ZAOULI – N° 9, Vol. 4 - Mars 2025 pp. 219-265 ISSN : 2788-9343
Soumission : **26/12/2024** Acceptation **: 28/02/2025** Publication: **31/03/2025**

Virtual Water as a Mechanism to Achieve Sustainable Water Security in Light of the Threats of the Global Water Future

Fatiha GUECHEROU
Laboratory of the management of local authorities and their role in achieving development, Economics, Business and Management Faculty,
University of Blida 02- Lounici Ali-Algeria,
guecheroufatiha2023@gmail.com

Abstract:
This study highlights the role of virtual water as a mechanism to achieve sustainable water security in light of various challenges such as water scarcity, climate change and international conflicts, as virtual water is used to reduce pressure on local resources by allowing water-scarce regions to import water-intensive products. The study emphasizes the need for water policies Improving infrastructure, enhancing international cooperation for equitable water distribution, public awareness of virtual water trade, the importance of modern technologies in improving water management, tracking virtual water flows, and investing in research to enhance the efficiency of its use. This makes it a tool to address global water challenges, reduce conflicts, and ensure water security for future generations.

***Key Word**: Virtual Water, Sustainable Water Security, Water Treats, Global Water Future.*

L'eau virtuelle comme mécanisme permettant d'assurer une sécurité hydrique durable face aux menaces qui pèsent sur l'avenir mondial de l'eau

Résumé :
Cette étude met en évidence le rôle de l'eau virtuelle comme mécanisme permettant d'assurer une sécurité hydrique durable face à divers défis tels que la pénurie d'eau, le changement climatique et les conflits internationaux, car l'eau virtuelle est utilisée pour réduire la pression sur les ressources locales en permettant aux régions souffrant de pénurie d'eau d'importer des produits à forte consommation d'eau. L'étude souligne la nécessité de mettre en place des politiques de l'eau visant à améliorer les infrastructures, à renforcer la coopération internationale pour une distribution équitable de l'eau, à sensibiliser le public au commerce de l'eau virtuelle, à souligner l'importance des technologies modernes dans l'amélioration de la gestion de l'eau, à suivre les flux d'eau virtuelle et à investir dans la recherche afin d'améliorer l'efficacité de son utilisation. Cela en fait un outil permettant de relever les défis mondiaux liés à l'eau, de réduire les conflits et d'assurer la sécurité hydrique pour les générations futures.

Mots clés *: Eau virtuelle, sécurité hydrique durable, traitement de l'eau, avenir mondial de l'eau.*

Soumission : **26/12/2024** Acceptation : **28/02/2025** Publication: **31/03/2025**

Introduction:

Water is the backbone of life and one of the most important natural resources that are indispensable to ensure the continuity of man and living beings on earth. It is not only an essential element for survival, but also a vital pillar of economic and social development, as it is used in various sectors such as agriculture, industry, and energy production. However, this vital resource faces significant challenges due to increasing consumption and environmental changes, placing it at the forefront of pressing global issues.

In light of these challenges, the concept of "water security" has become central to ensuring that water is provided in sufficient quantities and quality to meet the needs of individuals and communities, without harming ecosystems. Water security does not only mean securing water for direct use, but requires integrated and sustainable management of water resources to ensure a balance between present and future demand and supply, especially in the face of population growth and climate change.

Within this context, the concept of "virtual water" has emerged as an innovative tool to achieve water security. This concept refers to the amount of water used to produce goods and services traded across borders, providing an opportunity to ease pressure on local water resources. With a thorough understanding of virtual water movement, countries can strengthen their water strategies and achieve economic integration that contributes to sustainable water security. From this angle, the main problem of our research crystallizes as follows:

How can virtual water be employed as a mechanism to achieve sustainable water security in light of the escalating threats to the future of water globally?

Research Objectives:

This study seeks to achieve the following objectives:

- Clarifying the concept of water security.
- Know the various threats facing the future of international water security and its future challenges.
- Provide some mechanisms and solutions to face the water problem in the future.
- Highlighting the role of virtual water as one of the most important mechanisms used to achieve sustainable water security.

Research Importance:

The importance of this study lies in the following points:

- Increasing the world's water-related challenges.
- The issue of water is currently a topic of concern to all countries in general. and Arab countries in particular, as it is the scarcity region in the world.
- Water security is linked to food security and sustainable development.
- Global trend towards the use of virtual water mechanism.

Research Methodology:

In this research, we relied on two approaches, the descriptive approach was used to familiarize themselves with the concept of water security and the various concepts associated with it, the most important threats facing it, and the analytical approach in studying some indicators, data and reports and presenting some future strategies in the field of water security and the use of virtual water to achieve it. As for the study tools, we have relied in this research on a group of books, articles and various reports interested in this topic, and some websites.

Previous studies:

There are many previous studies that focused on the importance of water security and the challenges associated with the distribution of water resources, whether across borders or within countries, and dealt with different dimensions of water security, such as food security, data exchange between countries, the importance of comprehensive water policies, and the use of modern technologies, such as virtual water trade. Studies on the need for international and regional cooperation for water resources management, with a focus on future threats to water, among the most important of these studies we mention the following:

- A study entitled: "Egyptian Water Security in Light of the Water Conflict 1990-2020", Yazid Boussak, PhD thesis in Political Science and International Relations, specializing in African Studies, University of Algiers 3, Faculty of Political Science and International Relations, 2021-2022. One of the most important findings of the researcher is that water security is an important economic issue on how to ensure a clear and serious policy that protects water wealth from the risks of depletion.
- A study entitled: "Integrated Management of Transboundary Groundwater", Muhammad Hussein Sayed Hussein Banwan, Journal of the Arab Researcher, Volume 04, Issue 02, 2023, The most important findings of the researcher are the great importance of integrated water management and the need to develop long-term plans to face future chal-

lenges and the use of technology in groundwater monitoring and the exchange of data and information between countries to understand and improve the exploitation of resources.

- A study entitled: The Water Crisis and its Impact on International Relations (Nile Basin Countries as a Model),Tassaidit Charmali, Magister Thesis in international law and international relations, Faculty of Law, Ben Kanoun University, Algeria,2014, This study aimed to explore conflicts over shared water resources, focusing on the Nile River, where disputes arose between upstream countries, especially Ethiopia, and downstream countries, Egypt and Sudan, due to the lack of a comprehensive water-sharing agreement.
- A study entitled: The Role of Virtual Water Trade in Water Challenges in the Middle East, Amani Essam Mohamed, Journal of the Faculty of Economics and Political Science, Cairo University, Volume Twenty-Three, Issue IV, October 2022.This study aimed to examine the role of virtual water trade in addressing water challenges in the Middle East, suggesting it as an alternative solution to conflicts over water resources, it concluded that virtual water trade impacts social, economic, and food security, and should be part of a comprehensive national policy for national security.

The difference between the topic of our study and previous studies lies in the fact that previous studies have focused on **water resources management in general** and on **current challenges** such as water conflicts in the Nile Basin, water security, and transboundary groundwater management. While our study tries to give a scientific addition by analysing **the role of virtual water as a future solution** to the problem of water scarcity and facing future threats to global water, and tracking the various future trends of virtual water with the aim of enhancing sustainable water security.

1. Conceptual framework of the study variables:

In this section, we will present the conceptual framework of the study variables, which are: sustainable water security, water threats and virtual water.

