

Introduction

1.1 Opening Remarks

Water is synonymous with life. This has been the case since the pre-historic time to modern era (Tsiaras *et al.*, 2019). While the indispensability of water for sustaining life is well known, water being the first creation and as such the ubiquitous phase on earth as well as the cosmos is little known in the modern era. This is a typical problem related to New Science, which disconnected modern knowledge from the previous annals of science. In the pre-Socratic cosmogony of Thales, considered to be the first 'element'.^{*} This was more than a poetic gesture, it was rather an attempt to answer the question: "What is the common stuff from which everything is composed?" This notion of water being the first creation permeated through Christianity. In Genesis 1:1-2, it is stated, "And the Spirit of God was hovering over the face of the waters". Quran (11:7) points to the existence of water before any other creation, the exact word being: "and His (creator's) throne/dominion extends on the water - that He might manifest to you, which of you is best in action..." (Qur'an 11:7). This throne is similar to the notion of 'lotus' in ancient India (Tresdder, 1997). This, in addition to indispensability of water for sustainability of humans (67:30; 24:54) as well as overall origin of every life on earth (24:45). Islam (2014) presented the scientific justification of water as both the first matter of cosmos as well as the first material of life. As such, Islam (2014) characterized water as the ubiquitous phase. It follows that the purity of water is pivotal to global sustainability. For human health, water is the vehicle for carrying nutrients to all cells in our body and oxygen to our brain. Water allows the body to absorb and assimilate minerals, vitamins, amino acids, glucose and other substances. Water flushes out toxins and waste. Water helps to regulate body temperature and maintains the overall metabolism for sustaining life.

^{*} This term does not relate to modern scientific term, which emerges from atomic theory. Rather, it refers to a material in its natural state.

2 SUSTAINABLE WATER PURIFICATION

As such, humanity, civilization, the environment, and the cosmos are all connected seamlessly (depicted in Picture 1.1).

Modern investigation in material science has been marred with the first premise, which is inherent to the Big Bang theory. The fundamental



Picture 1.1 Humanity, civilization, environment and the cosmos are all connected through ubiquitous water and 'vital force' (Photo: Rola Icton, published with permission).

premise is: creation is made in two stages, namely 1) fundamental element is created out of nothing; 2) all other elements evolve from fundamental element. This theory considers hydrogen atoms as the first material in existence, thus creating paradoxical depiction of mass and matter. In the past decade, observations from space and the ground have found water to be the most abundant molecular species, after hydrogen, in the atmospheres of hot, gaseous extrasolar planets (Tsiaras, 2019). However, as early as 2011, evidence surfaced that the existence of hydrogen molecules is not factual and comes from the assumption that hydrogen is the first ‘element’ to come to existence. Khan and Islam (2016) point to the fact that scientists actually look for water molecules even in outer galaxy to consolidate the claim that the assumption that hydrogen, which is not the most abundant molecule in universe.

With the premise that water is the first ‘element’ in existence, the existence of ‘energy’ and its natural state can be properly retooled. Islam (2014) introduced the concept of characteristic time to assure sustainability. It involves identifying natural state of a matter, which is dictated by the time function. Table 1.1 shows fundamental properties of tangible (e.g. matter) and intangible (e.g. energy). The tangible-intangible duo can be regarded as a yin-yang. In ancient Chinese, as well as ancient Indian culture, water and fire are considered to be the original yin yang. The term ‘fire’ represents energy (Qi in Chinese, 氣 often translated as ‘vital force’, “material energy”, “life force” or “energy flow” in figurative sense and ‘air’ in literal sense).

Table 1.1 shows the yin yang nature of energy and matter. The yin yang shows contrast as well as interdependence. For instance, no matter is

Table 1.1 The tangible and intangible nature of yin and yang (From Islam, 2014).

