Water Sustainability:A Study in Future Challenges

الإستدامة المائية:دراسة في التحديات المستقبلية

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Abstract:

The study of future challenges in achieving water sustainability represents a significant scientific and intellectual paths,particularly when analyzed with a proactive perspective.This anticipatory framework can facilitate the development of fundamental approaches for effective planning methodologies that ensure survival and the continuous achievement of water self-sufficiency.Accordingly,this article will address the operational mechanisms for ensuring a secure surplus of water through an analytical logic focused on identifying and deducing pertinent variables and their potential for future deployment.

Keywords: Water sustainability. Sustainability. Water scarcity. Climate Change. Demographic Growth.

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Introduction

Water sustainability represents an undeniable imperative in confronting the escalating challenges facing the global water sector,this concept is regarded as the capacity to manage and utilize water resources in a responsible manner that ensures the fulfillment of current needs without compromising the ability of future generations to meet their water and environmental requirements.

Water sustainability transcends the mere preservation of available water quantity,also encompassing the maintenance of its quality and the protection of vital aquatic ecosystems that play a pivotal role in the water cycle and its provision.

Moreover,achieving water sustainability necessitates the adoption of a holistic and integrated approach that takes into account the intricate interactions between social,economic,and environmental factors,in addition to strategic planning to address future challenges arising from climate change and increasing population growth.

The adoption of water sustainability principles is not merely an option but a critical necessity for ensuring long-term water security and achieving comprehensive sustainable development.

The future of water resource systems is intrinsically linked to the concept of sustainability,which sets us on a trajectory of long-term future thinking.

We can proactively shape the future by examining various strategies and forward-looking plans that rationally ensure the sustainability of water resources through specific steps that will positively impact the continuous utilization of water in all areas,particularly in the realm of food security and the prevention of global famines. A central problem can be posed,revolving around the attempt to find a balance between fundamental variables-food,continuity,self-sufficiency,and climate change-while emphasizing the importance of future strategies for water sustainability.The following research problem:How can the sustainability of water resources be ensured in the following of future challenges?

This key question is associated with the following sub-questions:

▪What is sustainability and water sustainability?

▪What is the impact of climate change,population growth,economic and technological development on the future of water sustainability?

To answer the earlier research question as well as the sub-questions,we suggest the following hypothesis:

Climate change,population growth,economic and technological evolution negatively impact future water sustainability.

This study comprises two main sections addressing the future challenges of water sustainability:

▪ **The first section** sets a clear foundation by analysing the concept of sustainability and water sustainability.

▪**The second section** explores the future challenges to ensuring water sustainability.

▪The study employs an analytical approach to explore the link between water sustainability,climate change,demographic growth,economic and technology evolution,by examining and breaking down various concepts and variables to understand their importance and make connections.

Firstly:Evolution of Water Sustainability Concept

Our analysis explores the concepts of sustainability and water sustainability by pinpointing the variables that caused their rise in scientific domains.This process allows us to subsequently deduce a set of logical and rational strategies for the sustained availability of water resources for future generations.

1. Analysis of Sustainability Concept

The concept of sustainability denotes the ability to endure into the distant future,characterizing systems and processes that can operate and persist independently over prolonged timeframes [1].

Expanding on this fundamental idea,sustainability can be defined as maintaining well-being over a long or indefinite period,primarily covering the environmental aspect of the triple bottom line [2].Furthermore,sustainability concerns the resources we leave for future generations,including natural resources,environmental quality,and capital,while some economists like Robert Solow argue that losses in natural resources can be offset by increased capital,others maintain that certain essential natural resources must be preserved and cannot be substituted for true sustainability,but the point view of Pearce present two main perspectives on this: first,that future generations should inherit at least the same total wealth(including both man-made and environmental assets)as the previous generation;and second,that future generations should inherit at least the same amount of environmental assets as the previous generation[3].

