and had 8 goals which ranged from reducing extreme poverty rates to half to halting the spread of HIV/AIDS and providing universal primary education, all by the target date of 2015. Water was a part of the development goals, however, was integrated in development goals 6 and 7, to limit waterborne diseases and to ensure environmental sustainability. Increased water scarcity has galvanized unprecedented efforts to meet the needs of the world's poorest and the U.N. is also working with governments, civil organizations and other partners to build on this momentum generated by the MDGs to carry on with an ambitious post-2015 development agenda.

Despite of such ambitious goals, the U.N. SDGs have drawn sharp criticism since their adoption, primarily due to the fact that the goals are not legally binding and with countries left to set up their own frameworks for implementation. Furthermore, for lack of well-defined metrics, the goals may appear aspirational and perhaps even, contradictory. This leaves room for debate among the environmental and societal dimensions, but without really solving the root causes in the system responsible for such problems. In political space, there are discussion about access to water as fundament human rights and democracy. As shown in Fig. 1 and stated above, water forms the nexus of food, energy, safety, security, sustainability and economic well-being as one of the most fundamental necessity of sustaining life on earth, yet the progress on this front has not been at the proportionate scale. It should also be pointed out that in current crisis of COVID-19, the priority is compounded due to need for handwashing, increasing further demand on water for hygiene and also to mitigate contaminants from water supply is equally critical since trace amounts of COVID-19 strain has been detected in water, in several locations.

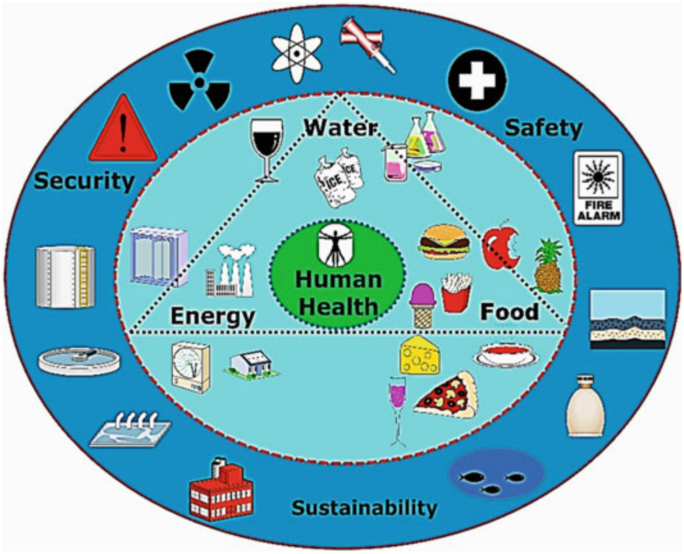

Fig. 1 Water-food-energy nexus and association with safety, Security and Sustainability

While implementing reasonable plans for providing clean water and rebuilding infrastructure are necessary for addressing the world's concerns, it certainly won't be inexpensive for SDG6 to address the global water crisis. Although these goals are comprehensive and well-informed, attaining these goals will be time-consuming, expensive, and may face further political division. It is estimated that in order to reach these goals, it will cost ~$114 billion dollars every year until 2030. Undoubtedly, maintaining clean water sources is an expensive proposition and even for large corporations, whilst motives are mostly internally focused, they already spend millions of dollars a year maintaining clean water sources for their production. However, in an era of perseverance based unmanned Mars exploration, artificial intelligence (AI), virtual and augmented reality (VR/AR), the efforts are incomparable, especially when the progress of development goals must depend on cross sector policies and local actions. Figure 2 provides a pictorial overview of global challenges, based on a Delphi survey, and Table 1 provides SDGs corresponding to the global challenges.

It is imperative that governments need to overcome issues that span individual sector silos and go beyond policies that are aimed at strengthening institutions, mobilizing financing, and delivering sustainable solutions for addressing water scarcity and building resilient water infrastructures for populations. This objective also helps protection of the Earth's biosphere and natural biodiversity. Closing the water access gap and solving intermittent water supply must be a high priority for universal and equitable access to safe drinking water for all. Implementing the principles of sustainable development, social environmental (ecological) responsibility, pro-ecological reforms of implementing eco-innovations in economic processes should become one of the important factors of globalization processes in the twenty-first century. The

Fig. 2 Global challenges with weight % as per Delphi survey

development of the implementation of eco-innovation and the implementation of the sustainable development goals does not necessarily mean reducing the scale of globalization. Hence, international cooperation, exchange of pro-ecological technologies, implementation of global eco-innovation, organizations coordinating and integrating on a global scale for the development of green circular economy, pro-ecological processes of the energy sector transformation, and development of renewable energy sources will only progress towards a more positive aspects of pro-environmental green globalization. If history is our guide, *homo sapiens* could have also been *homo economicus* and *homo ecologicus*.

