WATER SUSTAINABILITY

Abstract

Water is our largest natural resource, but only 3% is freshwater and only one- third of it is available for agriculture and drinking purposes. The freshwater we use comes from two sources: Surface water runoff and groundwater. Precipitation that flows into water bodies such as streams, rivers, and lakes at the surface of the earth without infiltrating the surface or returning to the atmosphere by evaporation or transpiration is called surface water runoff [1]. Some of the precipitation percolates to the surface, where it collects as soil water, partially filling the pores between surface soil particles and rocks. Aquifers are underground rocks that are water-bearing layers and water in them is called groundwater. The water collects on the layer of impermeable rock or on compacted clay called unconfined aquifers. When the water is collected between two impermeable rocks is called confined aquifers [2]. Sustainable water management means being able to meet current water demands without risking the ability of future generations. It requires multidisciplinary and comprehensive strategies that consider technical, environmental, economic, aesthetic, social, and cultural concerns. In recent years, the term "sustainability" has come to use frequently which includes various planning activities. It has a slightly different meaning depending on the user's point of View. Organising the different aspects of water management in order to maximize benefits is the goal of sustainable water management. This can be done through Several processes such as water reuse, water recovery, and minimal water Consumption. Long- term availability and supply of clean water for people and other

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living things are necessary for water sustainability. The physical, chemical, and Biological properties of natural waters that are required to fulfil long-term societal and Ecological needs are known as sustainable water quality [3]. The driving factors, Effects, and best management practices affecting the future of our water are Highlighted in this chapter.

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Water is our largest natural resource, but only 3% is freshwater and only one- third of it is available for agriculture and drinking purposes. The freshwater we use comes from two sources: Surface water runoff and groundwater. Precipitation that flows into water bodies such as streams, rivers, and lakes at the surface of the earth without infiltrating the surface or returning to the atmosphere by evaporation or transpiration is called surface water runoff [1]. Some of the precipitation percolates to the surface, where it collects as soil water, partially filling the pores between surface soil particles and rocks. Aquifers are underground rocks that are water-bearing layers and water in them is called groundwater. The water collects on the layer of impermeable rock or on compacted clay called unconfined aquifers. When the water is collected between two impermeable rocks is called confined aquifers [2]. Sustainable water management means being able to meet current water demands without risking the ability of future generations. It requires multidisciplinary and comprehensive strategies that consider technical, environmental, economic, aesthetic, social, and cultural concerns. In recent years, the term “sustainability” has come to use frequently which includes various planning activities. It has a slightly different meaning depending on the user's point of view. Organising the different aspects of water management in order to maximise benefits is the goal of sustainable water management. This can be done through several processes such as water reuse, water recovery, and minimal water consumption. Long- term availability and supply of clean water for people and other living things are necessary for water sustainability. The physical, chemical, and biological properties of natural waters that are required to fulfil long-term societal and ecological needs are known as sustainable water quality [3]. The driving factors, effects, and best management practices affecting the future of our water are highlighted in this chapter.

One of the most crucial resources that determine the ability to produce food and the corresponding potential for population growth is water. The spatial distribution of measured global water resources in terms of precipitation per unit area corresponds to the population density. Climate change, water pollution, and the negative effects of water resource management practices are the three main threats to the sustainability of water resources. The most recent thinking on the environmental, social, and political aspects of sustainable management of water supplies at local, regional, or basin scales is represented by sustainable water resource management [4].

According to experts, water scarcity and water pollution are among the biggest environmental problems for mankind in the 21st century. The search for determinants of water-saving behaviors is one of the main goals of environmental psychology and other environmental sciences, as human behaviors is the most important cause of water problems. Such searches enable intervention programs to include important predictors of water conservation to promote sustainability [5].

To assist water management authorities in recognizing instances of water stress, The Water Foundation and its collaborators including Environmental Science Associates, the Bay Institute and Sonoma Ecology Centre published a set of guidelines known as the Sustainable Water Management (SWM) Profile in 2012. By analysing management responses to these conditions and measuring soil, ocean water gauges progress toward sustainable water management. In December 2019, The Water Foundation and its partners published a paper summarizing the application of the SWM profile and the lessons learned during its development and testing through two pilot projects. In 2016, the Inland Empire Utilities

Agency worked with the Water Foundation to conduct a pilot assessment of water stress vulnerability and management measures.

Globally sustainable water means that at least 20 to 50 litres of water per day needed for life is affordable and available to everyone on this planet. Following this, the United Nations General Assembly recognized that the right to safe drinking water and sanitation is an essential human right for the full enjoyment of life and all human rights.

Typically, water utilities have long-term planning deadlines and long-term infrastructure operations and maintenance commitments. As a result, EPA sustainability guidelines require that drinking water and sanitation systems be “strong and comprehensive” so that water infrastructure investments are cheap, resource-efficient, and cost-effective.

These tactics ought to serve as the foundation for sustainable management of its water resources. Using wastewater as a source of water, energy, and fertilizer; prioritizing water conservation; reducing water demand; enforcing strict control over water pollution; prioritizing the use of rainwater as a source of water; and preventing flooding and water logging disasters [7].

I. WATER CONSUMPTION – IN AGRICULTURE

The agricultural sector uses 70% of the world's annual water supply, so it will be one of the first to feel the effects when water demand is higher than supply. Sundstrom said, "Groundwater is already being used up in many places, where there isn't enough capacity to meet demand, production will go down, which will directly affect farmers' income and food security"[8].