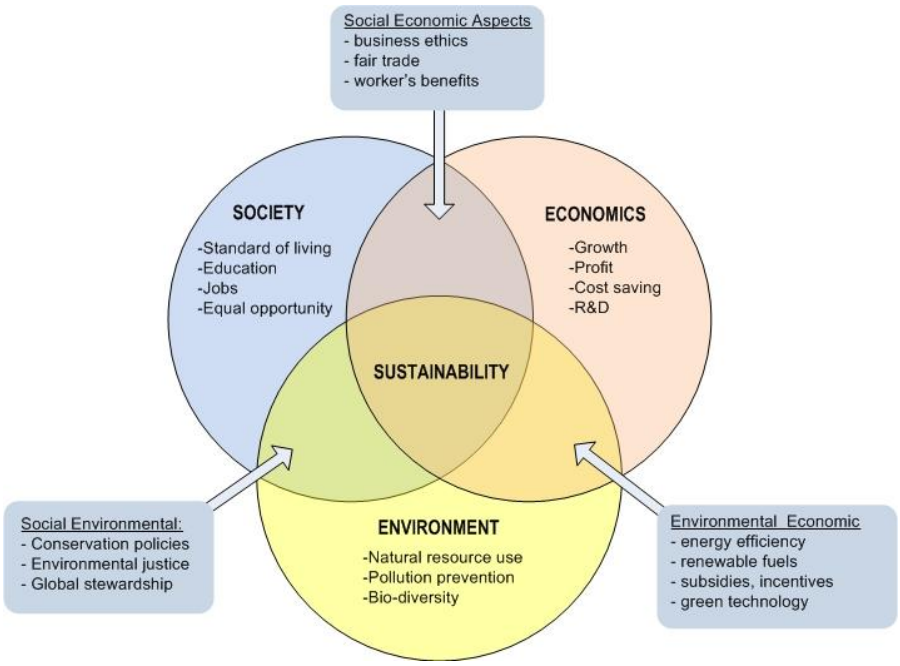
Building upon this foundational understanding,sustainability is defined as the proactive effort to conserve the environment for succeeding generations. Crucially,the practical implementation of this concept holds more profound meaning,revealing three fundamental and interconnected pillars:environmental integrity,social equity,and economic viability [4](**Figure N°1**).

The environmental dimension of sustainability is self-evident,underscoring the imperative to preserve and protect natural systems.Equally important,social equity emphasizes the critical need to prioritize fairness in environmental decision-making as we progress into the future.

The economic component of sustainability,similarly,acknowledges the necessity of environmental protection for future generations[5].

These three interrelated elements-environment,equity,and economics-are frequently referred to as the "three E's" or the "three pillars" of sustainability,and any decision-making process that aims to achieve sustainable development must take them into account[6].

Figure N°1:Interplay of the environmental,economic,and social aspects of sustainable development



(Source:Technologies for Sustainability Systems:Sustainability Definitions,in:https://www.e-education.psu.edu/eme807/node/575)

Given the profound implications discussed sustainability is presented as a profound and intricate problem directly impacting human survival due to unsustainable resource use,casting doubt on the future of civilization.Its complexity necessitates a continuous process,rather than simple solutions,focused on improving the present and securing the future by enhancing subsequent generations' ability to navigate their world[7].Historically,environmental awareness grew in the 1970s,The concept of sustainability became clearer in the 1980s when the Brundtland Report defined sustainable development as meeting present needs without compromising the needs of future generations.

Since then,there have been many definitions of sustainability that focus on enhancing human well-being and include ideas like preserving human and environmental health, managing resources effectively,addressing resource depletion,conserving nature, and ecological considerations[8].

A significant turning point in the formal articulation of this concept was the 1987 Brundtland Report,this report was pivotal in establishing the contemporary definition of sustainability,highlighting the connection between environmental and social considerations and defining environmentally sustainable development[9].

This report built upon the UN's earlier initiatives,notably the 1972 Stockholm conference,which signaled increasing global environmental consciousness.The report's introduction of intergenerational equity furthered the understanding of

sustainability's long-term implications.While the term saw earlier use,the Brundtland Report is recognized for its comprehensive articulation of the concept[10].

Furthermore,the Brundtland Report highlighted the critical link between global poverty and environmental vulnerability,noting that impoverished populations often lack the resources for conservation,it emphasized that addressing environmental sustainability necessitates a radical reduction in poverty and disadvantage present globally,and its concept of environmentally sustainable development influenced the "triple bottom line" model,marking a turning point in the evolution of the sustainability concept due to its direct and impactful approach[11].

Beyond defining sustainability and addressing poverty,the Brundtland Report also emphasized the interconnected nature of environmental problems,linking issues like population growth and industrialization to environmental decline.This understanding required a deeper analysis of the underlying cultural and social roots,rather than just regulating specific pollutants.Furthermore,the report detailed how inequality,across nations and within societies (based on factors like class and gender),results in uneven exposure to environmental consequences[12].

In practical terms,Elkington's Triple Bottom Line (TBL) model,encompassing People,Planet,and Profit,is an influential global approach for companies transitioning to long-term sustainability strategies based on environmental quality,social equity,and economic benefits[13].While the commonly used nested spheres (Venn diagram) model illustrates sustainability as the overlap of these dimensions,its limitation in showing hierarchy led Getzner to propose a "strong approach" using the Russian doll model ,this model depicts the economy and society as subsystems within a larger,limited environmental system,a view supported by Lawson and Beckmann who emphasize the compatibility of business activities with broader social and environmental systems[14].

Integral to achieving the successful implementation of these sustainability principles is the concept of resilience,originating from ecological science, resilience is central to sustainability studies,defining a system's capacity to absorb and recover from disturbances while retaining its core functions and adapting to change[15].