2 Emerging Trends and Future Pathways for Global Water Safety, Security and Sustainable Development

Access to safe, secure and sustainable drinking water resources is of paramount importance and an existential challenge worldwide, for governments and the scientific community, particularly in a time of climate change and dynamic urban and economic development, globally. The issue is shared among both developed and developing nations, since all nations require adequate levels of good quality water

Table 1 Top global challenges and corresponding actions of SDGs

Global Challenges	Corresponding Sustainable Development Goals	SDGs
Climate change	1, 2, 6, 7, 8, 9, 11, 12, 13, 14	1
Pollution	7, 9, 11, 12, 13	2
Violence	7, 8, 10, 12, 16	3
Security	7, 8, 10, 12, 16	4
Education	4, 5, 8, 10	5
Unemployment	1, 2, 4, 8, 9	6
Corruption	8, 9, 10, 16, 17	7
Malnourishment and Hunger	1, 2, 3, 8, 10	8
Substance Abuse	1, 2, 3, 4	9
Terrorism	1, 2, 4, 16	10
Clean water	6, 12, 14, 15	11
Population	2, 7, 11, 12, 15	12
Democracy	16, 17	13
Equality	1, 4, 8, 17	14
Global Health	2, 3, 6, 15	15
Disease	2, 3, 6, 15	16
Energy	7, 9, 12	17
War	1, 4, 8, 10	
Misinformation	8, 9, 10	
IT Dominance	8, 9, 10	
	UN SDGs: https://www.un.org/sustainabledevelopment/	

at a reasonable cost. A fundamental question is as to how to make drinking water systems safe, secure, and sustainable to meet current and future needs using emerging trends in contamination monitoring and remediation. Since the issue of water supply safety, security, and sustainability is highly diverse, the chapter presents the myriad of water supply challenges from a holistic viewpoint.

Water safety spans a wide spectrum of safe usage of water to meet the soaring demand at present and in the future. Water safety also refers to the procedures, precautions and policies associated with safety in, on, and around bodies of water, however, for the present discussion, the focus is on human health, agriculture and industries that require high volumes of safe sources of water for their daily operations, such as, environmental remediation, hydrocarbon processing, catalysis and chemical processing, food and beverage, mining and hydrometallurgy, pharmaceuticals, power generation and semi-conductors, just to name a few. The high volume of fresh or processed water required for manufacturing processes can make businesses unsustainable in areas with limited water availability. At the same time, these industries also have stringent requirements to control wastewater discharge in the environment. As industries grow incorporating recently developed more advanced technologies, clean water will become ever more critical to advance these operations and increasing the demand for the limited water resources. Table 2 provides several contaminants that are commonly present in water and need to be isolated from water supply lines for human safety. From policy standpoint, it is critical to research and develop effective water treatment and better distribution network management systems, as the pillars of sustainable water supplies. Creating better disinfection and purification technologies could significantly reduce many human health issues that much of the world currently faces and, equally importantly, certain economically disadvantaged regions of the world.

From a security standpoint, drinking water distribution systems are largely exposed and vulnerable to intentional and/or inadvertent contamination. Such contaminants can be classical and chemical, including but not limited to non-traditional agents (NTAs), toxic industrial chemicals (TICs), and/or toxic industrial materials (TIMs). It is, thus, extremely important to monitor, control, and mitigate contaminants using state-of-the-art materials and technologies to maintain "water quality"—typically defined as physical, chemical, and biological characteristics of water in relationship to a set of standards [26]. Water quality is a rather complex subject and is intrinsically tied to the regional ecology, application, and point-of-use. Detection methodologies based on nanomaterials and other advanced strategies are capable of ppb/ppt and atto-molecule resolution with high selectivity, sensitivity and specificity [27]. For mixed compositions, such methodologies are particularly important in identifying constituent chemical composition. Additional complication arises due to presence of unused pharmaceuticals present in water supply since most filtration systems are not designed to filter such contaminants. Due to large number of contaminants that greatly differ in chemical structure and chromatographic/spectroscopic behavior, it is extremely difficult, if not impossible, to apply a common method to interrogate in real-time.