Agroforestry: The best way to keep groundwater from running off and to keep the land from getting worse is to keep plants alive. But cutting down trees is often done to make more room for farms or pastures. In Colombia, the GEF is helping herders keep the tree cover high so that cattle can graze in the shade. It has made pastures more productive and also cut down on how much water isused. Wetlands need to be protected because they keep fresh water from getting dirty or drying up during dry spells. Burkina Faso's pasture land and water supplies have been hurt by too many cattle. The Least Developed Countries Fund is working on a project to improve how the Mare d'Oursi Wetlands Basin in the north of the country is managed. This will help farmers deal with the effects of climate change. It will also keep the lakes and streams in good shape, which they use to raise animals. To maintain balance in the ecosystem, food, water, and energy all depend on each other. In the last ten years, the GEF has been a leader in improving the security of water, food, and energy by using an integrated nexus approach. The nexus approach is the GEF's current four-year plan for dealing with water use and waste at the level of ecosystems in agriculture, energy, and the urban environment. There are two main places where water comes from: rivers and lakes, like the Great Lakes, and aquifers in the ground. Both sources can be used for a lot of different things, like homes, businesses, industries, farming, making energy, mining, and having fun. The Upper Midwest Water Science Centre collects basic hydrological data and does studies to find out how much water is available now, how surface water and groundwater interact and affect availability, how quickly we are using our water resources, and how much water will be available in the future [9].

Leaders of thought from inside and outside the water industry will get together in small groups called "think tanks" to look at the future of water through the lens of five key drivers. The Water 2050 ‘thinks tanks will look at these drivers and use them to guide all the work that will be done in the future.

II. INDICATORS

One of the key problems to economic development and food production is the sustainable use of global resources. In recent years various studies have reported that there has been an increase in the usage of non-renewable water resources due to human reliance. This has affected the regional water supply and also food production due to less irrigation. Indicators are widely used in water sustainability management [10]. Several parameters are used to qualitatively and quantitatively analyze different parameters to represent water sustainability. They are used to get information and estimate changes over a while and evaluate progress toward goals. Indicators must be chosen carefully and there are different categories considered before an indicator is chosen. Some of them are water supply reliability, water quality, ecosystem health, social benefits, equity, etc. Various indicators are used to estimate the usage like using the water crowding index (threshold value) which shows different levels of water scarcity. Water stress refers to the state in which water accessibility is limited due to mobilization issues. The threshold value of water is set between 0.2-0.6. Apart from water stress indicators, the water availability index takes into account the monthly blue water availability to the monthly blue water demands of all sectors and compares it. These indicators do not integrate environment flow factors and they also don't assess the non-renewable source of water which is widely used in semi-arid areas, indicators that have the above requirements are very few. It is important to include non-renewable sources of water to develop management policies and plans for the sustainable use of water. The blue water sustainability index (BlWSI) includes both non-renewable sources of water and also non- sustainable usage of water. Effective indicators should be unbiased, address problems, be based on data sources and methods, and be accessible and easily understood [11].

III. CHALLENGES

An important step in determining our future direction – the challenges we face is to identify the key issues that water resource managers must address today and how these will change over time.

One of the key factors influencing both water quality and quantity is land use management. Changes in available water quantities, adjustments to the frequency and timing of runoff and infiltration, and adjustments to the spatial distributions of available water are all cumulative effects of land use change on water resources that have an impact on both terrestrial and aquatic ecosystems. Water resources are impacted by land management initiatives like hubs and corridors, working lands, and aquifer protection programs. Sustainable water resources management must also include integrated watershed management because changes in land use can either help or hinder sustainable water.

IV. CLIMATE CHANGES

Energy production, infrastructure, human health, agriculture, and ecosystems are just a few of the sectors that will be impacted by climate change's effects on water availability and quality. The management of water resources is already under pressure from several factors, including pollution, land use changes, rapid population growth, and damming of rivers. Rainfall is a key climate variable because it is the flux of water from the atmosphere to the surface. The relationship between rainfall rate and all other significant hydrologic variables, including river flow and recharge, is proportional. The distribution of rainfall is likely to change as a result of any significant climate change, and the distribution of all other significant hydrologic variables, including river flow and aquifer recharge, will follow through the water cycle. Due to this, the sustainability of water resources may be threatened by climate change. This might not be true in all scenarios involving climate change. A change in the climate that shifts the distribution of rainfall toward wetter conditions is likely to improve the region's sustainable water resources. The water cycle is impacted by climate change because it alters where, when, and how much precipitation occurs. Over time, it also causes weather events to become more severe [12].

The disruption of the hydrological cycle is the primary impact of climate change on the world's water resources. The increase in temperature consequently causes the amount of water vapor in the atmosphere to increase, the pattern and intensity of precipitation to change, the amount of water evaporating from the earth's surface to increase, the amount of snow cover to decrease, and the melting of glaciers. All important economic sectors are impacted by the effects of climate change on water resources. Both natural and man-made factors may be the cause of climate change. The two main human activities that have a significant impact on the environment are (1) the emission of greenhouse gases, which changes the chemical composition of the atmosphere, and (2) deforestation and desertification, which change the global land cover as it is observed. These two human activities have the potential to significantly alter the climate, which could have an impact on how sustainable water resources are distributed.