Consequently,sustainability research often utilizes the social-ecological systems perspective,while sustainability focuses on long-term goals and outcomes,employing indicators for assessment,resilience emphasizes the inherent dynamism of systems and the development of adaptive capacity to manage disturbances,as noted by Charles Redman's distinction between prioritizing outcomes versus process.Therefore, understanding and fostering resilience is a critical aspect of achieving the long-term viability of social-ecological systems the central aim of sustainability[16].

Expanding on this comprehensive view,the concept of sustainability is presented as a comprehensive and multidisciplinary study of the entire planet as a unified system, noting Earth's billions-year history of dynamic equilibrium as a form of inherent sustainability,informed by diverse scientific fields[17].

The discussion extends to the historical relationship between humanity and the biophysical world,a field of study called environmental history,the passage concludes by emphasizing that understanding these past interactions within the complex social-ecological system is vital for informing future strategies aimed at achieving greater sustainability[18].Generally,sustainability refers to systems and processes that can operate autonomously over extended periods,preserving natural capital and determining the ethical and economic quality of human practices.

2. Water Sustainability:A conceptual analysis

The concept of water sustainability is linked to the effective management of water resources in the future.Therefore,we begin our analysis of this term from the standpoint of rational strategies to ensure the continuity of water resources for future generations,which are represented in effective policies and legal frameworks are essential for developing,implementing,and enforcing rules and regulations for controlling water uses.The legal system through which water law operates can be a powerful tool for change or an obstacle to progress,water law establishes the general framework for stakeholders' use of water resources and often responds slowly to demographic,economic,and social pressures.Policies and laws that do not directly address water issues can affect the management of the aquatic environment and include land-use planning,environmental assessment,nature conservation and environmental law[19].

Public health laws also affect water supply and sanitation,as well as land tenure reform.Moreover,conflicts and regional instability (or stability) can influence water demand and use,especially in water-scarce regions[20].

Legitimate,transparent,and participatory processes can effectively mobilize inputs for the design and implementation of water resource policy in response to numerous and conflicting pressures.

Therefore,the development and management of water resources for the benefit of national development goals require effective policies and legal frameworks that also respect traditional customary practices.Participatory processes that take into account the socio-economic and cultural characteristics of the country or community will significantly contribute to meeting this challenge[21].

However, the biggest challenge is ensuring that these supporting laws and regulations are effectively administered and enforced, as ineffective or inadequate resource management often leads to conflicts over water resources and ecosystems. Other political issues include the privatization of water systems and customer expectations regarding the safety and reliability of their water supply,information communication to water customers,water as a human right, water pricing,and innovative partnerships between water and wastewater utilities and other sectors[22].

In this context,it is necessary to reform political and social institutions to reflect the regional or local nature of water problems and to establish or streamline systems that will coordinate national or international policies with regional decision-making bodies and local solutions[23].The need to build international alliances and frameworks

and find new ways of cooperation is also evident, with the development of two types of strategies:top-down and bottom-up for more efficient water sharing,allocation and use[24].

From another perspective,the repercussions for transboundary water sharing in 2050 are seen as creating a web of conflicts among shared water users[25] .Given that shared surface and groundwater constitute a significant portion of the world's freshwater, conflict between nations is expected to intensify.The importance of transboundary water sharing will continue to increase,and similarly,the significance of water scarcity challenges will grow due to the continuous rise in water demand driven by increasing populations and the decrease in water supplies exacerbated by climate change[26].For example,in 2009 the growing burdens of water scarcity were primarily a result of increased demand for reliable clean water supplies.However,by 2050 the challenge will be significantly compounded not only by increased demand but also because accessible water supplies will shrink as the anticipated impacts of climate change disrupt the pattern and distribution of available water.Consequently, addressing these challenges is a primary task,one that will require nations to reorder their thinking about sovereignty.In this context,collaborative management involving governmental,quasi-governmental, private, and non-governmental actors can achieve equitable and effective water management in 2050[27].

Central to confronting the challenge is the need to establish,implement and enforce effective water-sharing agreements between governments.Certain principles of negotiation are essential for creating these agreements,along with their integration into an administrative and institutional framework that ensures the agreement's implementation is feasible and effective[28].

There is also technical strategies to ensure future water sustainability,the most technologies include the following[29]:

- **Monitoring:**Future technologies will be used to detect changes in soil moisture, water stored in snow,and river and lake levels.New technologies and algorithms will extend these measurements from local levels to the continental scale to estimate river discharges, groundwater changes,and snow water equivalent.The goal is to improve these technologies to provide more accurate and frequent data updates for controlling flood management systems, predicting droughts,and distributing water.
- **Efficient Irrigation Technologies:**The optimal application of irrigation using new sensors and remote monitoring will continue to be developed.
- **Treatment of Non-Potable Water:**Systems include the desalination of seawater and brackish groundwater, with multi-quality parallel supply systems increasing the flexibility of developing and operating distribution networks.
- **Treatment of Recycled and Manufactured Water:**Treatment and transport systems produce and deliver customized product flows that meet the quality requirements for specific uses.