Securing safe and sustainable drinking water supplies is a prominent challenge, especially when the water supply lines are mostly above ground. In fact, transport of supply of water has been a great challenge since the ancient Roman times, as water was transported by pack-animals to a great distance. Disruption of water supply can serve as a significant and strategic deterrent. In recent military rotations, water supply trucks were provided extra security protection. Also, extra protection was also provided for aquifers, especially for the ones that are located at or near transboundary regions. It was reported by Russian Times that aquifer near Libya was contaminated causing shortage of clean water and drinking water was transported in Libya from

Table 2 List of contaminants

Categories	Sources	MRL/MCL	Health effect
Pesticides			
Atrazine	Runoff from herbicides used on crops	3 μg/L	Cardiovascular diseases; reproductive problems
Carbofuran	Insecticide widely used on field crops	40 μg/L	Blood, nervous, and reproductive system diseases
Methoxychlor	Runoff/leaching from insecticide use	40 μg/L	Reproductive difficulties
Glyphosate	Runoff from herbicide use	700 μg/L	Kidney problems, reproductive difficulties, increased risk of cancer
2,4-Dichlorophenoxyacetic acid	Runoff from herbicide used on crops	70 μg/L	Kidney, liver and adrenal gland pathologies
Pharmaceuticals			
Antibiotics (metronidazole, tinidazole, etc.)	semisynthetic modifications of various natural compounds	Physiological conditions vary	Long term impairment of immunity, loss of probiotics
Steroids	Semisynthetic modifications of various natural compounds	Physiological conditions vary	Weaken the body's immune system, risk of insomnia, infertility, excess fluid retention
Testosterone	Semisynthetic modifications of various natural compounds	Physiological conditions vary	Cancer, especially prostate cancer, aggressive/criminal behavior
Acetaminophen	Semisynthetic modifications of various natural compounds	Physiological conditions vary	Harmful to liver (base on dose level)
Ibuprofen	Semisynthetic modifications of various natural compounds	Physiological conditions vary	Nausea, heartburn, and stomach pain including heart attack
Microorganisms			
Cryptosporidium	Human and animal fecal waste	–	Gastrointestinal illness (e.g., diarrhea, vomiting, cra mps)
Legionella	Found naturally in water; multiplies in heating systems	–	Legionnaire's Disease, a type of pneumonia

(continued)

Table 2 (continued)

Categories	Sources	MRL/MCL	Health effect
Enteric viruses	Human and animal fecal waste	–	Gastrointestinal illness (e.g., diarrhea, vomiting, cra mps)
Total coliform (including fecal coliform and *E. coli*)	Indicator if other potentially harmful bacteria may be present	–	Fecal coliforms and *E. coli* come from human and animal fecal waste
Metals, organics, VOCs			
Arsenic	Erosion of natural deposits; runoff from orchards,	0.010 mg/L	Skin damage or problems with circulatory systems, and may increase risk of cancer
Styrene	Discharge from rubber and plastic factories; leaching from landfills	0.1 mg/L	Liver, kidney, or circulatory system problems
Trichloroethylene (1,1,1; 1,1,2)	Chemical factories/degreasing agents	0.2 and 0.005 mg/L	Liver, nervous system, circulatory problems, kidneys and immune systems
Vinyl Chloride	Leaching from PVC pipes; discharge from plastic factories	0.002 mg/L	Increased risk of cancer
Xylenes	Discharge from petroleum factories; discharge from chemical factories	10 mg/L	Nervous system damage
Uranium	Erosion of natural deposits	30 µg/L	Increased risk of cancer, kidney toxicity
Emerging contaminants			
Micro/nano plastics	Discarding plastics bottles, bags and several products that use plastic microbeads		Lungs, dermal, genetic, carcinogen
COVID-19 virus	Untreated discharge from COVID-19 patients		Effects still unfolding but flu is a companied by serious cardiovascular and respiratory consequences
Petroleum products, VOCs, long chain hydrocarbons	Discarded oil, oil wells	–	Carcinogen, irritant