1.1. The concept of water security

1.1.1. Definition of water security:

Water security is defined as the stable status of water resources, and this situation is achieved when the available water resources respond to the demand for them, that is, the degree of water security of a country depends on the nature of the relationship between the supply of water and the demand for it in a certain period of time, and then the concept of water security can be dealt with as a relative concept that increases and decreases according to the nature of the relationships between water supply and demand(Ali Abdullah, 2014, P: 02).

The concept of water security for any country is determined by the analysis of the water balance, which can be in three cases (Ali Abdullah, 2014):

- Water BALANCE: It decreases when the demand for water equalizes the volume of supply.
- Water SURPLUS: When the volume of water resources is greater than the size of needs.
- Water DEFICIT: In which the volume of available water resources is less than the volume required to meet the necessary water needs.
- Water security is also defined in the World Water Council document in the launch of the work towards water security as: "Any member of society has access to sufficient clean and safe water at an affordable cost in order to lead a healthy and pro-

ductive life without affecting the sustainability of the natural environment (FAO, 2024)."

- Water security is based on several foundations (Naim Ibrahim, 2000, P:88):
- Water is one of the basic requirements for development, as without water it is not possible to carry out development processes and various economic sectors, especially in the fields of drinking, agriculture and industry.

Competition for water resources between countries makes it a vital commodity and a cause of conflict.

Considering water as an economic good commodity, meaning that it is not a free commodity, and therefore wasting water or not rationalizing its use will lead to damage to the environment.

1.1.2. Concepts related to water security:

There is a close link between the concept of water security and other concepts such as food security, national security and human security, including:

- **Water Security and Food Security:**

The Food and Agriculture Organization of the United Nations (FAO) has defined food security as: "The access of all people at all times to all foods that meet their food needs and tastes in order to lead active and healthy lives (FAO, 2024)." Food security will remain linked to water security forever no matter how circumstances change, and this link becomes more evident in times of crisis, as water acquires great importance in order to meet the basic needs of the population, as there is no well-being without water and development (Boudouama, 2016, P:143).

ZAOULI – N° 9, Vol. 4 - Mars 2025 pp. 219-265 ISSN : 2788-9343
Soumission : 26/12/2024 Acceptation : 28/02/2025 Publication: 31/03/2025

The concern for achieving food security has always been the problem of all countries, especially after the emergence of the global food crisis and the extension of its negative effects on most sensitive sectors such as the economy, as 30-40% of the world's food comes from 7% of the total arable land that uses irrigation water in its cultivation, in addition to that a fifth of the total value of fish production comes from farming using clean water, and therefore the development of water for food production is a key element in increasing food security(Ould Cheikh,2024).

- **Water and National Security:**

National security is defined as the concept of protecting the state and citizens through the policies of imposing power, whether political, economic, diplomatic and military. Water security is linked to national security in an influential relationship, as the lack of water resources inevitably leads to food shortages, on which human existence depends, and food has become today one of the most dangerous weapons used by countries in their foreign relations, which would raise the ceiling of challenges posed by the economic requirements and management of strategic management, which depends more on the internal resources of the state and competencies, as security in its origin is indivisible as a concept, indication or application, whether related to This is in the security of the State, or in the security of the individuals contained in that State (**UNESCO, 2023**).

1.2. Threats to the future of water security

In this section, we will address the various factors that pose a threat to the future of water, represented by natural and environmental factors, economic and human factors, scarcity and limited water resources, climate change, international conflicts over water and the absence of a legal framework to protect water security.

1.2.1. Natural and environmental factors affecting water security:

- **Drought:**

Drought is one of the results of sand encroachment, which leads to low rainfall and water scarcity, which is a natural phenomenon witnessed by several countries, and the largest part of the Arab lands is located in the arid and semi-arid region of the world, which leads to the scarcity of financial resources (Dhaifallah, 2020, P: 101)

- **Desertification:**

It is a negative phenomenon that spreads in many parts of the world, especially the Arab region, and desertification has severe damage to the environment and its organisms, and it often results from interaction in natural climatic fluctuations.

- **Salinization:**

It is the unsuitability of water for drinking and irrigation, as salinization is a logical product of water shortage, in Iraq 50% of the irrigated area faces the problem of salinization, and the efficiency of irrigation use is reduced to 40%. Syria also faces the problem of salinization resulting from poor drainage and misuse of water (Mufaddal, 2024).

- **Unbalanced distribution of water:**

We find that the population of the earth currently consumes 54% of renewable freshwater sources for industry, agriculture, irrigation and others, and that as a result of the significant increase in the population, their needs of renewable fresh water will reach 70% of the total available resources by 2025, we find that the per capita consumption of fresh water increased from 1990-1995 by 50%, so attention must be paid to increasing fresh water resources, by building dams on rivers to reduce the amount of loss, conserve water from pollution, search for non-conventional water resources and reduce wasteful water use at all levels (Ingrao et al, 2023).

II-2-1-5-Pollution: One of the most important threats to water resources in the world, due to the weakness of environmental protection techniques from the effects of industrial pollution, which leads to the loss of large quantities of water, groundwater and surface resources. Increased waste from industry, agriculture and humans leads to increased pollution (Karfaj, 2019, P: 56).

2.2.2. Economic and human factors:

- **Weak infrastructure:**

The weakness of the infrastructure and the primitive technologies available to the supplier countries weaken their capabilities to store and benefit from water, as well as distribute it, in addition to the fact that their financial capabilities do not allow them to complete development projects and investments in this field, such as desalination of seawater, for example. This is done by knowing the extent of development of water networks in the country, the volume of water uses in domestic, industrial and health uses, the quality of agricultural activity and the system followed in the production of agricultural crops (Charmali,2014, P:55). It should be noted that in the case of the Nile River Basin countries, for example, which suffer from extreme poverty, despite the availability of water in large quantities in the "Nile River Basin", where the amounts of rainfall are estimated

Annually on the basin about 1600 billion m3, and despite the fact that this water is characterized by its purity, the state of poverty suffered by the countries of the basin prevents the completion of projects.

- **Waste:**

The problem of waste is one of the internal dimensions of the Arab water security gap, and the misuse of available water resources in the Arab region and the corruption of the Arab water policies followed are among the internal threats to Arab security, as they end up wasting national capabilities and capabilities, and there are a number of factors that lead to the waste of Arab water:

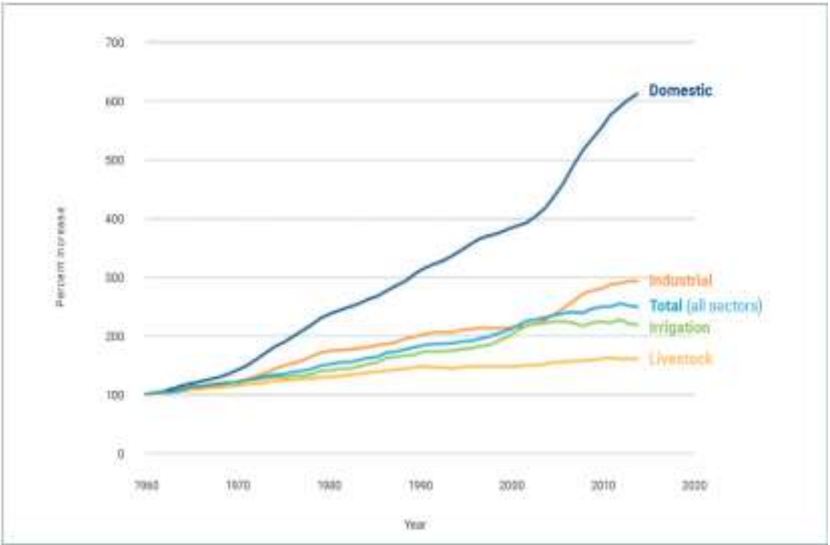
- Adopting improper irrigation systems.
- Wasteful use of Arab water reserves in unproductive activities.
- Lack of financial allocations required for water resources development programs and projects.