- **Point-of-Use Water Treatment Technologies:**While public urban water supply systems should be obligated to provide drinking water quality,there are opportunities and valid reasons for parallel progress with other future technologies[30].
- **Strategic Planning for Water Maintenance:**Water considerations will be integrated into the planning and maintenance of land use and land cover at all levels.Such initiatives will reduce the loss of usable surface water,reduce flooding, improve drainage flow regimes,reduce downstream pollution,and employ better management practices for the direct use of regulated flows.
- **Models and Decision Support Systems:**Models are being developed to predict supplies and floods in rivers,water bodies,groundwater,wetlands,and other ecosystems.Effective optimization methods will support management decisions under uncertainty in the water resource sector.

Consequently,methodologies for formulating water management policies,strategies, and master plans include[31]:

-Defining the physical,regulatory,and institutional water system and dividing it into subsystems;

-Identifying the system's objectives and organizing them in a hierarchy;

-Determining the measures by which the achievement of water sustainability objectives are evaluated;

-Identifying all policy areas and their components;

-Identifying all rational alternatives;

-Identifying and analyzing the impacts of each alternative on all measures;

-Constructing comprehensive policies for a single policy area or a group of areas or all areas by selecting one alternative for each component;

-Evaluating these policies according to their impact on the measures and thus on the objectives using multi-objective evaluation methods;

-Interacting with decision-makers,interest groups,and experts in all activities to assist in decision-making;

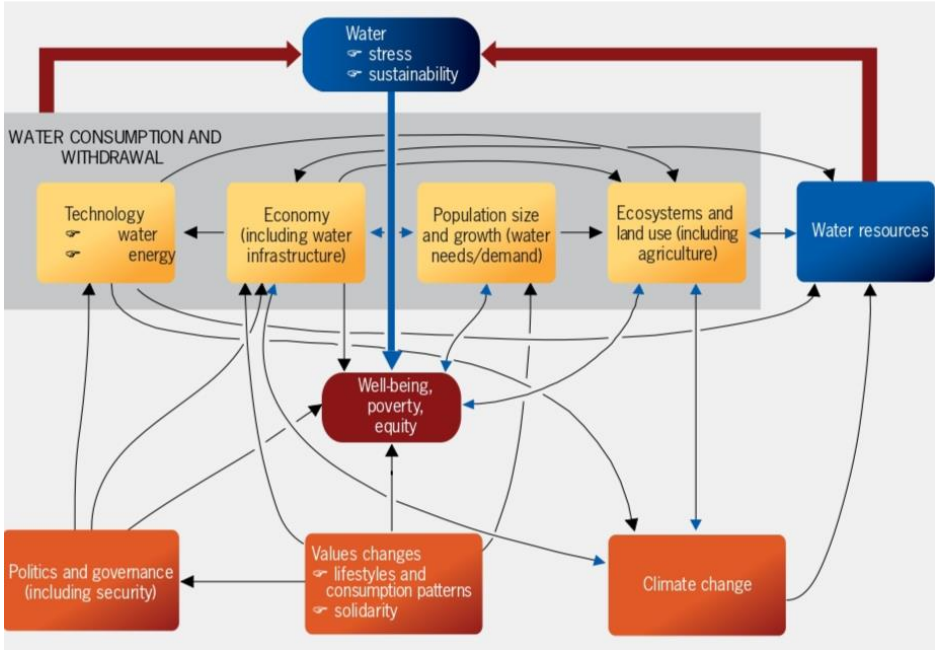
-Continuously monitoring and evaluating changing conditions and the effectiveness of implemented policies,which are communicated to decision-makers, providing feedback on all stages of the analysis.

Through the above, the problem of water sustainability can be explained in (**Figure N°2)** which illustrates that water stress and sustainability are directly determined by available water resources and the amount of water withdrawn and consumed. Furthermore,both water resources and consumption levels are influenced by numerous factors (only the most significant factors and their connections relevant to water scenarios are depicted here).Human well-being and water are key criteria for evaluating the favorability of these scenarios.

The figure organizes the primary drivers sequentially from top to bottom distinguishing between direct drivers that immediately impact water stress and sustainability,and indirect drivers that primarily exert their influence through their effects on these direct drivers.The arrows indicate causal relationships between these

factors,with bidirectional arrows(blue double-headed)signifying reciprocal or feedback causality in some instances[30].