Yin (tangible), water	Yang (intangible), ‘energy’ (Qi)
Produces form	Produces energy
Grows	Generates
Substantial	Non-Substantial
Matter	Energy
Contraction	Expansion
Descending	Ascending
Below	Above
Water	Fire

produced without energy and no energy is produced without matter. Water is needed for plant, which is then needed for fire. This logic also shows nothing is natural (hence sustainable) unless it is part of the positive negative cycle. For instance, fire without water is not real. That would explain why diamond cannot be set on fire even though it is made out of carbon. Similarly, the presence of mass would indicate the presence of energy. This would make the existence of zero energy and infinite mass an absurd concept, even though new cosmic physicists routinely tout that notion (Krauss, 2012).

Figure 1.1 depicts a water-fire yin yang. It shows how yin and yang encircle each other alternating as a continuous function of time. As time progresses, yin becomes yang and vice versa. This progression confirms the existence of characteristic time function for every object at every scale. Within the limitations of natural traits that is finite, the following picture depicts the role of two counteracting entities being held in harmony by the ‘mother’, the one that dictates the universal order (Islam, 2014).

This most important takeaway of this discussion is that water and energy form the foundational yin yang pattern and sustainability is making sure they are at their natural state. As we will see in Chapter 2, this gives a new and scientifically accurate starting point for discussion of sustainability. With this definition, all other descriptions in physics and chemistry have to be retooled. For instance, even the term ‘gravity’ bars an implicit assumption that the force between two objects is uniquely related to their

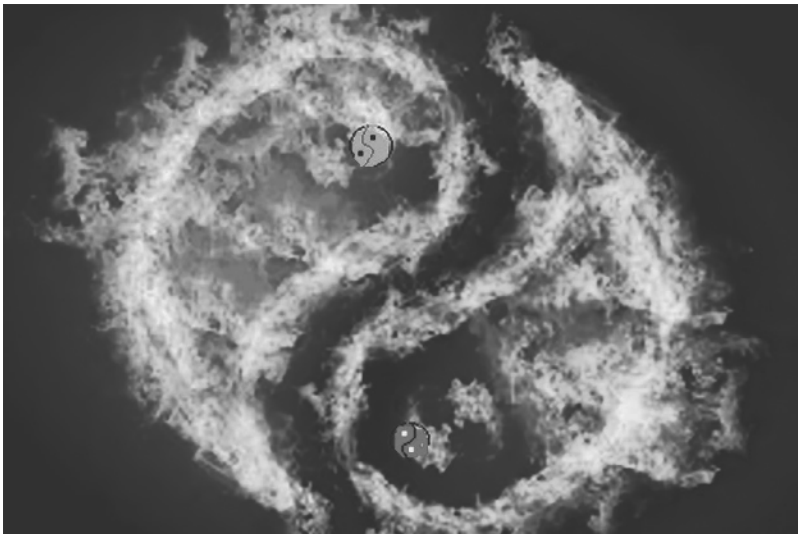


Figure 1.1 Water-fire yin yang, showing how without one the other is meaningless.

masses, independent of other factors, such as history, or current state of motion. Scientifically, if two objects are in natural state, the force between them would be different from that prevailing if at least one of them is not.

1.2 Climate-Water-Food Nexus

Climate-Water-Food nexus epitomizes current civilization that depends on energy as the driver. As such it is one of the most popular themes used in both sustainability and climate change research (Hellegers *et al.*, 2008; Bazilian *et al.*, 2011). Table 1.2 shows key elements of the water component of the nexus.

The primary energy source of the Earth is the sun. The sunlight is essential to photosynthesis that requires CO₂ and water as well as the presence of a plant biomass. As such, CO₂ is integral to the Energy-Water-Food nexus (Figure 1.2). In this process, any pollutant added to the process that produces CO₂ can alter the quality of food, which then can alter the entire water cycle, thus forming a ‘spiraling down’ mode in the overall ecosystem. In an agricultural process, any artificial chemical added to the water or soil system will affect the quality of food. Equally impactful is the overall composition of the atmosphere and the temperature, because each of the oxidation reactions is a sensitive function of temperature and composition. Even

Table 1.2 Synergies between water and sustainable growth (modified from UN Water, 2013).