Climate change-related thermal expansion of the upper ocean causes sea levels to rise, which in turn causes saltwater to infiltrate freshwater horizons, lowering the quantity and quality of their reserves. In addition to harming fisheries and water intake systems, the movement of saltwater up river mouths also threaten agriculture by causing soil salinization. Rising sea levels will exacerbate conditions like flooding, erosion, and other hazards in the coastal zone, endangering critical infrastructure and habitations and making small islands particularly vulnerable. Rising temperatures cause glaciers and snow cover to melt, reducing water supplies and reducing water availability during warm and dry seasons in areas receiving water from mountain ranges.

Understanding the relationship between finite water resources, climate variability, and different aspects of sustainability is necessary for securing a reliable water supply, which is essential for achieving Sustainable Development Goals (SDGs). A timely and thorough analysis of sustainability as it relates to water resource management in the context of climate change risks is provided in the book “Water, Climate Change, and Sustainability”. The water cycle is impacted by climate change because it alters where, when, and how much precipitation is happening. Over time, it also causes weather events to become more severe [13]

1. **Water Pollution**: Pollution is a by-product of economic development and continues unabated in many bodies of water due to indiscriminate dumping of domestic, agricultural, and industrial wastes. Many rivers have slowly accumulated pollutants over the years, rendering them aesthetic and biologically and chemically toxic. The introduction of advanced wastewater treatment methods such as membrane technology, recycling, and wastewater recovery helps to alleviate the pollution problem to some extent. In the long term, an integrated approach to water management, where all aspects of the water sector are considered and optimized_within a single ecosystem framework, seems the way to go. Pollution has multiple sources and is primarily related to land use patterns and emissions of gaseous, liquid, and solid wastewater. Domestic and industrial wastewater contains potentially toxic compounds and must be treated before being discharged into waterways or the ocean. Gaseous emissions from power plants, mines, and industries combine with atmospheric water to form dilute acids. When it hits the ground as so-called "acid rain", it can have far-reaching effects on soil, vegetation, and water bodies far from the original pollution source. The incomplete removal of phosphates and nitrates in wastewater from domestic, industrial, and agricultural water sources leads to nutrient build-up in downstream waterways.

   The sustainability of water resources may be seriously threatened by all human activities that alter the quality of water during the hydrologic cycle. Examples of such activities include the following:

   - Air pollution from industrial emissions that result in acid rain
   - Surface runoff pollution from drainage from irrigation plans that use dangerous chemicals like pesticides, and
   - Contamination of aquifers and lakes from industrial waste discharges.

   Adoption of pollution prevention strategies as well as the creation of remediation technologies that deal with contaminated sites may be able to guard against these dangers for sustainable water resources.

   The discharge of untreated or partially treated sewage into water bodies, sometimes as a result of improper sewage handling procedures by municipal bodies, is one of the most frequent primary sources of water pollution. In significant cities, this is not unusual. When sewage and other waste are dumped into the water, it causes the water's oxygen levels to drop and promotes algal growth. Seepage pits, garbage dumps, septic tanks, barnyard manures, transportation accidents, and other pollutants pose a threat to groundwater [14].

2. **Agricultural Discharges:** Two-thirds of India's agricultural production comes from one-third of its irrigated land. The rest come from wet areas that employ large populations. To meet the growing demand for food and agricultural jobs, India needs to increase irrigated areas and boost productivity in both irrigated and rain-fed areas. In the agricultural sector, water and electricity for irrigation are subsidized for various reasons. This led to wasteful flood irrigation rather than adopting more optimal practices. The excessive use of chemical fertilizers and pesticides has an even greater negative impact on water quality. Chemicals used as fertilizers and pesticides used to fight disease are the two main types of agricultural discharges. Their spills get into water bodies; therefore, pollution has

increased as a result of increased production as well as increased use [9].

3. **Drinking Water Security:** The cleanliness of drinking water supplies determines the health of the nation. Approximately 1 billion people do not have the means to safe drinking water. This situation is worsened due to improper sanitation facilities. Due to poor sanitation, child death occurs every 20 seconds and the statistics continue rising. This issue is often not given attention as it is only a problem of underdeveloped and developing countries. The effect of lack of drinking water is spread over a vast area. Water scarcity occurs when there's not enough water, poor quality, or due to the inability to store and maintain water. Arid and deserts suffer a lack of water in general and this is intensified due to pollution. Hence traditional methods like using groundwater and non-renewable sources for water are exploited [15].

4. **Food Security:** The food intake globally has increased in the last few years and many factors like an increase in land and water productivity, an increase in the global trade of food, increase in population in areas with low productivity, have a role to play. Water sustainability is affected because of changing dietary plans due to lifestyle changes. The water used for the production of food grains, meat, milk, and fish has increased substantially. Many countries have switched from fossil fuels to biofuels which again has exploited the use of water. Rainfall dependant irrigation does not ensure a successful harvest and the flooded mode of irrigation results in the evaporation of the water surface. To efficiently use the water resources, the rate of evapotranspiration must be reduced and this is achieved by the use of drip irrigation, sprinklers, etc [16].

5. **Disaster Management:** Water is an influential resource and can be used to control various aspects of livelihood. It is said to take over oil as an economic commodity soon. No matter how beneficial water is, it can be destructive too. Floods and tsunami cause various damages and casualties which are alarming and dangerous to humankind. A hazard is referred to as a disaster when the community does not have enough coping mechanism and are vulnerable to such inevitable circumstances. There are various disaster management practices in countries all around the globe, but their practice is slow and influenced by various other factors [17].