Figure N°2: Key drivers and causal links affecting water stress and sustainability and human well-being



(Source:Gilberto Galopin, Five Stylized Scenarios :Global water futures 2050 (2012), p08)

Secondly:Future Challenges to Ensuring Water Sustainability

Future changes in the distribution and quality of water resources depend on natural variations and human activities,which in turn create challenges due to the interactions between them,these interactions affect future water resource systems. Consequently,attempting to analyze and understand these challenges and their impacts helps in thinking more clearly about various future strategies for water sustainability,more importantly it assists in identifying the decisions and actions that may be necessary to achieve those future visions[31].

1. The Challenges of Climate Change Impacting Future Water Scarcity

Natural geological,hydrological and atmospheric processes exacerbated by climate change and indiscriminate pesticide use, directly and indirectly modify water and environmental systems.Notably,warmer temperatures can disrupt aquatic life's metabolism,and excessive biological production from heat or pesticide runoff deteriorates water quality,with adverse effects on aquatic animals[32].

Climate change presents diverse dangers to water resources and the environment such as straining ecosystems,destabilizing pest control,increasing water pollution and sedimentation,hindering groundwater replenishment,fueling more wildfires,and raising the likelihood of coastal flooding and saltwater contamination of aquifers. Addressing these potential impacts requires local utilities to conduct ongoing re-

evaluations of water infrastructure development policies and adaptive management practices, along with periodic reassessments of the complete water and sanitation lifecycle for successful adaptation[33].

When considering the future of water availability a major unknown factor is the definitive impact of global climate change on global water resources.

The complete ramifications of global warming on the hydrological cycle remain unclear.Nevertheless,persistent warming trends indicate the strong possibility of unprecedented and serious challenges,potentially leading to substantial damage to current water infrastructure by disrupting the predictable patterns, timing,and volume of natural rainfall worldwide[34].Climate change will likely drive decisions regarding ecosystems,energy,food security,and land use,with consequent effects on water resources and environmental sustainability.

By 2050 a major challenge will be to decrease the economic and social sensitivity of human populations to substantial shifts in water patterns[35].

Global warming has the potential to severely disrupt water availability, agricultural productivity,and consequently,food supplies.As scientists analyze the long-term effects, policymakers and economists are also evaluating the potential economic and social ramifications. These water-related shifts include decreased precipitation in arid regions such as Southern Africa and the Western US,coupled with increased rainfall in already wet areas.This pattern suggests that regions already having sufficient water for agriculture may experience more intense rainfall, potentially causing severe flooding in densely populated areas[36].The challenge of water sustainability especially in the climate change is a strategic imperative for future preservation of the water dimension.

2. The Challenges of Demographic Growth

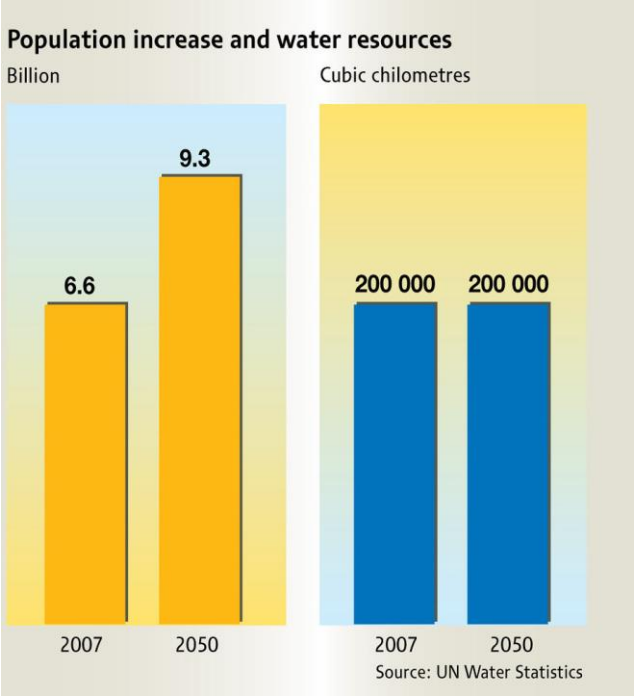
The continued growth of populations in arid environments and in urban and coastal areas,where water supplies are already most stressed, will necessitate looking beyond simply increasing water supply to find solutions for meeting water demand.Trends in population and demographic shifts are among the major pressing factors that will influence how the water industry operates in the coming decades[37].According to some estimates,the global population could reach approximately seven and a half billion people around 2040 or the growth rate could rebound,leading to the Earth supporting ten billion people by mid-century[38].

Increasingly populated communities will need to find resources to fund new water and wastewater facilities and infrastructure.Conversely,regions with stable or shrinking populations face the challenge of a diminishing customer base,leading to reduced revenues needed to maintain underutilized infrastructure or replace aging infrastructure.Other demographic aspects that may affect the management of water facilities include an increasing number of educated individuals,ethnic shifts,and changes in dietary habits and lifestyles,alongside widening income gaps[39].