Characteristics of sustainable growth	Characteristics of water security
Effective use of natural resources	Meet social and economic development need of water
Valuing ecosystem	Supply of adequate water for maintaining ecosystems
Inter-generational economic policies	Sustainable water availability for future generations
Protection of vital assets from climate-related disasters	Balance the intrinsic value of water with its uses for human survival and well being
Reduce waste of resources	Harness the productive power of water, maintain water quality, and avoid pollution and degradation.

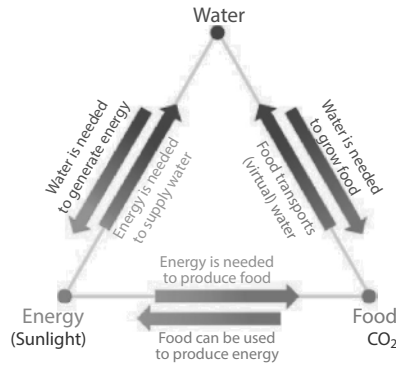


Figure 1.2 The Water-Food-Energy Nexus (Modified from Lal, 2013).

a small amount of toxins can alter the natural pathway irreversibly through catalytic actions. In connection with environmental resource management, the term nexus was introduced for the first time during the 1980s, notably in a project by the UN University (Food-Energy Nexus programme, as pointed out by Sachs and Silk, 1990). However, the Nexus Approach only gained prominence in international academia and policy circles in the lead-up to the Bonn Conference (2011) on the “Water, Energy and Food Security Nexus”. The well-known definition of ‘nexus’ was reinforced in this conference to delineate “management and governance across sectors and scales”, reducing trade-offs, and building synergies, overall promoting sustainability and a transition to green economy (Hoff, 2011).

When looking at the before mentioned nexus of water, energy, and food security, the question arises as to which environmental resources have to be managed in an integrated way to achieve the sought integrated and sustainable management. Considering the fact that nature is continuous, meaning there is no barrier to either mass or energy transport, not a single particle of mass (thus energy) can be isolated, any point is inflicted with toxicity will have an impact on the rest of the ecosystem. In this regard, it is important to recognize the science used to study this process. Scientists cannot determine the cause of global warming with the science that assumes all molecules are identical, thereby making it impossible to distinguish between organic CO_2 and industrial CO_2 . In the mean time, the environmental resources to be studied are: water, soil, and atmosphere. In modern society, waste, instead of atmosphere is made into an integral part of this nexus (Figure 1.2). It is because the modern age is synonymous with wasting habits. Such wasting habits are systemic and integral part of technology development. Such a tendency comes from the fact that in today’s

society everything is denatured and the artificial version is constructed and promoted as the ideal version. In Chemical Engineering, an entire subject is dedicated to denaturing materials and then sold in medicine/medical industry - which itself is 100% artificial and harmful to humans. Such a process is inherently unsustainable (Khan and Islam, 2007).

Figure 1.3 depicts how any of the waste forms its own cycle and never assimilates with the ecosystem. As an example, if one considers CO_2 that is generated from industrial activities or exhausts of combustion engines, any such CO_2 would end up being rejected by the ecosystem. In contrast, any CO_2 produced through organic activities (such as breathing of plants and animals) will be readily absorbed by the plants that will transform it into carbohydrates. Thus, from the same activity (oxidation or breathing), either waste (CO_2 from exhaust) or a beneficial product (CO_2 from breathing) is generated. In this process, waste accumulates within a system separate from the ecosystem and grow into a cancer-like entity within the overall global system. The remedy to this accumulation of waste and its inherent unsustainability is in making the use of fuel and mass wholly zero-waste, which can happen only when any product that is the outcome of an engineering process is entirely usable by some other process, which in turn would result in products that are suitable as inputs to the process. A perfect system is 100% recyclable and, therefore, zero waste. Such a process remains zero waste as long as each component of the overall process also operates at zero waste.