(continued)

Table 2 (continued)

Categories	Sources	MRL/MCL	Health effect
Nanomaterials	Broad classification of ultrafine particulate matter used in more than 1,800 consumer products and biomedical applications		Translocate into the circulatory system through the lungs, accumulation of compounds in the liver, spleen, kidney, and brain
Trichloro propane (TCP)	Chemical intermediate, solvent, and cleaning product		Carcinogen
Perfluoro-octane sulfonate (PFOS) and Perfluorooctanoic	Used in additives and coatings, non-stick cookware, waterproof clothing, cardboard		Carcinogen, may cause high cholesterol, increased liver enzymes, and adverse
Polybrominated diphenyl ethers (PBDEs)	Flame retardant and used in plastics, furniture, and other household products		Endocrine disruptor as well as caecinogenic, also, may cause neural, liver, pancreatic, and thyroid toxicity
Dioxane	Stabilizer of chlorinated solvents, manufacturing of PET, manufacturing by-product		Disruption of lung, liver, kidney, spleen, colon, and muscle tissue, may be toxic to developing fetuses and is a potential carcinogen
Hexa hydro-trinitro-triazane (RDX)	Explosive	–	Kidney and liver damage, possible carcinoma, insomnia, nausea, and tremor

Lampedusa, during the second Libyan civil war that was fought between different armed groups.

Yet another security challenge, is Internet of Things (IoT) operation of water plants for high-level process supervisory management via graphical user interfaces (GUI). As recent as January 2021, water services in the state of Florida were hacked and chemicals were remotely discharged in disproportionate amounts. Similar incidents were previously reported in Michigan by breaching Supervisory control and data acquisition (SCADA) control system, an architecture comprising of computers, programmable logic controllers (PLC) and other peripheral devices networked for data communications. Disabling and/or tampering with urban water distribution systems can impact millions of customers, while intermixing with waste water systems can render them as tools for weaponization by a variety of industrial and commercial contaminants.

Funded through a NATO Science for Peace activity, a GPS/GIS based Contamination Identification and Level Monitoring Electronic Display Systems (CILM-EDS) prototype was developed [27] to spatially monitor contaminants and water levels using advanced (nano) technology based platforms for inadvertent and intentional contaminants. The prototype is also capable of sending signals to provide situational awareness for water distribution system using a smart and connected communities project and advance warning for sudden rising water levels for areas prone to flash floods and Tsunamis. The U.S. EPA initiated a WaterSentinel program for the design, development and deployment of an integrated water contamination monitoring incorporating real time system wide water quality monitoring contaminant sampling and analysis.

Obviously, the basic need for clean drinking water and water resources is a national security and policy concern. There are numerous national security threats emanating from the growing crisis of global freshwater scarcity. Many of the earth's freshwater ecosystems are being critically depleted and used unsustainably to support growing residential and industrial demands; thereby increasing ecological destabilization, and creating a greater regional divide thus directly impacting current political, economic and social landscapes. Finally, in striking contrast to water scarcity are threats to clean water systems posed by high water, as experienced in some flesh flood prone regions and tsunamis in the Asian-Pacific Rim, South-East Asia, and many regions in Europe and even in America when contaminated water infiltrates clean water supplies.

3 Proposed Solutions, Policy Implications and Legal Framework

It is evident that, the society has ignored the problem of use, reuse and recycle water for a long period of time and at the time of realization, it seems that it is already too late. Due to safety, security and sustainability aspects, the scientists and policymakers must work together to develop a paradigm shift plan with built in resiliency, redundancy and incremental improvement. The challenge to overcome the cost of late realization requires a long term vision of critical problems that need to be addressed in plans that cover the next 1, 5, 10 and 25 years.

Conventional methods employed to sense/detect such contaminants use commercial-off the shelf (COTS) systems and broad-spectrum analytical instruments with interpretive algorithms to detect and characterize toxic contaminants. Due to a large number of contaminants that greatly differ in chemical structure and chromatographic/spectroscopic behavior, it is extremely difficult, if not impossible, to apply a common method to interrogate in real-time. Use of nanomaterials based sensors/detectors have been demonstrated to be able to interrogate contaminants in small quantities in mixed environments. Nanomaterials based sensors, in conjunction with plasmonics have demonstrated remote detection capability—which is desirable for biological samples, especially those exhibiting toxic characteristics. It has already been demonstrated that output from these sensors/detectors can remotely be displayed using GIS/GPS based technology.