Consequently,future demographics will exacerbate conflicts over water supplies. Global population growth is also projected to rise from 6.6 billion in 2007 to 9.3

billion in 2050 according to the United Nations Department of Economic and Social Affairs(**Figure N°3**) and (**Figure N°4**).In the absence of greater conservation,this will require an approximate 30% increase in water supplies or a reduction in per capita water use to accommodate this growth.This increase must come from already water-stressed environments and will come at a significant economic and environmental cost[40].

Figure N°3:Population increase and water resources



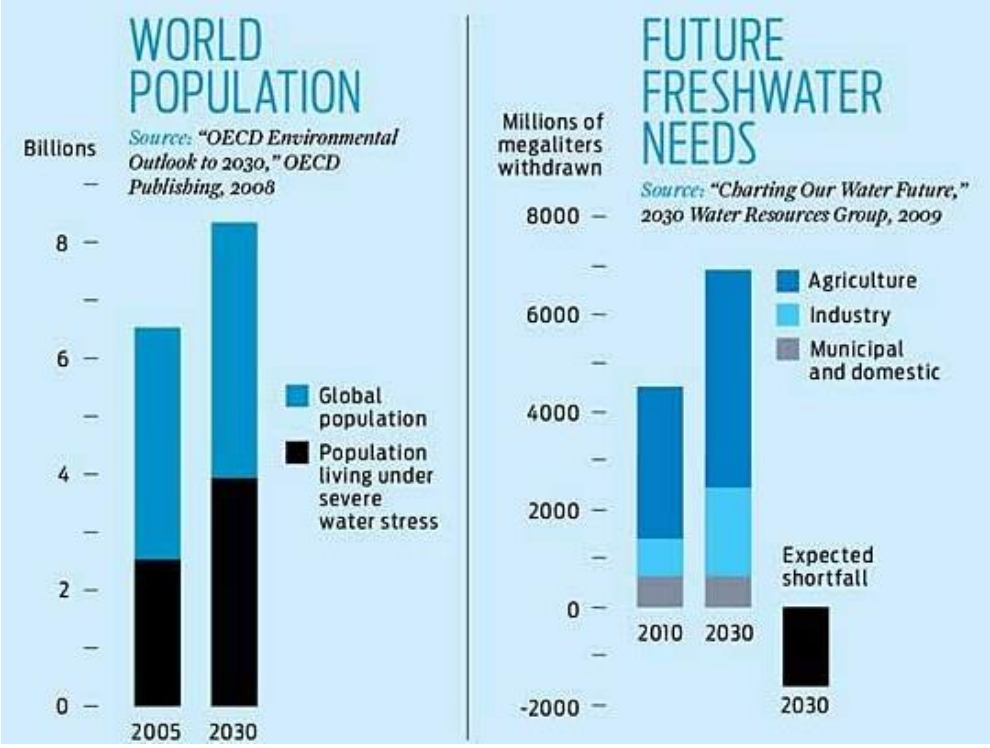
(Source: UN Water Statistics,in: https://www.grida.no/resources/7604)

Countries or regions experiencing population decline will face shrinking rate bases and escalating costs for repairing and rehabilitating existing water infrastructure.For example in the United States the population is projected to rise from an expected 318 million in 2010 to 404 million in 2050, with much of this growth still expected in the South and West regions already facing water supply shortages.Ironically,water supplies in some of these same areas are projected to be disproportionately affected by climate change.Furthermore,the ongoing development of water catchments will contribute to the pollution load on water sources,thus,the shift from agricultural to urban land uses leads to a change in the nature of the pollution load on water[41].

The issue of water management in a dynamic population environment, characterized by water scarcity and floods, and its negative impacts on local ecosystems as well as on humans and infrastructure,leads to decisions regarding environmental migration. Consequently,the social,economic,and political context within which such water stresses occur will influence the migration response,if the natural environment becomes sufficiently degraded,there will be an impetus for

people to move to other areas where their quality of life can be improved,once this migration occurs,these areas must be provided with water resources which may lead to further environmental pressures.Social issues affect water resource systems through the nature of poverty,education,cultures,value systems including religious beliefs,lifestyles,and consumption patterns.All of these social perceptions and attitudes towards the environment and water resources create pressures that affect water requirements and use[42].

Figure N°4:World population and future freshwater needs



(Source: Water Demand and Management Issues,in: https://igeogers.weebly.com/water-demand-and-management-issues.html)

Growing populations drive increased water demand across agriculture (70%),industry (22%), and domestic use (8%), potentially causing a 2000 megaliter deficit by 2030.

3. Challenges Associated with Economic and technological evolution

The escalating global standard of living, in conjunction with increasing population, presents a substantial challenge to the long-term viability of water resources.Meeting the growing demand for goods often necessitates the unsustainable exploitation of natural resources,concurrently generating waste and detrimental byproducts.The fundamental dilemma is balancing human needs and aspirations with the inherent ability of natural systems to supply or regenerate the resources required for their fulfillment[43].