The predominance of selfishness over joint Arab action, such as the waters of the Shatt al-Arab, which represents the confluence of the Tigris and Euphrates rivers, as they waste waste in the sea while the Gulf countries spend huge amounts of money on desalination at a rate of six dollars per cubic meter of desalinated water (Karfaj, 2019, P:57).

Poor infrastructure to deliver and store water supply to users (Ziam, 2023, P: 334).

ZAOULI – N° 9, Vol. 4 - Mars 2025 pp. 219-265 ISSN : 2788-9343
Soumission : 26/12/2024 Acceptation : 28/02/2025 Publication: 31/03/2025

Figure 1: Increase in water withdrawals for different sectors, 1960-2020



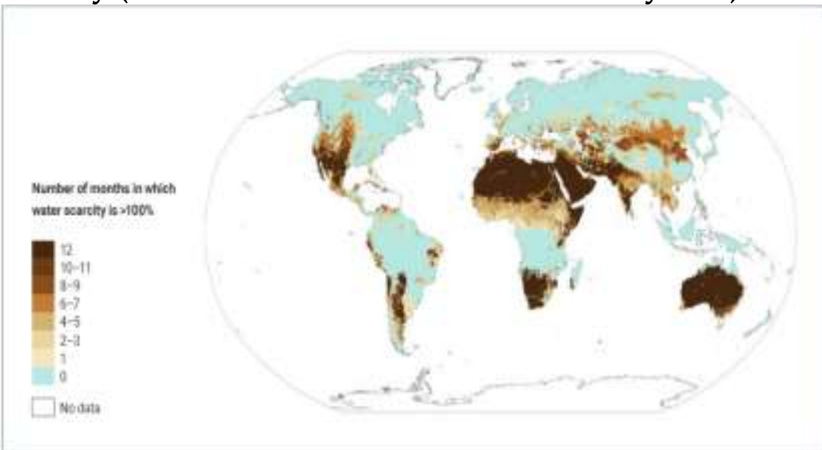
Source: UNESCO, Water for prosperity and peace, United Nations World Water Development Report, 2024, p: 11, https://unesdoc.unesco.org

Recent and future trends in water demand are notoriously difficult to measure and estimate. However, the available evidence (figure 1) suggests that water demand from the municipal (or domestic) sector has experienced a considerable increase relative to the other sectors and is likely to continue growing as populations urbanize and the water supply and sanitation systems servicing these cities expand.

1.2.3. Scarcity and limited water resources:

Freshwater represents a scarce resource, as the volume of water on the planet is 1.4 billion km3, while the volume of fresh water suitable for human consumption is only 2.5, and most of it is inaccessible as most of it is found in glaciers, snow and ice, and the largest source of fresh water is represented by 08 million km3 of groundwater, where rivers, streams and lakes contain only 0.3% of fresh water (105.000 m3) (Wardam, 2003, P:304). The following figure (figure 2) represents the geographical diversification of water-scarce areas represented by the number of months per year.

Figure 2: The number of months per year with severe water scarcity (ratio of water demand to availability >1.0)



Source: UNESCO, Water for prosperity and peace, United Nations World Water Development Report, 2024, p: 12, https://unesdoc.unesco.org

1.2.4. Climate change:

This climate change has affected water resources worldwide and led to an average sea level increase of 1.75 mm per year during the second half of the twentieth century. They cause widespread confinement of non-polar glaciers, reducing water flow in the dry season, solar energy trapped in the atmosphere by greenhouse gases directs the hydrological cycle, and any increase will lead to a marked

ZAOULI – N° 9, Vol. 4 - Mars 2025 pp. 219-265 ISSN : 2788-9343
Soumission : **26/12/2024** Acceptation **: 28/02/2025** Publication: **31/03/2025**

intensification of the cycle, altering rainfall patterns and exacerbating extreme events such as droughts and floods (Makki,2023, P:119).

1.2.5. Disputes and conflicts over water:

The United Nations recognizes that disputes over water are caused by the conflicting interests of water users, public or private sector, disputes often occur over fresh water and freshwater resources because of their necessity and scarcity in the conflict zone, and the ineffectiveness of seawater desalination technologies in terms of cost (Boussak,2021).

The United Nations World Report 2024 entrusted to UNESCO confirms that tensions over water exacerbate conflicts around the world, and that if countries want to maintain peace, they must advance international cooperation and stimulate cross-border agreements, as the more water stress exacerbates, the greater the risk of igniting conflicts at the local and regional levels. The international community has recently become more aware of water issues and their escalating importance and the future conflicts and wars that threaten to increase day by day, as they are the first engine of economic growth, and the United Nations report predicted a 40% supply deficit by 2030, which calls for pushing the challenges by developing new water management mechanisms (World water development,2024).

1.2.6. Absence of legal frameworks:

In principle, it is noted that there is no explicit legal provision on the right to water security, whether at the level of international or national law, due to the lack of legal structures adapted to the nature of human rights based on the logic of the philosophy of human security and the absence of the possibility of codifying the foundations and components of the right to water security (Gleick,1999). The strategic, political and economic role of water will increase in the coming decades worldwide, and therefore water is not only about food, but constitutes the basic basis for industrial development, economic development, social and political stability and civilizational growth in its various fields.

1.3. Virtual water and various associated concepts

The concept of virtual water is related to many concepts, which we will explain in this section.

1.3.1. Concept of virtual water:

It is a relatively recent concept, it appeared in the mid-nineties, and "Tony Allen" is the first to launch this concept, and "Tony Allen" defined virtual water as (Abdul Rahim,2014, P:02) "Water used in other places to produce food that is exported to areas of water scarcity. "Since water is an important variable in crop production, different countries should determine how much water is needed to produce the food they need, and when a country imports a ton of wheat and maize, it actually also imports virtual water, i.e. water needed to produce those crops," he argues: "Since water is an important variable in crop production, different countries should determine how much water is needed to produce the food they need, and when a country imports a ton of wheat and maize, it also actually imports virtual water, i.e. water needed to produce those crops." The concept was introduced in 1993 by Allen but it took a decade to be adopted as a resource for water security at all levels (Abdul Rahim, 2014, P:03).

It should be noted that the first international conference on this subject was entitled International Expert Meeting on

Soumission : **26/12/2024** Acceptation : **28/02/2025** Publication: **31/03/2025**

Virtual Water Trede, Duteh City of Deflit, Nertherland, 2003, and this concept includes water used in the production and trade of food and other consumer products at all stages of production. In light of this, virtual water is defined as the past content in any product, and therefore virtual water exported from a country or region is only that water contained in Product or goods exported from this country (Abdul Rahim, 2014). Water-scarce countries can reduce the cultivation of water-intensive crops by importing them from water-abundant countries.