6. **Education:** There should be enough knowledge and exposure provided to all human beings at different levels of life about the water cycle and its relationship with the environment.

V. SUSTAINABLE WATER SOLUTIONS: THE BASICS

Maximize environmental, economic, and social benefits by targeting and selecting projects through a transparent and inclusive process with the community. Achieve consistency across a range of alternatives that meet both utility and community goals and improve the technical, financial, and long-term management capacity of the civil service.

In essence, water utilities must engage in long-term planning and uphold their infrastructure responsibilities for an extended period. Their investment decisions should consider the potential costs and advantages over time. To align with EPA sustainability guidelines, drinking water and sanitation systems need to be robust and all-encompassing.

This ensures that investments in water infrastructure are both economical and efficient, while the fees charged throughout the infrastructure's life cycle remain reasonable. These actions should align with the specific objectives of each community [17].

The following list from IWA explains the sustainable use of different water resources:

1. **Surface Water:** Surface water resources face limitations due to their uneven distribution across the world and the pollution resulting from various human activities, rendering untreated surface water unfit for consumption. Dams, when constructed effectively, offer a sustainable solution as they can serve multiple purposes like generating power, supporting irrigation, controlling floods, diverting water, and facilitating navigation. However, large-scale dam projects can pose sustainability challenges, including adverse environmental effects on wildlife habitats, fish migration patterns, water flow, and water quality, along with socioeconomic impacts. Consequently, conducting a comprehensive sustainable impact assessment becomes imperative in such cases [18].

2. **Groundwater:** Groundwater accounts for more than 50% of the world's fresh water and is essential for drinking water. Groundwater can only be a sustainable water supply if the amount of water entering, leaving, and storing in the system is conserved. The IWA states that unsustainable use of groundwater leads to reduced water levels, reduced runoff, and poor water quality, with a direct impact on local communities.

   Water sustainability also varies across utilities. Some utilities and local governments are incorporating sustainability considerations into their planning processes, but are looking to improve and refine their current efforts. Others may focus on how these considerations can help meet existing regulatory or service requirements cost-effectively [19].

3. **Rainwater:** Rainwater harvesting stands out as one of the most sustainable sources of water supply due to its inherent safeguards against the over-exploitation of surface and groundwater resources. It directly provides high-quality drinking water. However, it's crucial to design and maintain stormwater collection systems properly. This ensures efficient water collection, safeguards against contamination, and utilizes robust treatment systems in case of water contamination.

   There are various on-site drinking water treatment methods available, each with its own set of advantages and disadvantages. These methods encompass solar treatment, boiling, filtration, chlorination, combined approaches such as filtration and chlorination, flocculation, and chlorination.

   From a technical perspective, considering the Earth's surface area and precipitation levels, rainwater harvesting has the potential to meet global water needs. However, it should be viewed as a complementary addition to sustainable water supply systems. Rainwater harvesting systems exhibit resilience in the face of high levels of uncertainty, particularly concerning factors like climate change, and they can coexist with other land-use applications in a competitive manner [19].

4. **Desalination:** In certain countries where fresh water is scarce, desalination has proven to be a valuable source of water for an extended period. However, the increased energy demands associated with heat and membrane treatment in desalination, compared to conventional ground and surface water treatment methods, have raised concerns about its sustainability.

   Nonetheless, the International Water Association (IWA) suggests that the sustainability of the desalination process can be significantly enhanced by integrating it with renewable energy sources. One promising approach is the implementation of solar-powered decentralized desalination systems. This strategy has been recommended as a more sustainable means of providing water, particularly in regions with unique challenges, such as the approximately 6,000 Greek islands.

   By harnessing solar energy to power desalination processes, not only can the environmental impact be reduced, but also the overall sustainability of water supply can be improved, making it a viable solution for areas facing water scarcity. This approach aligns with the growing emphasis on renewable energy integration to address water-related challenges in a more environmentally friendly manner [20].

5. **Reclaimed Water:** Recycled water, often referred to as water reuse, represents another sustainable source of water that can alleviate pressure on critical water sources like surface and groundwater. The suitability of reclaimed water depends on its intended application, whether it's for purposes like irrigation or industrial use. Treatment processes are applied to reclaimed water to ensure it meets the necessary quality standards.

   The extent of water reuse varies worldwide, with certain countries taking a prominent lead. For instance, countries like Spain and China have been at the forefront of water reuse initiatives. China, in particular, has made significant strides in this regard, accounting for a substantial 49% of contract capacity related to water reuse between 2010 and 2017.

   This global variation highlights the growing recognition of water reuse as a sustainable solution to address water scarcity issues and reduce the strain on conventional water sources. It underscores the importance of tailored treatment processes to make reclaimed water suitable for various applications, ultimately contributing to more efficient and sustainable water management practices [21].

VI. SUSTAINABLE WATER MANAGEMENT STRATEGIES

Many technologies are employed to preserve water from wastage and loss. They are used to maximize the use of water resources in the country, based on the demand and supply of water, the technologies used differ according to the field of use: domestic, irrigation, or industrial

According to IWA, sustainable water supply is part of integrated water resource management. The association defines this as "the practice of bringing together many stakeholders with different perspectives to determine the best way to manage water". To decide whether a water system is sustainable, many economic, social, and ecological factors need to be taken into account.

Meanwhile, the United Nations (UN) has identified the following strategies where sustainable management of water resources is needed, in line with the overarching goal of "Ensuring sustainable water for all."