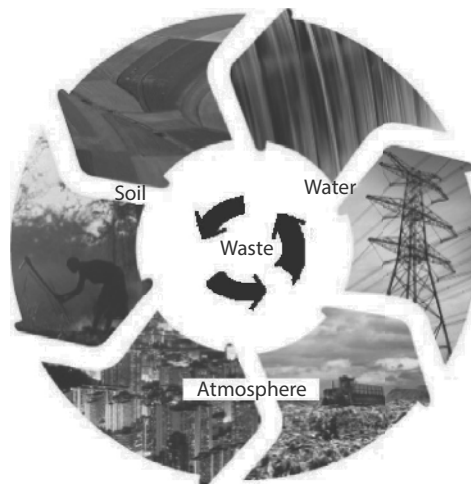


Figure 1.3 The water-soil-atmosphere nexus.

The production of food relies on water, soil, and atmosphere. There is no waste generated if all nutrients and all pesticides are wholly organic. This not be the case for last 100 years or so (ever since the plastic culture has dominated current civilization), significant amount of waste is generated. This waste thus ends up creating further pollution of soil, water, and atmosphere and propagate through the food chain creating long-term insult to the environment. Equally important is the role of energy sources.

1.3 Background

Water is a transparent, tasteless, odorless, and nearly colorless chemical substance, which is the main constituent of Earth's hydrosphere, and the fluids of most living organisms. It is vital for all known forms of life, even though it provides no calorie organic nutrients. Its chemical formula is H_2O , meaning that each of its molecules contains one oxygen and two hydrogen atoms, connected by covalent bonds. Water is the name of the liquid state of H_2O at standard ambient temperature and pressure. It forms precipitation in the form of rain and aerosols in the form of fog. Clouds are formed from suspended droplets of water and ice, its solid state. When finely divided, crystalline ice may precipitate in the form of snow. The gaseous state of water is steam or water vapor. Water moves continually through the water cycle of evaporation, transpiration (evapotranspiration), condensation, precipitation, and runoff, usually reaching the sea. The distribution of water on the Earth's surface is extremely uneven. Only 3% of water on the surface is fresh; the remaining 97% resides in the ocean. Of freshwater, 69% resides in glaciers, 30% underground, and less than 1% is located in lakes, rivers, and swamps. Looked at another way, only one percent of the water on the Earth's surface is usable by humans, and 99% of the usable quantity is situated underground.

Due to different types of natural and anthropogenic activities surface and ground water become contaminated. Water pollution by toxic pollutions (inorganic and organic) has become a subject of interest especially since the establishment of the EPA (Environmental Protection Agency) in 1970. The problem of water quality degradation of both surface and sub-surface streams has been evident for a long time. Achieving an acceptable quality of surface water focuses on reducing emissions of known pollutants to within safe industrial and drinking standards. In developing nations, many of today's industrial projects are environmentally hostile.

The quality of drinking water is an important factor in determining human welfare. It has been noted that polluted drinking water is the cause

for waterborne diseases which wiped out the entire populations of cities. The major sources of water pollution are domestic waste from urban and rural areas, and industrial wastes which are discharged into natural water bodies. The rivers and lakes near urban centres emit disgusting odours and fish are being killed in millions along the sea coasts.

Extensive studies of the subject of water pollution by toxic pollutions (inorganic and organic) have been developed during the recent years. In today's world, the study and research of pollutants should not be confined to their more removal or relocation. Economic feasibility, one of the key factors in any engineering project, must be addressed. Many of today's engineering works are environmental friendly but that criterion is no longer sufficient. Time has come to make environmental works appealing rather than friendly. Islam and Wellington (2001) gave much stress on the development of environmentally appealing research projects mentioning introduction of novel methods in the areas of engineering research.