1.3.2. Concepts associated with virtual water:

There is a relatively recent trend in the literature concerned with water file management towards taking advantage of technology to achieve optimal use of water resources. Many studies point to concepts such as virtual water, virtual water trade, economic aspects of virtual water trade, sustainable flow of virtual water resources, the nature of virtual water flow in the context of international trade, water footprint, and the water footprint industry as an emerging global trend (Essam Mohamed,2022, P:131).

- **Virtual water trade:**

This concept is one of the means that will increase the efficiency of water use worldwide, as it indicates that countries suffering from water scarcity can import goods relatively low in virtual water content to maximize the value of the limited water they have, and in this way the importing country achieves savings in real water to relieve pressure on its water resources, and at the same time this saving can be used for other purposes and uses with high productivity, i.e.

generate A greater multiplier value per unit of water (Essam, 2022).

- **Water savings:**

The most positive impact of virtual water trade in importing countries, and water savings are at the local level through the import of stingers that consume more water than producing them locally, and virtual water trade does not involve the process of saving water only, but also involves the process of water loss for exporting countries, meaning abundance and loss here from the material aspect and not from the economic aspect(Essam,2022).

- **Virtual water balance:**

It is the sum of virtual water exchanged during a certain period for a country, that is, it is equal to the difference between what exports and imports contain in virtual water according to the needs of each good or service, if what the state exports exceeds the water it imports, this is calculated as a deficit, and if the import exceeds the estimate, there becomes a surplus of virtual water.

- **Water footprint:**

As the second use of the concept of virtual water lies in the fact that the virtual water content of an approach reflects the environmental impact of the consumption of this product, in other words, knowing the virtual water content of a product gives an idea of the volume of water needed to produce various goods, and then knowing which goods have a significant impact on the water system, and Keith can achieve water savings through that, and the concept that reflects this is known as the water footprint provided by AOEKSTRAX AEING In 2003, the water footprint of a coun-

Soumission : **26/12/2024** Acceptation **: 28/02/2025** Publication: **31/03/2025**

try is defined as "the total volume of water needed to produce goods and services consumed by each member of the state, and the water footprint of any group of consumers such as (family - company - village - city - state), the internal water footprint is defined as: "the use of local water resources to produce goods and services consumed by each member of the state (Essam, 2022)."

A water footprint measures the amount of water required to provide a good or service. It estimates the amount of water used by a particular person, organization or region. This total includes the green water footprint, the blue water footprint and the grey water footprint as follows (Water Footprint Network, 2024):

- **Green water footprint:**

The amount of rainwater used in crop irrigation and production is known as the "green water footprint", and is expressed in cubic meters per year and square meters Since green water is the main source of water for agriculture, it constitutes the most important part of the water footprint and since water evaporates from soil or plants and is not visible, the water footprint is also the least obvious.

- **Blue water footprint:**

The amount of surface and groundwater required for production is known as the "blue water footprint" and is expressed in cubic meters per year and square meters, and it includes groundwater, aquifers and surface water, such as rivers, streams and lakes, and blue water acquires great importance because it is the water that people and companies use frequently.

- **Gray water footprint:**

The amount of contaminated water released from manufacturing is known as the gray water footprint. Each square foot is expressed in kilograms per year, and this includes water contaminated by chemicals or other industrial pollutants Since the eye can see water, the portion of the water footprint is more visible.

2. Strategies to confront the water problem in the future:

With the increasing pressure on the world's water resources, it has become necessary to find strategies and solutions to confront water scarcity in the future, by improving water resources management, increasing water efficiency, as well as resorting to international cooperation in solving the problem of transboundary water and achieving sustainability in these resources.

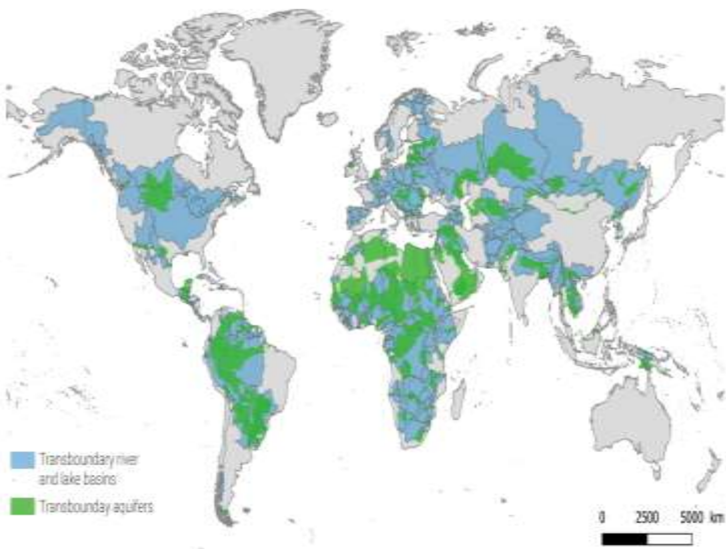
2.1. International cooperation in the field of transboundary waters:

Cooperation across shared water, rivers and aquifers between countries is important for several reasons, one of which is related to their material importance, transboundary waters account for 60% of the world's freshwater flows, and 153 countries have lands within at least a basin out of 286 transboundary river and lake basins and 592 transboundary aquifer systems .Therefore, ensuring water availability and sustainable water and sanitation management for all while maintaining healthy ecosystems requires countries to consider how they manage the quantity and quality of water originating from or flowing into another country's territory(UNESCO,2020).

ZAOULI – N° 9, Vol. 4 - Mars 2025 pp. 219-265 ISSN : 2788-9343
Soumission : 26/12/2024 Acceptation : 28/02/2025 Publication: 31/03/2025

Cooperation in transboundary waters also plays a crucial role in addressing the impacts of climate change that are putting significant pressures on the world's transboundary waters, as cooperative arrangements in transboundary basins allow for more effective adaptation to changing conditions through the sharing of evidence and the expansion of planning space that in turn can help promote political stability and sustainable development at the regional level. Water resources and adaptation options within countries that share a river, lake or aquifer (UNESCO, 2020).

Figure 3 : Transboundary River and lake basins, transboundary aquifers and international borders



Source: United Nation (UN), Progress on Transboundary Water Cooperation,2018, P:14, https://www.unwater.org

Through this map(figure3), we can see those transboundary rivers and lakes, which are represented in areas colored in blue, are abundant in North America, Europe, parts of Asia and Africa, while transboundary groundwater basins appear green and are found significantly in large areas of Africa, South America and Southeast Asia. International borders are marked with gray lines showing how rivers, lakes and groundwater basins intersect with political boundaries between states, reinforcing the idea of water resources management, which requires effective international cooperation to avoid conflicts and ensure equitable and sustainable use of water.

Among the most important actions to achieve cooperation in transboundary waters are (United Nation, 2018):

Scientific and legal research and studies shall be adapted to take note of all aspects relating to aquifers shared by two or more States, particularly with regard to their composition, the impact of the benefits prevailing over them and the nature of the surrounding places.

Working on the development of comprehensive agreements between the countries involved in groundwater and transboundary basins so that all concerned countries participate in them and that they are implemented in good faith to achieve the benefit of all countries (Sayed Hussein,2023, P:104).