1. **Agriculture:** Agriculture indeed holds the distinction of being the largest consumer of water on a global scale, utilizing approximately 70% of the world's freshwater resources. However, it's important to note that this percentage can vary significantly from one country to another.

   The predominant agricultural production system worldwide relies on rainwater, and current crop yields from rainfed agriculture typically achieve just over half of their potential under optimal agricultural management practices. This indicates substantial room for improvement in rainfed agriculture to enhance food production.

   Looking ahead to the year 2050, the global agricultural sector faces a considerable challenge. It will need to increase food production by an estimated 60% to meet the growing demands of a rising global population. In developing countries, the challenge is even more significant, with a projected need for a 100% increase in food production. Meeting these demands while maintaining sustainable water management practices is a complex task that necessitates innovation, efficient resource utilization, and environmentally sound agricultural practices [22].

2. **Industry and Energy:** Industry and energy sectors collectively account for approximately 20% of global water demand. However, it's important to note that the distribution of industrial freshwater withdrawal varies significantly between more developed and less developed countries. In more developed nations, industrial water usage tends to be much higher compared to less developed countries, where agriculture remains the dominant sector in terms of water consumption.

   Balancing the sustainability imperatives with the traditional approach to industrial mass production presents several challenges for industries. One of the most pressing issues is related to globalization and the need to ensure that the benefits of industrialization are spread worldwide without causing unsustainable impacts on water and natural resources.

   Globalization has led to increased industrial activity in various regions, often driven by economic considerations such as cost efficiency and access to markets. However, this can lead to disparities in water usage and resource consumption, which may be unsustainable in regions with limited water availability or fragile ecosystems.

   To address this issue, industries and policymakers must adopt strategies that promote sustainable practices, including responsible water management and resource conservation. This may involve the adoption of water-efficient technologies, recycling and reusing industrial water, and considering the environmental impacts of industrial activities in various regions.

In summary, achieving a balance between industrial development, globalization, and sustainability is a complex task that requires careful consideration of water and natural resource impacts, especially in regions where water resources are limited or vulnerable. It calls for a shift towards more sustainable industrial practices and responsible resource management to ensure that the benefits of industrialization are shared globally without compromising the planet's long- term health [22].

3. **Domestic Sector:** Urban water uses accounts for 10% of total water use. And yet, globally, an estimated 748 million people still do not have access to improved water and there is a lack of sanitation facilities for about 2.5 billion people in this world.

- **Cities:** More than half of the world's population already lives in urban areas, and by 2050, more than two-thirds of the world's nine billion people are expected to live in cities. Furthermore, much of this growth will occur in developing countries, which have limited capacity to cope with this rapid change, and this growth will also lead to an increase in the number of people living in the world. in the slums, where living conditions are often very poor, including poverty, water and sanitation facilities. Therefore, the development of water resources for economic growth, social justice, and environmental sustainability will be closely linked with the sustainable development of urban areas.

- **Ecosystem:** Indeed, one of the most significant challenges to sustainable development in recent decades is the global ecological crisis. Despite efforts to promote sustainability, it's clear that these efforts have not been entirely successful. The world is facing a critical global environmental degradation problem, with many major ecosystems nearing a threshold that could lead to a significant collapse.

  This challenge is underscored by the emerging concept of planetary boundaries. These boundaries represent the limits within which humanity must operate to safeguard Earth's life-support systems. Breaching these boundaries can have severe consequences for the planet's stability and the well-being of current and future generations.

  Recognizing and respecting these planetary boundaries is essential for developing a sustainable framework for the future. It means acknowledging that our planet has finite resources and that our activities must operate within these ecological constraints. This shift in perspective is crucial for achieving true sustainability, as it emphasizes the interconnectedness of human well-being and environmental health.

  Addressing the global ecological crisis and respecting planetary boundaries requires a collective effort involving governments, businesses, communities, and individuals. It involves rethinking our patterns of consumption, reducing our ecological footprint, and adopting more sustainable practices in various sectors, including agriculture, energy, and transportation.

  In summary, the ongoing global ecological crisis poses a significant obstacle to sustainable development. To overcome this challenge, it is imperative that we prioritize the protection of Earth's life-support systems and operate within the boundaries defined by our planet's ecological limits. Only by doing so can we hope to achieve a sustainable and prosperous future for all [23].

4. **Desalination:** Removing dissolved salts from seawater or brackish groundwater is an attractive way to increase freshwater supplies. Distillation and reverse osmosis are the two most common desalination methods. Two other methods are freezing the salt water or running an electric current through it. Distillation heats the brine until it evaporates and condenses as fresh water, leaving the salt in solid form. In reverse osmosis, salt water is forced through a thin membrane at high pressure, allowing water molecules to pass through but not dissolved salts [20].

5. **Cloud Seeding:** For years, some countries have experimented with injecting chemicals into clouds to bring rain to dry areas and snow to mountains. Cloud seeding involves finding a suitable large cloud and injecting it with a propellant like silver iodide from an airplane. Small water droplets in clouds gather around small particles of chemicals to form droplets or ice particles, large enough to fall to Earth as precipitation [24].

6. **Rainwater Harvesting:** Rainwater harvesting is the collection of water from the rooftop of buildings and preserving it for future use. It helps in improving groundwater levels by raising the water table which further enhances supply of water. It is crucial to maintain groundwater, prevent movement of water towards lands and preserve surface water runoff during rainy season [25].