Society must pursue the twin objectives of enhancing human welfare and living standards while safeguarding the sustainability of ecosystems and environmental conditions that underpin the provision of desired goods and services. Realizing this

balance requires a comprehensive human awareness and understanding of the intricate relationships between our actions and the condition and resilience of the natural world [44].A case in point is the situation in emerging Chinese cities, which are dealing with a broad range of water challenges,their drinking water and wastewater infrastructure are a significant and growing worry,likely to become more severe as cities and economies expand.

This implies that China is heading towards a time of greater water stress,irrespective of whether it completes all its planned dam construction[45].

Generating behavioral shifts through increased awareness is a crucial yet demanding undertaking,economic growth is contingent upon a broad spectrum of policy decisions,ranging from international commerce to educational and public health initiatives.Moreover,demographic variables,including population distribution, the size of the local labor pool, the social characteristics and capabilities of the workforce,and the accessibility of new technologies,can affect the prospective rate of economic advancement[46].

From this standpoint, the outcomes of future economic development are uncertain due to growing trends in openness,changes in agricultural water utilization, and the possible effects of technological innovation.Technological change can either spur development that strains water resource infrastructure or optimistically,offer solutions to lessen the consequences of economic expansion.

Accordingly, sufficient investments in water management, infrastructure, and services can yield substantial economic returns by mitigating the dangers posed by floods,water shortages,water pollution,and risks to public and ecological well-being[47].

Another example considers Dubai widely regarded as one of the most advanced and luxurious cities in the world.Yet,it did not build a wastewater treatment infrastructure system,the entire city relies primarily on a single wastewater treatment plant located 20 miles west in the desert.Therefore,all waste is collected in cesspool pits and then must be pumped into trucks and transported to the treatment plant[48].

The emirate also relies on energy-consuming desalination plants for almost all of its clean water.Often,only a four-day supply of clean drinking water is held in reserve. Brine a byproduct is discharged directly back into the ocean and salinity levels have reached dangerous levels in coastal ecosystems.Although the emirate transformed itself from a small desert port to one of the world's major cities in just a decade or two,its environmental problems are numerous[49],advancements in science and engineering have progressively refined the methodologies employed in the planning,design,and operation of our water resource systems.

In the early 20th century,scientific inquiry primarily centered on characterizing these systems through the quantification of riverine flow and the measurement of dissolved and suspended materials transported within. With the subsequent evolution of science and engineering disciplines, the focus of inquiry shifted towards the exploitation of these resources for purposes such as drinking water provision,hydroelectric power generation,irrigation,and waste management[50].

Subsequently,questions emerged concerning the optimal amount of water an individual could withdraw from a river or groundwater aquifer to achieve desired economic gains.Similarly,inquiries addressed the permissible volume of waste discharge into a river without causing detrimental harm to human populations or aquatic organisms[51].

Over time,the central questions transitioned from a focus on resource exploitation to strategies for resource restoration and preservation.The transition to an era prioritizing sustainability is fundamentally changing water management inquiries.

Questions are moving from purely extractive concerns, such as "What is the available water quantity?" or "How much water can we extract?",toward essential ecological considerations like, "How much water must remain within the river system,and what quality of habitat will this sustain?" [52].

For instance,despite generally meeting basic water supply and sanitation needs in the United States,the nation has faced inadequate maintenance of its technological infrastructure over the last century.Consequently,aging infrastructure has become a prominent issue,impairing the effectiveness of water treatment, distribution networks, and wastewater collection systems.

The American Society of Civil Engineers estimates a $2.2 trillion investment is needed over five years to restore this infrastructure to a satisfactory condition, highlighting its current state of disrepair and the urgent requirement for immediate repair,rehabilitation,and replacement.

As we look towards 2050 more inventive solutions are needed to fulfill the functions currently provided by these deteriorating water and sewer lines,especially given the apparent societal reluctance to fund their traditional excavation and replacement[53].

Furthermore,technological innovations exert a dual influence, creating both beneficial and detrimental pressures on water resources,affecting not only their quantity but also their quality.

Certain innovations mitigate environmental burdens by reducing emissions or enhancing water use efficiency,while others amplify these burdens by increasing the demand for water in their production processes.The Green Revolution and genetically modified organisms in agriculture serve as examples of technological advancements that,while offering benefits, can also place additional strain on the environment. Environmental regulations that incentivize industries and other water users to develop technologies addressing water availability and quality issues can yield societal and environmental improvements.However,these regulations may also inadvertently stifle further technological progress if the established standards become overly restrictive, thereby diminishing the motivation for continued innovation[54].