All the necessary capabilities must be available to build an integrated and comprehensive database on the available and expected groundwater resources also used from groundwater resources at the present time so that the database includes the locations of wells and their properties, with the need for these data to be characterized by culture to work to achieve integrated management.

ZAOULI – N° 9, Vol. 4 - Mars 2025 pp. 219-265 ISSN : 2788-9343
Soumission : 26/12/2024 Acceptation : 28/02/2025 Publication: 31/03/2025

States involved in transboundary aquifers shall join forces to establish, transform and maintain international purchasing committees as an effective basin management mechanism, with the right to issue

Binding decisions in the field of environmental protection of the aquifer, to be composed of representatives with experience in the hydraulic and legal field, are proposed by each country (Sayed Hussein, 2023, P:105).

2.2. Water Demand Management:

Water demand management is one of the most important strategies to confront the water problem in the future, and this strategy depends on a set of tools including governance, scientific research and information technology, and developing skills to address the water problem.

2.2.1. Governance:

Integrated water management and governance relies on a multi-level participatory approach to manage water allocation and resolve related disputes, promoting prosperity and peace. Equitable water distribution encourages investment, supports equitable benefit-sharing, and promotes social cohesion (United Nation,2004). Water governance requires arrangements that focus on strengthening cooperation, managing challenges and resolving tensions, by setting rules for allocating water among its multiple uses and setting policy objectives in vital areas such as health, agriculture and energy and infrastructure and investment.

2.2.2. Science, Technology and Information:

Water management makes great use of modern technology, including information technology, communication networks, remote sensing, advanced sensing equipment, low-cost citizenship science applications, and big data analytics Artificial intelligence is a promising option to address the challenges of water and sanitation systems, agriculture, industry, and water resources management. However, the overall implications of this technology remain unclear, as there are potential risks such as Design errors and cyberattacks, which may lead to infrastructure failure in the worst-case scenario. IT companies need large amounts of water to cool and power AI equipment. Effective water resources management also requires accurate data on location, quantities, quality and demand, which is often lacking in relevant government agencies due to their limited capacity to collect and analyse data. (United Nation,2004).

2.2.3. Capacity Development through Education:

Despite significant advances from reliance on new technology, there is a growing gap between the worsening water management problems and the knowledge and skills available to address them in many places, this reality hinders new technologies in water treatment and integrated river basin management, leading to increased water wastage and pollution of freshwater sources along with unsatisfactory levels of water, sanitation and hygiene services. Education and capacity development play a pivotal role (United Nation,2004).

3. The role of virtual water in achieving sustainable water security

Virtual water plays a vital role in achieving water security, a concept that refers to the amount of water consumed in the production of goods and services, with the increasing demand for water resources and the challenges of climate change, it becomes necessary to understand how water is used in production and distribution chains, through virtual water trade countries can improve water management strategies, reduce losses and enhance efficiency, contributing to achieving water security at the local and global levels, this approach can also help achieve tensions between states around shared water resources, supports sustainable development and ensures the availability of water for future generations.

3.1. Virtual water as an ideal solution to achieve the Sustainable Development Goals:

The issue of water scarcity captured a full session of the "Bio Vision 2018" conference held in Alexandria, where it was agreed that virtual water carries in its nature one of the optimal solutions to confront water poverty that the world fears, and that millions of people, mostly children, are dying due to diseases associated with inadequate water supply, sanitation and hygiene, and water scarcity affects more than 40% (Bio Vision Alexandria Reports, 2018). The world's population is expected to rise, hence the importance of virtual water, as this importance is that it is an important axis for rationalizing water consumption in personal and agricultural consumption, but if we look at the concept of virtual water more broadly, we find that the importance can be summarized as follows:

Achieving water efficiency: Using virtual water trade as a tool to achieve efficiency in water use and reduce its capacity, it may be more reasonable to import water through the import of food, instead of using the scarce and high-cost water element in the production of all developmental food, and therefore virtual water trade can be seen as a tool of cooperation, exchange and communication between countries.

Achieving food security :Using the concept of virtual water in achieving food security to meet the challenge in providing food security, which is largely related to water security through virtual water trade, where the state can achieve food security despite the scarcity of its local water resources.

Rethinking the export policy of countries: The concept of virtual water should prompt many countries with scarce water resources to reconsider their export policy, especially when they realize that they export their water cheaply.

Environmental Awareness of goods and services consumption impact: Knowing the water content of various goods and services leaves individuals aware of the environmental impact of their consumption of these goods and services, and then knowing which goods have a significant impact on the water system and how water savings can be achieved through this.

3.2. Analysis of virtual water quantities in Agricultural and food products:

The following table shows examples of virtual water volume in some food products.

Table 1: Virtual Water Quantity for Some Crops and Products (m^3/ton)

Product	Virtual Water (m^3/ton)	Notes
Wheat	1,000–2,000	Depends on climate and irrigation methods
Rice	2,500–5,000	Requires large amounts of water

Product	Virtual Water (m^3/ton)	Notes
Maize (Corn)	500–900	Less than wheat and rice
Potatoes	250–500	Less water-intensive crop
Tomatoes	100–200	Depends on farming practices
Soybeans	1,500–2,500	Used for feed and oil production
Cotton	8,000–10,000	For fiber production, not seeds
Beef	15,000–20,000	Includes water for growing animal feed, drinking, and processing
Pork	5,000–6,000	Less than beef
Chicken	3,500–4,500	Less water-intensive
Milk	800–1,000	Per ton of milk
Coffee	18,000–21,000	Per ton of beans
Tea	8,000–10,000	Per ton of leaves
Chocolate	17,000–24,000	Due to cocoa cultivation

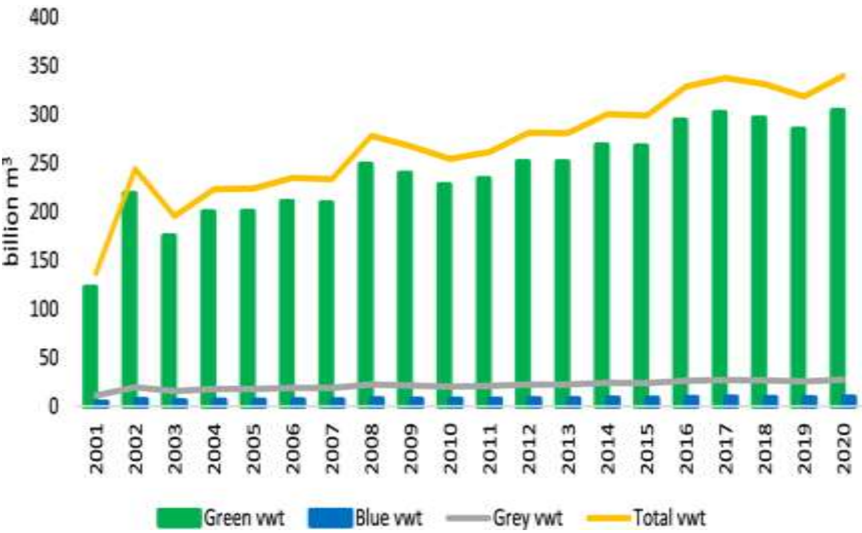
Source: Prepared by the researcher based on data from: https://www.waterfootprint.org,2024.