1.4 Insufficiency in Water Purification Processes

Vast majority of water contamination is due to industrial waste, which contain synthetic (unnatural) chemicals, which emerge from the industrial applications. The contaminated water, which contain synthetic chemical, biological, organic waste and other contaminants, suspended solids, and gases are treated in order to remove the undesired components in the water stream. It is routine that water is first disinfected in order to remove bacteria and organic organisms, algae, etc. Although most water is purified for human consumption, the purification agents are invariably synthetic chemicals, which are toxic to the environment and to humans. In addition, water is subject to chlorination, fluoridisation, and others with the pretext of maintaining levels of chemicals under certain pre-determined values. Even for commercial applications, synthetic chemicals are added in order to make the water usable. For medical and pharmaceutical purposes, the purity of water is increased by exposing water to rigorous purification processes, which invariably use one or more of the following techniques:

- filtration
- sedimentation
- distillation
- chemical processes
- electromagnetic and other form of irradiation (such as ultra-violet light)

Although the above processes reduce the concentration of suspended particles, parasites, bacteria, algae, viruses, and fungi as well as reduce the concentration of a range of dissolved and particulate matters, the water stream picks up parts of the chemicals used to purify and as long as the concentration is smaller than the regulatory body's requirement there remains no way to determine their long-term impact. Jaspal and Malvy (2020) reviewed major water purification composites. The use of such composites is considered to be the latest technology in water purification. The use of different types of composites ranges from nanocomposites, activated charcoal composites, polymer composites, oxide-based composites, hybrid composites, and biosorbent composites, etc. Water purification takes place via adsorption process. These composites have been explored for treating or elimination of various hazardous substances like heavy metal species, different classes of colored contaminants (dyes), several organic and inorganic pollutants from wastewater. The most significant advantage of the use of composites is the combination of properties of two materials into one for specific applications. In the current scenario, composites have gained popularity in various fields such as constructional, aeronautical, vehicular, biomedical, industrial etc. (Mahajan and Aher, 2012). The use of the said materials in wastewater treatment is becoming a research focus

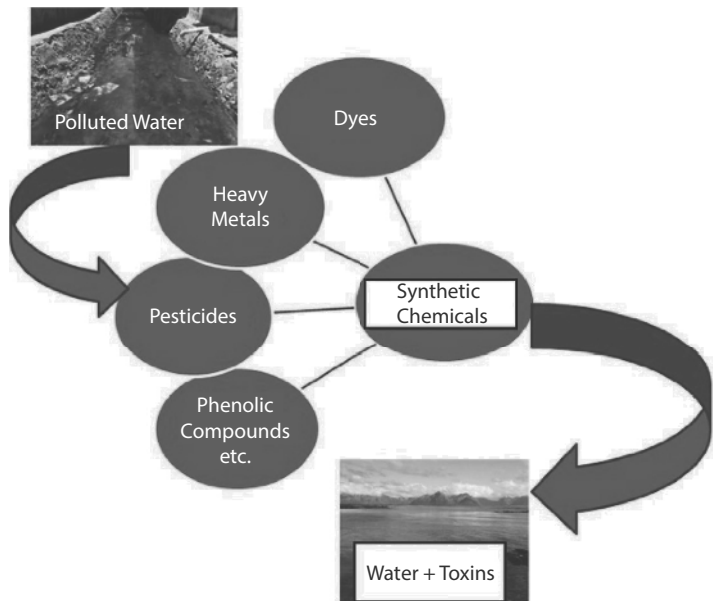


Figure 1.4 Water purification process.

for many. The properties offered by composites include specific strength, processability, and design flexibility. While these composites successfully eliminated Zn^{2+} , Ni^{2+} , Cu^{2+} , Pb^{2+} , Hg, etc., each ion is replaced with another component from the adsorbing chemicals that are used in the process. Each of these composites would be considered unsustainable if environmental sustainability were considered (Khan and Islam, 2016). Figure 1.4 shows how chemicals are removed from the contaminated water only to be replaced with toxins, which arise from the purification process.

The above purification process does not include the impact of using unnatural radiation (e.g. ultraviolet). Although conventional analysis makes it impossible to identify the impact, let alone quantify it, Islam and Khan (2019) Islam *et al.* (2016) have shown that the effluent water would carry the signature of each unnatural process (energy or mass) used during the purification cycle.