In addition, a comprehensive effort aimed at improving water management systems with aim towards “capacity building” as a holistic approach, which requires an assessment of current water management systems and creating a managerial and engineering environment that will support improvement in water management systems. As such, we must first analyze the overall environment and working culture of an organization tasked with Water Quality Management and propose systematic measures aimed at making the organization more effective, resilient, responsive and efficient. Other pathways being the source water protection, such as in aquifers. The plans should include sustainable withdrawal capacity. We should identify new sources of water, such as atmospheric water sources, reuse of wastewater by smart plumbing at each and every site, leak reduction (which accounts for almost 30% wastage of water) through smart metering, potable water supplies through reuse of existing wastewater and development of brackish and saline sources and use of cisterns for agriculture. Conservation via improved efficiencies and reduction in waste can significantly reduce overall cost and water savings in conjunction with minimizing the withdrawals for direct draw applications. Furthermore, efforts of scalability, ramp-up and advancing technologies from laboratory to production should be encouraged through academia-industry partnerships. Far too often, the innovations do not advance to protype due to patent considerations. By rapid attribution mechanism, one should facilitate the testing and advancing of new materials and technologies development to marketplace.

Lastly, the concept of water as a human right has been introduced in various contexts. Water has not always explicitly been referred to the worldwide bill of Human Rights, global human rights regulation composed via the popular assertion of Human Rights (1948), the International Covenant on Civil and Political Rights (1966), and the worldwide Covenant on financial, Social, and Cultural Rights (1966). However, many activists have argued its validity based on the UN SDG6, which is to “ensure access to water and sanitation for all,”. Water, while not explicitly recognized as an independent human right in international treaties, international human rights law contains specific requirements regarding individuals’ right to access safe drinking water [28]. These requirements call on governments to ensure that citizens have access to adequate safe drinking water for personal and domestic use, drinking water, personal hygiene, laundry, cooking, and water necessary for personal and home hygiene. These requirements also call on governments to gradually ensure access to adequate sanitation facilities, a fundamental element of privacy and human dignity, and maintain the quality of drinking water supplies and resources [29].

4 Conclusions and Future Pathways

A vision of Water Sector's Security is a safe, secure, resilient and sustainable drinking water and wastewater infrastructure that provides clean and safe water as an integral part of life. This vision assures public safety and the economic vitality of and public confidence through a layered defense of effective preparedness and security practices in the sector. The vision through research and communication plan will enable better understanding of water borne contaminants, their remediation strategies, improved information-sharing and exchange mechanisms, and a platform to inform certain owners and operators of critical Water Sector infrastructure to be able to prevent, detect, respond to, and recover from attacks, such as intentional acts, natural disasters, and other hazards. Also, the broad problem of water can be solved through technologies, policies and improved laws.

The following directives are aimed at research, development and engineering processes, and also to support policymakers with water quality management:

- Conduct an analysis of state-of-the art water management systems to identify technologies that provide the most efficient and economical means to manage water systems.
- Adopt new engineering and managerial processes for water management systems through process reengineering.
- Conduct an analysis of the current water management system to identify shortcomings and performance standards.
- Use state-of-the-art contamination monitoring/detection systems.
- Design smart water management systems.
- Mandatory installation of smart water leak detection systems with appliances.
- Invest in atmospheric water harvesting systems.
- Invest in state of the art membranes capable of desalination, removing pharmaceuticals and metals from water.
- Reduction on use of single use plastics bottles. Alternatives materials from single use plastic bottles to multi-use containers.
- Monitor new and emerging contaminants and fund research to study impact of such contaminants on human health.
- Enhance cyber security to protect SCADA system.
- Define a Universal Water Quality standard.
- Conduct a resource analysis to determine what resources are needed to perform a certain job effectively.
- Develop a plan to address deficiencies in physical infrastructure, equipment, and machinery.
- Develop a short and long-term (1, 5, 10, 25 years) strategic plan for addressing human resources, infrastructure, equipment, and machinery needed for value efficient water management systems.
- Introduce a performance monitoring system which collects information against predetermined targets and performance standards for the water management system.

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