We note through this table (table1) the possibility of predicting and estimating the volume of water required to produce various commodities. This provides a general idea of the most water-intensive products and highlights opportunities for water savings. For example, the table shows that **beef** has a high virtual water consumption, estimated at **15,000–20,000 m^3 per ton**. This is because **virtual water** refers to the total volume of water used in the production of a good or service, including water consumed at all stages of the supply chain, such as irrigation for growing animal feed, drinking water for cattle, and water used in processing and transportation. By understanding these values, we can identify which products have the greatest impact on water resources and explore ways to reduce their water footprint.

The following is an example of virtual water flow during the global wheat trade and its impact on the sustainability of water resources, where approximately **268.5 billion cubic meters** of water are transported annually between countries through wheat exports and imports. This water is divided into **green water (89.33%)** (rainwater stored in the soil), blue water **(2.65%)** (irrigation water extracted from surface and underground sources), and gray water **(8.02%)** (Contaminated water as a result of the use of fertilizers and pesticides) (Hekmatnia et al, 2023).

ZAOULI – N° 9, Vol. 4 - Mars 2025 pp. 219-265 ISSN : 2788-9343
Soumission : 26/12/2024 Acceptation : 28/02/2025 Publication: 31/03/2025

Figure 4 : The flow of wheat virtual water trade in the world from 2001 to 2020.



Source: Mehran Hekmatnia, Ahmad Fatahi Ardakani, Amir Isanezhad, Hamidreza Monibi, A novel classification of virtual water trade for the sustainability of global freshwater resources,2023, https://www.researchgate.net

The figure above (Figure 4) shows the flow of virtual water trade for wheat in the world from 2001 to 2020 where wheat trade affects the sustainability of global water resources significantly, as wheat exporting countries consume huge amounts of their domestic water resources to produce the crop, which can lead to the depletion of these resources, especially in water-scarce areas. On the other hand, wheat importing countries indirectly depend on the water resources of exporting countries, exposing them to the risk of instability in the event of changing climatic or political conditions. In addition, greywater from pollution contributes to deteriorating water quality, increasing pressure on global water resources. The figure reflects these complex interactions and emphasizes the need for more sustainable management of these water flows to ensure a balance between food and water security at the global level. In summary, the figure highlights the vital role of water resources management in promoting global sustainability.

4. Future changes in the trading of virtual water:

Trying to track and forecast future changes in virtual water trade is very important to achieve sustainable water management, enhance water and food security, reduce the depletion of domestic resources, and support trade policies that balance economic efficiency with environmental conservation, and this is what we will try to illustrate through this section of the study.

4.1. Global virtual water flows from 1995 to 2100:

Water stressed regions rely heavily on importing water-intensive goods to compensate for insufficient food production caused by social, economic and environmental factors. The water embedded in these traded commodities, virtual water, has received increasing attention in the scientific community. However, the overall future outlook for virtual water trade is still absent. Some international reports show changes during the twenty-first century in the number of different types of water required to meet international agricultural requirements. Taking into account the evolution in social, economic and climatic conditions, virtual interregional water trade is estimated in the future so that trade in renewable water sources may triple by 2100 while at least non-renewable groundwater circulation may double. Basins in North America, the La Plata River and the Nile will contribute extensively to virtual water exports, while much of Africa, India and the Middle East rely heavily on virtual water imports by the end of the century (Graham et al,2020, P:01).

The following table represents the future of exports of virtual water (green, blue and non-renewable groundwater) by 2100:

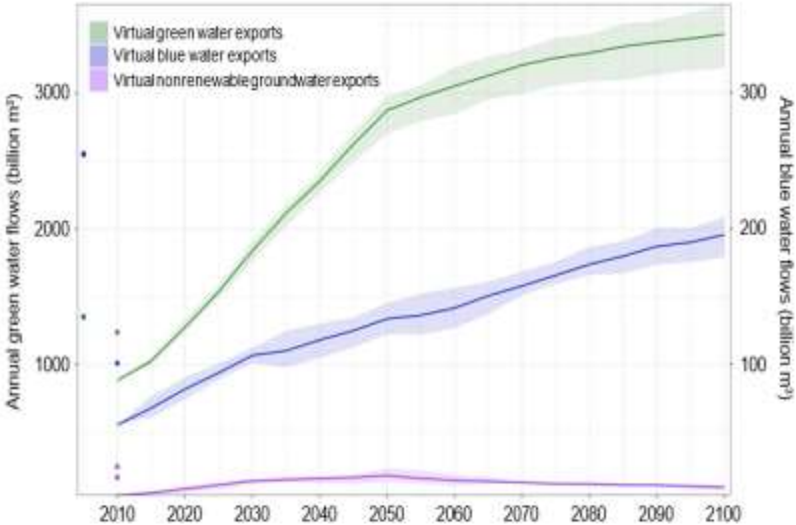
Table 2 : Global virtual water flows from 1995 to 2100

Water flows	Annual flows (billion m^3 per year)			
	1996–2005	2010	2050	2100
Virtual green exports	1352			
		1239		
		905	2745–3040[b]	3222–3708[b]
Virtual blue exports	255			
		101		
		56	122–145[b]	179–208[b]
Virtual nonrenewable groundwater exports		25		
		17		
		4	13.5–23.5[b]	7.5–11.5[b]

Source : Graham, N.T., Hejazi, M.I., Kim, S.H. et al. Future changes in the trading of virtual water. Nature Communication 11, 3632 ,2020, p: 03. https://doi.org/10.1038/s41467-020-17400-4.

It is clear from the table above (table2) that virtual green water exports and virtual blue water exports more than triple from 905 billion m3 and 56 billion m3 in 2010 to more than 3200 billion m3 and 170 billion m3, respectively, by the end of the century in response to increases in population and the resultant demand increases.

Figure 5 : Annual water flows of green, blue, and groundwater embedded in agricultural trade from 2010 to 2100



Source : Graham, N.T., Hejazi, M.I., Kim, S.H. et al. Future changes in the trading of virtual water. Nature Communication 11, 3632 ,2020, p: 03.

The above figure (figure 5) illustrates the annual flows of green water (rainwater stored in soil), blue water (surface and groundwater used for irrigation), and non-renewable groundwater embedded in agricultural trade from 2010 to 2100. These flows are displayed in billion cubic meters, tracking changes in the use of these water resources over the years. This highlights the impact of agricultural trade on water resource consumption and its implications for long-term water sustainability.

4.2. Virtual water trade fluxes by water type, region, and crop in 2100:

Future trends of virtual water flows in the world include predicting the future of green and blue virtual water trade, the shift in global production and demand for virtual water, and the future impacts of this water on sustainability and food security in general.

4.2.1. The future of green virtual water trade:

A large proportion of the virtual green water trade in 2010 is associated with oil crops (e.g. soybeans). Increases in corn, wheat, and oil crops and lead to significant virtual green export increases by 2100. These three crop commodities represent the largest proportion of current VWT and the highest green to blue water ratio required for production. Africa, Europe, and India represent the largest importers of virtual green water (Graham et al, 2020, P. 03).

4.2.2. The future of blue virtual water trade:

Virtual blue water trading shows significant differences arising in China, Pakistan, India, and the Middle East as the availability of water for irrigation decreases and populations change throughout the century. In 2100, globally, China represents a large source of virtual water exports due to the trading of wheat and rice products (Graham et al, 2020, P. 04).