Viewing the issue from the lens of interconnected sectors,a strong nexus exists between water and energy,water is indispensable for energy generation and utilization,while energy is equally crucial for the purification,conveyance,and application of water. Given that renewable energy sources alone are projected to be

insufficient to meet the substantial surge in energy demand expected by 2050,the extraction of fossil fuels and the expansion of nuclear power,at least in numerous countries,will likely continue to rise, consequently amplifying their impact on both water resources and the environment.The potential for increased energy costs may compel water and wastewater utilities to prioritize enhanced energy efficiency to mitigate these expenses.However,the energy-intensive nature of novel treatment technologies may hinder their full realization of anticipated benefits[55].

Shifting perspective to international relations, the dynamics of transboundary water sharing in 2050 are anticipated to create a complex web of conflicts among nations that share water resources[56].As shared surface and groundwater systems constitute a significant proportion of the world's freshwater reserves,interstate conflicts are predicted to intensify.The importance of effective transboundary water sharing mechanisms will continue to grow,paralleled by an increasing significance of water scarcity challenges driven by sustained population growth and a climate change-induced reduction in available water supplies.For instance,while the growing pressures of water scarcity in 2009 were primarily attributed to escalating demand for reliable clean water sources,the situation by 2050 is projected to be considerably more severe due not only to further demand increases but also to the contraction of accessible water supplies as the anticipated effects of climate change disrupt the natural patterns and distribution of usable water.Consequently,addressing these multifaceted challenges represents a significant undertaking that will necessitate a re-evaluation of national sovereignty concepts[57].

Within this context,collaborative management frameworks involving governmental, quasi-governmental,private sector,and non-governmental stakeholders hold the potential to achieve equitable and effective water management by 2050.Establishing and enforcing robust water-sharing agreements among governments is essential to effectively address the challenge of water management.

Specific negotiation principles and their integration into comprehensive management frameworks are crucial for the successful implementation of these agreements.[58].

Conclusion

The study objective was to analyze the dynamic relationship between the variable of water sustainability and climate,demographic growth,technological and economic evolutions variables,through the pattern of interaction among these variables as future challenges in an attempt to ensure water sustainability,three important ideas related to three levels can be concluded:

Firstly,the first level is related to pathways for assessing how future strategies impact water sustainability by measuring the extent to which issues related to future water scarcity are reduced.

The first level of engagement is all about figuring out how well future strategies will work by directly measuring how they will affect water sustainability.This is

basically the analytical and foresight stage that decides if the proposed plans are strong enough to deal with the threat of future water shortages.

Secondly,the level related to ensuring the rational implementation of proactive future plans,which determines the extent of the ability to activate areas of water conservation as a resource that ensures the continuity of self-sufficiency and the ontological security of the state.This is the process of successfully converting strategic water policies-created by projecting future demand,climate risks,and technological capabilities-into tangible,quantifiable,implemented projects.

Rational implies that decisions are evidence-based economically and environmentally sustainable,avoiding political expediency or short-term gains at the expense of long-term water health.

Thirdly,the level related to the processes of perceiving the existential and normative value of the idea of water as a mechanism for future sustainability.

This level reflects the fundamental change in social ethics and human consciousness needed to address the world's water problems.It transcends technical management to internalize water's profound,dual value and make it the focal point of all upcoming sustainability initiatives.

Margins:

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[24] Ibid,p204.
[25] Stephen Draper,Op.Cit,p52.
[26] Ibid,p53.
[27] Idem.
[28] Ibid,p53.
[29] Uri Shamir and Charles Howard,**Water Management in 2050**.in:Walter Grayman **and other,Toward a Sustainable Water Future:Visions For 2050.**American Society of Civil Engineers,2019,p39.
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[31] Ibid,p41.
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[32] Idem.
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[34] Steve Maxwell and Scott Yates,**The Future of Water:A Starling Look Ahead.American Water Works Association**,2011,p191.
[35] Walter Grayman and other,Op.Cit,p27.
[36] Steve Maxwell and Scott Yates,Op.Cit,p191
[37] Walter Grayman and other,Op.Cit,p25
[38] Steve Maxwell and Scott Yates,Op.Cit,p185-186.
[39] Walter Graymanand other,Op.Cit,p25
[40]Stephen Draper,Op.Cit,p118
[41]Idem.
[42] Walter Grayman and other,Op.Cit,p25-26.
[43] Idem.
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[46] Walter Grayman and other,Op.Cit,p26.
[47] Steve Maxwell and Scott Yates,Op.Cit,p193.
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[52]Robert Hirsch,**The Science,Information Engineering Needed to Manage Water Availability and Quality in 2050**.Walter Grayman and other,**Toward a Sustainable Water Future:Visions For 2050.**American Society of Civil Engineers,2019,p218.
[53] Walter Grayman and other,Op.Cit,p27.
[54] Ibid,p28.
[55] Ibid,p30.
[56] Stephen Draper,Op.Cit,p52.
[57] Idem.
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