7. **Better Irrigation Practices:** Conservation of water in agricultural sector is crucial because most of the water resources are used here as it helps in the growth of crops. Due to increase in the usage of groundwater and increase in salinity from fertilizers, the quality of water has decreased drastically. Different water harvesting and recharging techniques are applied all over the world to eradicate the problem [17].

8. **Use of Saline Water for Irrigation:** There are plenty of saline water available but isn't widely used for agricultural purposes as it restricts the growth of plant and also its yield. Various salt resistance plants have been developed in recent times.

9. **Fog and Dew:** Netting surfaced traps or polyethylene sheets are artificial settings that are exposed to fog and dew to trap water for further use. Its principle is based on the ability of fog and dew to condense when in contact with the metallic net. It can be used even in areas with less moisture content. There are also certain plant species that have adapted to use fog and dew.

10. **Mulching:** It is the use of organic or inorganic components like plant compost, debris to cover the surface of the ground and they are referred to as mulch. It prevents surface run off, decreases evaporation losses, improves soil moisture and soil fertility and prevents soil erosion. Various types of mulch exist, like: like plastic mulch, organic mulch, ornamental mulch.

11. **Contour Farming:** Used in hills and lowland areas to conserve soil and water. It can be achieved by using furrows, crops rows and wheel tracts all over the slopes. They act as reservoirs to trap rainwater, which allows increased infiltration and consistent distribution

of groundwater. Contour farming reduces the impact caused by heavy rains hence preventing major disaster and landslides.

12. **Soak Pit Construction**: Soak pits are built near water points to prevent water logging and water run offs. This also helps in the increase of ground water. The water undergoes partial treatment and it produces clean, non-harmful water which infiltrates into the soil [25].

13. **Tree Plantation:** Planting of trees near the banks of river and other water bodies preserve water resources by helping in infiltration of rain water into the soil, preventing water runoff, and preventing disruption of livelihood near river banks by holding streams.

VII. SUSTAINABLE MANAGEMENT OF WATER RESOURCES

Sustainable water strategies are not one-size-fits-all solutions; they must be tailored by regional and national governments to suit their specific circumstances. These strategies depend on a range of factors, including the state of irrigation infrastructure, the effects and vulnerabilities to climate change, the level of government commitment, regulatory frameworks, and access to financial resources, among others.

The International Water Association (IWA) emphasizes that sustainability is not only a goal but also an outcome. The conceptual framework for sustainable water resource management recognizes water as a renewable yet finite resource, subject to global and regional limitations. This framework should encompass ecological, economic, and social considerations and be supported by institutional and legal regulatory structures aimed at achieving sustainable water resource management.

In essence, sustainable water management recognizes that water resources are limited and must be managed in a way that balances the needs of the environment, the economy, and society. It involves taking a holistic approach that considers not only the availability of water but also its quality, distribution, and equitable access. Additionally, it recognizes the importance of governance and regulation in ensuring that water resources are used efficiently and fairly.

Ultimately, sustainable water management is about preserving this vital resource for current and future generations while meeting the needs of society and protecting the ecosystems that depend on it. It is a complex and multifaceted challenge that requires collaboration, innovation, and a long-term perspective to achieve lasting success.

There are many case studies in which government-led sustainable water management strategies have been developed, taking into account national regulations. Below we've listed examples that vary widely, from city to city and across the country:

VIII. SINGAPORE

Singapore's "Four National Faucets" strategy is a remarkable example of innovative and sustainable water resource management in a region with high water demand and limited natural water resources. Here's a breakdown of Singapore's approach:

1. **NEWater:** NEWater is Singapore's primary method of water regeneration. This advanced treatment process transforms used water into clean, safe, and usable water. It involves several stages, including microfiltration, reverse osmosis, and UV sterilization. NEWater plays a significant role in meeting Singapore's water needs and has the potential to contribute even more in the future.

2. **Reservoirs**: Singapore has 17 reservoirs across the island that serve as sources of water. With extensive local catchment techniques, including culverts, canals, and small ponds, rainwater is efficiently channelled into these reservoirs. Marina Reservoir, for example, covers a substantial area and contributes to a significant portion of Singapore's water supply.

3. **Importing Water:** Singapore has historically imported water from neighbouring Malaysia through agreements. These agreements have helped meet a substantial portion of Singapore's water needs, though the water importation agreements have specific expiration dates.

4. **Desalination:** Desalination plants turn seawater into potable water using reverse osmosis technology. While desalination is energy-intensive, Singapore has implemented measures to reduce energy consumption, such as electric deionization. This approach aligns with sustainability goals while ensuring a reliable water source.

   Challenges and Efforts: Increasing Demand and Climate Change: Singapore recognizes the growing demand for water due to population growth and industrial activity, as well as the impacts of climate change on water availability. This underscores the need for proactive planning and sustainable practices.

   - **Wasteful Habits:** Despite easy access to clean tap water, Singapore acknowledges the potential for wasteful habits. To combat this, public awareness and education campaigns promote responsible water usage.

   - **Technology and Environment:** Singapore invests in research and development to make desalination processes more energy-efficient while monitoring seawater quality to minimize environmental impacts.