Interestingly, China shifts from importer currently to exporter in the future, because of a reduced growth rate after 2030 that ultimately causes population to decline. Reduced domestic demands allow the use of all excess production to meet international agricultural demands. Regions in Africa experience nearly the opposite effect as population rapidly increases throughout the century, resulting in increasing demand that is unmet by domestic production (Graham et al, 2020).

The United States represents another main source of future virtual blue exports through corn, fibers, and oil crops, with a corresponding import of only miscellaneous crops (MiscCrops, e.g. fruits, vegetables, nuts), as part of the southwestern United States shifts production away from MiscCrops toward the end of the century. Finally, we have found an intensification of VWT in the early part of the century as population growth continues and exports originate from water-intensive regions of the Middle East, Pakistan, and India, while toward the end of the century, exports come from water-rich areas that require smaller amounts of water to grow.

4.2.3. Shifts in Global Production and Demand:

Africa will experience a rapid population increase throughout the century, leading to rising demand for virtual water that cannot be met by domestic production. In contrast, regions like the Middle East, Pakistan, and India will initially export virtual water but will cease exports after mid-century due to worsening groundwater depletion. This shift highlights the growing pressure on water-scarce regions to balance domestic needs with international trade demands. Non-renewable groundwater trade is projected to increase fivefold by mid-century, doubling by 2100 compared to 2010 levels. Major exporting regions include the United States, Mexico, western South America, and northern Africa. Water-scarce regions will export non-renewable groundwater in the early part of the century but will stop

ZAOULI – N° 9, Vol. 4 - Mars 2025 pp. 219-265 ISSN : 2788-9343
Soumission : 26/12/2024 Acceptation : 28/02/2025 Publication: 31/03/2025

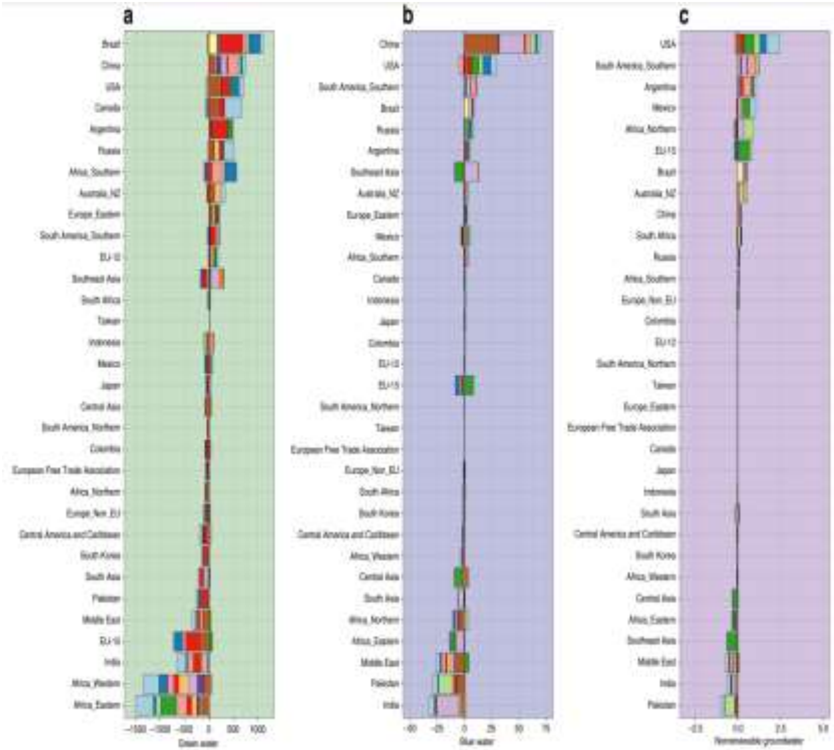
after mid-century as groundwater depletion worsens and demand patterns shift.

4.2.4. Implications for Sustainability and Food Security:

The global food production landscape will undergo significant changes, with production shifting from water-scarce regions to water-rich areas. This shift is driven by changes in demand, increasing water scarcity, and groundwater depletion, making it impossible for many regions to meet their needs through domestic production alone. These trends underscore the urgent need for sustainable water management practices to ensure long-term food security and resource availability.

The following table represents virtual water trade flows by water type, region, and crop in 2100:

Figure 6: Virtual water trade fluxes by water type, region, and crop in 2100



Source: Graham, N.T., Hejazi, M.I., Kim, S.H. et al. Future changes in the trading of virtual water. Nature Communication 11, 3632, 2020, p. 04. https://doi.org/10.1038/s41467-020-17400-4.

Average global virtual green water trade (billion m3), b virtual blue water trade (billion m3), and c virtual non-renewable groundwater trade (billion m3) by crop and region in 2100.

(Figure 6) shows the projected virtual water trade flows by 2100, where the global exchange of hidden water will be tracked via trade in crops such as wheat, rice, corn, oil and sugar crops. These flows will include three main types of water: **green water** (rainwater stored in the soil), **blue wa-**

ter (surface and groundwater irrigation water), non-renewable groundwater (water that is extracted faster than its rate of regeneration). Regions such as Brazil, China, the United States and Russia will emerge as the largest participants in this trade, with some regions exporting large quantities of virtual water, while others will rely on imports.

These flows will have significant impacts on the sustainability of global water resources, as they will increase pressure on areas already suffering from water scarcity. In the future, climate change will affect water availability, leading to increased reliance on virtual water in drought or water shortage areas. Therefore, sustainable water management policies and strategies will be urgently needed to ensure food and water security globally. This data will provide valuable insight into decision-makers to plan and implement policies Effectively addresses future challenges related to water and food.

5. Results and discussion:

This study came up with a set of findings:

- Water security is closely linked to food security, as food production depends heavily on water availability, with 30-40% of global food production dependent on 7% of irrigated land.
- The lack of water resources is a direct threat to national security, as it leads to food shortages and economic and social instability, in addition to that, water may be a source of conflicts between countries, especially in areas suffering from scarcity of shared water resources.
- Water resources face challenges like population growth, climate change, and pollution, threatening

sustainability. Natural threats (drought, desertification) and poor management worsen water scarcity, especially in arid regions. Effective policies and better management are essential to ensure long-term water security.

- Many countries suffer from poor infrastructure and primitive technologies in storing and distributing water, which limits their ability to implement development projects such as desalination. In addition, unbalanced water distribution is a major problem, with the earth's population consuming 54% of renewable freshwater, and this percentage is expected to reach 70% by 2025.
- Freshwater is a scarce resource, accounting for only 2.5% of the planet's total water, and most of it is not available for human use. Climate change is exacerbating this problem, causing sea level rise and melting ice, reducing water flow and increasing the incidence of droughts and floods.
- Effective water management relies on a participatory approach and modern technology such as artificial intelligence. However, mechanisms must be developed to protect infrastructure from potential threats, such as cyberattacks, to ensure the sustainability of water resources.
- Education and capacity building are key to improving water management, as they contribute to the development of water treatment technologies and integrated river basin management, reducing water waste and pollution of fresh sources.
- To ensure the sustainability of water resources, international cooperation must be strengthened, water

ZAOULI – N° 9, Vol. 4 - Mars 2025 pp. 219-265 ISSN : 2788-9343
Soumission : 26/12/2024 Acceptation : 28/02/2025 Publication: 31/03/2025

governance should be improved using modern technology, and capacity building through education should be strengthened. These mechanisms are essential to address future water challenges.