1.5 Introduction to Zero Waste Engineering

Natural additives have been used for the longest time, dating back to the regime of the Pharaohs of Egypt and the Hans of China (Gove, 1965). However, the renaissance in Europe has given rise to industrial revolution that became the pivotal point for the emergence of numerous artificial chemicals. Today, thousands of artificial chemicals are being used in everyday products, ranging from health care products to transportation vehicles. With renewed awareness of the environmental consequences and more in-depth knowledge of science, we are discovering that such ubiquitous use of artificial chemicals is not sustainable (Khan and Islam, 2016). If the pathways of various artificial chemicals are investigated, it becomes clear that such chemicals cannot be assimilated in nature, making an irreparable footprint that can be the source of many other ecological imbalances (Chhetri and Islam, 2008). Most persistent and bioaccumulative chemicals eventually find their way into our bodies via the food chain. Chemical industries mass produce artificial additives and, therefore, gain the advantage due to the economy of scale, in line with modernization since the industrial revolution.

Federal regulators have determined that about 4,000 chemicals used for decades in Canada pose enough of a threat to human health or the environment that they need to be subjected to safety assessments (The Globe and Mail, 2006). These artificial additives are either synthetic themselves or derived through an extraction process that uses synthetic products. Even when the source is natural, it may have been contaminated through

artificial agents, such as chemical fertilizer, pesticide, etc. These artificial chemicals have a number of hidden adverse side effects. Furthermore, once artificial additives are disposed into the environment, they remain in nature for a very long time. These synthetic products never degrade biologically; they are either pulverized (hence become invisible) or oxidized to produce toxins (Khan and Islam, 2016). On the other hand, natural additives are naturally occurring substances that are considered valuable in their natural form. Most of the natural materials are readily biodegradable, so they have zero waste and they have no long term negative impact. Natural materials are inherently superior to synthetic materials with regard to efficacy and safety in matters related to human health. Any attempt to improve current engineering practices should investigate the possibility of replacing artificial additives with natural ones that are environment friendly and truly sustainable (Khan and Islam, 2007).

1.6 Scope of the Book

This book takes a holistic approach for water purification. All existing technologies are reviewed and evaluated against a sustainability criterion. Based on the shortcoming of existing technologies and overall lifestyle, new line of technologies are proposed. These technologies are all wholly sustainable, meaning they simultaneously meet environmental, economical, and technological challenges. Such technologies are presented for three categories, namely, drinking water, agricultural use, and industrial waste management. It is shown that each of the proposed technologies has the potential to turn waste into asset, thus creating double dividend.

1.7 Organization and Introduction of the Chapters

The introduction chapter (Chapter 1) introduces the readership such concepts as zero waste engineering, sustainability and others. This is followed by Chapter 2, which discusses water science. With a truly scientific approach, this chapter offers a delinearized history of water science and delineates the role of water in all aspect of life all through history.

Chapter 3 (Sustainability of Current Water Purification Techniques) presents a detailed account of all major water purification techniques. Each technique is tested for its sustainability.

Chapter 4 (Sustainable Drinking Water Purification Techniques) presents a discussion on what needs to be done in terms of lifestyle adjustment.

This is following by the presentation of an array of sustainable technologies, all suitable for drinking water. Recommendations are made for the best options for drinking water.

Chapter 5 (Sustainable Purification Techniques for Agricultural Wastes) presents a number of options for purifying agricultural waste. The possibility of deriving double dividend by adding value to the waste or by extracting minerals from the waste stream is discussed.

Chapter 6 (Sustainable Purification Techniques for Industrial Wastes) presents a discussion on how to reset the current 'technological disaster' to a sustainable mode. It then presents several options for complete sustainability during industrial waste water treatment. A number of emerging technologies, each having tremendous commercial potentials, are presented.

Chapter 7 (Summary and Conclusions) lists a summary and key conclusions from each chapters.

Chapter 8 is a comprehensive bibliography and a list of references.