     Singapore's comprehensive approach to water resource management demonstrates how a combination of technology, efficient infrastructure, and proactive policies can address water scarcity challenges in a sustainable manner. It serves as a valuable example for other regions facing similar issues and highlights the importance of individual efforts in water conservation as well

IX. COUNTRY-WIDE SUSTAINABLE WATER: A LONG-TERM WATER STRATEGY FOR NORTHERN IRELAND

This sweeping strategy focuses on the sustainable management of water in rivers, lakes, lakes and aquifers used for domestic, agricultural and industrial purposes. The document proposes a sustainable way of managing excess storm water at the local level to reduce the impact of flooding on communities. It also looks at how we can reduce the amount of energy needed to move and treat drinking water and wastewater.

1. Statewide: Sustainable Water Strategy For Victoria, Australia

Within Australia's state-wide statutory water resource planning process, there are four regional water strategies. Driven by the Water Act of 1989, these sustainable water strategies must be reviewed at least every 10 years. The review of the Sustainable Water Management Strategy in the Central Region began in 2016 and is now completed. Five-year assessments of the Western Region and Gippsland Sustainable Water Strategies began in 2017 and have also been completed. The review of the Northern region's sustainable water management strategy is expected to begin in late 2019.

2. City-Wide: Rotterdam – At The Forefront Of Urban Resilience

The Dutch city of Rotterdam tops Arcadis' list of the Water Index for Sustainable Cities. The city has been innovative and proactive in its approach to water management, including investing heavily in the reservoir catchment system. Rotterdam has become an example of urban resilience that leads directly to a sustainable water supply: The city is among the highest in the world in terms of water reserves.

Urban Water Development: Access to clean water is undeniably essential for healthy and productive human development. Water and socio-economic development are intricately connected, and their relationship can either foster positive development or exacerbate challenges. Here are some key points highlighted in your text:

- **Water and Development:** Access to clean water is a fundamental requirement for socio-economic growth. Without it, communities can face significant challenges in health, productivity, and overall well-being.

- **Urban Water Challenges:** Rapid urbanization in developing countries presents complex economic and logistical issues for providing clean water to growing cities. Informal and unplanned urban development further complicates predicting water demand and tracking consumption.

- **Measuring Water Management:** Various organizations, including the United Nations Center for Human Settlements and the United Nations Environment Program, are working on developing indicator methods to assess the relationship between urban water management and environmental sustainability. These indicators are crucial for effective water resource management.

- **Indicator Criteria:** A review of water management indicators found that technical and social criteria are more critical for ensuring the proper functioning of water systems compared to financial and institutional criteria. However, all these aspects are essential for sustainable water management.

- **Water Distribution:** Efficient water distribution systems must be tailored to the water availability in a region. Water-rich areas aim to optimize pressure, while water-scarce regions focus on equitable distribution, even if it means intermittent supply.

- **Operational Challenges:** Challenges in water systems include pipe leaks, water theft, material and construction issues, power supply, and maintenance problems. These challenges can affect both water-rich and water-scarce regions.

- **Sustainability and Accountability:** Accountability, knowledge, and coordination are essential in addressing water system challenges. In rural sub- Saharan communities, a significant percentage of water systems are not operational, highlighting the need for improved infrastructure and governance.

- **Regional Conflict**: Differences in water management needs can lead to conflicts between regions with varying levels of development. Political conflicts and water tensions often go hand in hand. International cooperation and conflict resolution are crucial in transboundary water management.

- **Sustainable Solutions:** Sustainable water management includes participatory planning, water collection, and reuse. Adequate training, oversight, adherence to regulations, and community engagement are vital for maintaining water systems.

- **Gender Equality:** Water management can have significant effects on gender equality. In contexts where women historically managed water resources, their involvement in decision-making processes is crucial. Sustainable water services should consider local knowledge and customary management techniques [26].

X. PROJECTS

1. **Huaifang Groundwater Recovery Plant (HWRP):** This project was awarded the Gold Medal at the 12th IWA Project Innovation Award under the title "Beijing Sustainable Solution for Ecological Water Reuse". The 31-hectare wastewater recycling plant is designed to relieve the pressure of sewage treatment in the south of Beijing and improve the water quality of the Liangshui River. The underground wastewater recycling facility will feature four 160-square-foot bioreactors that will produce recycled water that meets the fourth (IV) environmental quality standard for surface water. As an underground wastewater treatment plant, the purpose of the installation is to reduce land use and limit noise and odours emitted from the plant. The gray water will be used for industrial and municipal purposes while the sludge will be treated and reused for landfill and forest land enrichment.

2. **Omdurman Water Optimization Program, Sudan:** The Omdurman Water Supply and Optimisation Programme, one of the most significant steps towards the Millennium Development Goals (MDGs) in sub- Saharan Africa in 2008, was created to address severe water shortages of drinking water in and around Khartoum, the capital of Sudan. After receiving funding, Biwater constructed a sizable water storage, primary distribution, and treatment facility with a Nile inlet downstream of the White and Nile River confluence. Blue. The cutting-edge intake structure was designed to stably handle extreme river level fluctuations, high flows, and the significant amount of silt that the river carries during the wet season each year.

3. **Improving Conditions in The Andean Community:** In the Andes of Peru, Bolivia, and Colombia, a project called AICCA is in progress that will concentrate on drinking water and climate change. With a combined contribution of $10 million USD, the Latin American Development Bank and the Global Environment Fund supported the project. The project aims to address the problems caused by climate change with a focus on the Andean people's water sustainability.

4. **Water Conservation Projects and Initiatives in India:** The Jal Shakti Department of the Government of India launched the Jal Shakti Abhiyan in 2019. It is a national water conservation campaign to encourage people to participate in promoting water conservation at the local level. The water-saving project was implemented in two phases from July 1, 2019 to September 30, 2019 and from October 1, 2019 to November 30, 2019.

   On World Water Day, 22 March 2021, the government launched the campaign 'Jal Shakti Abhiyan: Welcoming the rain' (JSA: CTR) with the theme "Where the rain falls, where does the rainfall". It covers rural and urban areas of all districts of India, during pre-monsoon and monsoon periods, until 30 November 2021. According to the campaign, the government is focusing on creating/maintaining structures that conserve water and collect rainwater, renovate various traditional water reservoirs, reuse and recharge boreholes, and develop river basins and intensive afforestation.

5. **Jal Sanchay:** An effort to conserve water called Jal Sanchay was started in the Bihar district of Nalanda. Construction of test dams, silt removal, and irrigation system and traditional water body rehabilitation are the main components of the water conservation project. In order to keep groundwater levels stable, it also entails spreading awareness of conventional water conservation practises and rainwater harvesting methods. Additionally, the project is carried out with the aid of neighbourhood farmers and through campaigns. The Mahatma Gandhi National Rural Employment Guarantee Programme (MGNREGP)'s National Achievement Award shortlisted the project in 2017.

6. **Jal Bhagirathi Foundation:** The NGO is leading efforts to tackle water scarcity in Rajasthan's Marwar region, one of the most densely populated arid regions in the world. The NGO focused on restoration and construction of stormwater harvesting structures to replenish groundwater. It also assists communities in the construction of rainwater or tanka reservoirs.

7. **Living Dreams:** The NGO is supporting farmers in the Tamil Nadu delta by restoring the ponds that are the main source of water for households, irrigation, livestock, wildlife, and more. It also focuses on improving farmers' livelihoods, by increasing groundwater levels. level and fight against water scarcity. Environment Fund of India:

   It is an environmental conservation group that focuses on conserving wildlife and restoring freshwater habitats such as lakes and ponds through scientific means. Some of the water conservation projects undertaken by the organisation include the restoration of the Kinhi-Gadegaon Reservoir in Maharashtra, Lake Tirunelveli-Keezh Ambur in Tamil Nadu and Navule Kere in Shivamogga, Karnataka.

8. **Tarun Bharat Sangh:** An environmental non-profit organisation called Tarun Bharat Sangh uses best practises and community participation at all stages of development to achieve its goals of water conservation. local water extraction. In Rajasthan, one of India's most water-scarce states, this NGO has revived ten rivers and transformed 10,000 square kilometres of drought-prone areas.

9. **SARA (Sustainable Alternative to Rural Agreement):** The organisation led the Swagrama program and worked on different levels of practice to understand and implement sustainability models. This water saving project is inspired by Mahatma Gandhi's dream project, "Village Swaraj", and aims to achieve autonomous rural development.

XI. HOW TO ACHIEVE WATER SUSTAINABILITY?

There are three key aspects needed to achieve water sustainability, which are:

- Resilience
- Effective
- Quality

1. **Resilience:** The range of resilience includes both disaster recovery and structure and protection. The soft infrastructure of society, such as employment, income distribution, social cohesion, and other elements that aren't typically taken into account in water management, is also affected by resilience.

Urban solutions with multiple uses and green space

As an alternative to conventional piped drainage systems, many cities are implementing green infrastructure projects to address stormwater management issues. Green infrastructure can improve biodiversity and ecological resilience while also providing valuable green space and recreational opportunities for city dwellers.

2. **Efficiency**

- **Optimization of Urban Water Use:** The first step in maximizing water resources is to have a thorough understanding of the assets, system performance, and usage types and levels, both current and future. Combining this knowledge with understanding of the system's vulnerabilities, risks, and stress points results in actionable plans that can help utilities run more efficiently.

3. **Water Quality:** Given the significance of drinking water to quality of life, it is possible that urban sustainability performance is highest where water quality is concerned. Cities in the industrialized world have historically experienced increases in prosperity and economies only after adequately addressing problems with water quality and sanitation. Water quality must be raised for developing cities to develop into prosperous, sustainable urban hubs [27].

XII. CONCLUSION

Continued development must include sustainable water management in urban, agricultural, and environmental systems. There are numerous models and metrics available to assess sustainability management practices. The interdependence of social and physical systems should be the main focus of these methods' advancements. Urban water management in developing areas faces difficulties with equitable distribution, particularly in light of the city's rapidly expanding population. Plans for sustainable management should priorities enhancing stakeholder participation, developing infrastructure, and regional water extraction and reuse. Develop. Even though the costs and risks of implementing this technology continue to be barriers in both developed and developing nations, reusing water will ease stress during droughts. By lessening competition between the agricultural sector, urban users, and the environment, increasing crop water productivity can be advantageous for all water users discussed in this article. Changes in crop water allocation and the adoption of effective on-farm irrigation technologies can improve crop water production in irrigated areas, while irrigation would be beneficial in rainwater-driven agriculture. If only the near future is taken into account, maintaining a sustainable water supply in natural systems may be seen as incompatible with development practices. The focus on restoring and safeguarding water resources in developed nations is evidence that long-term economic development is inextricably linked to the health of environmental systems. In the application, thresholds for environmental degradation can be set in the context of objectives for economic and social development based on estimates of the value of ecosystem services. Although different regions can manage water resources in ways that support socially, economically, and environmentally sustainable development, sustainable water management will vary by geography and economic viability.

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