- Virtual water trade enables countries with limited water resources to secure food by importing goods that require large amounts of water, reducing the pressure on domestic water supplies. This approach is particularly beneficial for regions facing water scarcity, as it allows them to meet food needs without depleting their own water resources.
- By 2100, virtual water trade is expected to double, with a significant increase in the export of green and blue water. China, driven by its low population growth, will transition from being an importer to an exporter of virtual water, while Africa, with its rapid population growth, will become more reliant on imports to meet its water and food demands.
- High virtual water consumption in products such as beef, coffee, and chocolate underscore the importance of optimizing both production and consumption patterns to improve water efficiency. This shift is critical in minimizing water waste and enhancing sustainability in water-scarce areas.
- Global wheat exports, which transfer approximately 268.5 billion cubic meters of water annually, have a substantial impact on the sustainability of water resources in exporting countries. This highlights the need for countries to manage their water resources carefully, balancing agricultural production with long-term water availability.

- As water scarcity intensifies in certain regions, agricultural production is expected to shift from water-stressed areas to regions with abundant water resources. This realignment will help ensure both food security and water sustainability globally, making it crucial for countries to adapt to these changes.
- Water-stressed regions, including the Middle East and Africa, will increasingly rely on virtual water imports to meet their food needs, especially with the growing challenges posed by climate change and prolonged droughts. This trend will likely continue as these regions face more severe water shortages in the future.
- Countries that export virtual water at low prices should reconsider their policies to ensure the optimal use of water resources. It is essential for exporting nations to recognize the long-term implications of these practices on water sustainability and adopt more responsible policies that support water conservation and efficient resource management.
- Virtual water is a powerful tool for achieving sustainable water security. By improving water resource management, reducing losses, and enhancing efficiency, virtual water trade contributes to both local and global water security, ensuring resources are used more effectively.
- Virtual water trade also fosters international cooperation, reducing tensions over shared water resources and supporting sustainable development. As countries become more interconnected through this trade, they are encouraged to collaborate on water man-

ZAOULI – N° 9, Vol. 4 - Mars 2025 pp. 219-265 ISSN : 2788-9343
Soumission : 26/12/2024 Acceptation : 28/02/2025 Publication: 31/03/2025

agement solutions, which benefits the global community.

- Future policies must focus on balancing food security with sustainable water resource management. As virtual water trade grows, it will be essential for countries to implement strategies that prevent water-related crises, ensuring that resources are available for future generations while meeting the global demand for food.

Conclusion:

Virtual water is a strategic tool to achieve sustainable water security, especially in light of growing challenges such as water scarcity and climate change. By importing goods that require large amounts of water rather than producing them locally, countries with limited water resources can ease pressure on their domestic resources and achieve food security. Virtual water trade promotes international cooperation and reduces tensions over shared water resources. With water demand expected to increase in the future, adopting policies based on Virtual water is essential to ensure sustainability. This requires promoting awareness of the importance of virtual water, improving water resources management, and building capacity through education and modern technology. Ultimately, virtual water is an innovative solution to address water challenges and ensure their sustainability for future generations.

Recommendations:

Establish international platforms to facilitate virtual water trade and enhance cooperation between countries in the management of shared water resources.

Develop transboundary agreements to ensure equitable distribution of water resources and minimize conflicts.

Promote virtual water trade in countries with limited water resources by importing goods that require large amounts of water instead of producing them locally. This helps relieve pressure on local water resources and achieve food security.

Develop sustainable export policies, by reconsidering their export policies, especially those that export virtual water at cheap prices. They must adopt policies that ensure the optimal use of water resources and avoid their waste.

Raising awareness of the water footprint, by organizing awareness campaigns to understand the water footprint of goods and services, helping individuals and companies make more sustainable decisions in their consumption and production. This encourages water rationalization and reduced waste.

Support research and development in virtual water to better understand the impacts of virtual water trade on water resources and the environment. This includes developing tools to accurately measure the water footprint and analyse the impacts of trade on water security.

Encourage investment in sustainable agriculture by encouraging countries to import water-intensive crops from countries with abundant water resources, with a focus on sustainable agriculture in the local production of less water-intensive crops.

Establish and **develop** comprehensive databases on virtual water to track its flows and impacts on water resources. This helps in making informed decisions to achieve water sustainability.

Transparency in virtual water trade should be enhanced by requiring companies and countries to disclose the water footprint of exported and imported goods. This helps in achieving greater equity in the distribution of water resources.

Future prospects for the research:

1. Analyze the impact of virtual water trade policies on water security
2. Development of indicators to measure the water footprint
3. The role of technology in improving virtual water trade
4. Environmental Impact Assessment of Virtual Water Trade
5. The role of virtual water in reducing water conflicts

Referrals and References:

[1]. Ali Mohamed Ali Abdullah (2014), The Nile River between the Millennium Dam and the Congo River (Crises and Solutions), Arab Book House Library, Cairo, First Edition, Accessed on: 20/12/2023, https://books4arab.me

[2]. (FAO) Food and Agriculture Organization (2024), Accessed on 14/01/2024, https://www.un.org

[3]. Al-Taher Naim Ibrahim (2000), Water Security and Menace, Cairo, Al-Ahram Center for Translation and Publishing, 1st Edition.
[4]. Mustapha Boudouama (2016), The Problem of Water Resources and the Challenges of Food Security, Journal of Economic Studies and Research in Renewable Energies, Issue 04, University of Sétif, Faculty of Economic and Fine Sciences.
[5]. Ali Ould Cheikh (2024), Pillars of the Development Strategy for Food Security, Accessed on: 18/03/2024,https://www.aljazeera.net
[6]. UNESCO (2023), *Partnerships and cooperation for water*, Accessed on: 24/03/2024, https://unesdoc.unesco.org
[7]. Ali Ahmed Ali Dhaifallah(2020), Climate Change and its Future Effects on Yemen, Journal of Visions in Arts and Humanities, Al-Namar University – Yemen, Accessed on: 11/04/2024 http://www.ashpierist.dz
[8]. Waheed Mohamed Mufaddal (2024), Globalization of Desertification, Causes and Repercussions, Accessed on: 15/03/2024, http://www.alhazeera.
[09]. Carlo Ingrao, Rossana Strippoli, Giovanni Lagioia, Donald Huisingh (2023), Water scarcity in agriculture: An overview of causes, impacts and approaches for reducing the risks, Volume 9, Issue 8, Accessed on: 20/03/2024, https://www.sciencedirect.com
[10]. Laila Karfaj (2019), The Struggle over Water in the Arab Region, Nour Publishing, Accessed on: 02/04/2024, http://www.noor.pulisharg.com
[11]. Tasaidit Charmali(2014), The Water Crisis and its Impact on International Relations (Nile Basin Countries as a Model), Magister Thesis in international law

and international relations, Faculty of Law, Ben Kanoun University, Algeria.

[12]. Abdel Nour Ziam (2023), The International Conflict over Water between Internal National Security and International Law - Higher National School of Political Science, Algerian Journal of Political Studies, No. 1.

[13]. Bater Muhammad Ali Wardam (2003), Globalization and the Future of the Earth, Foreseeing Natural Resources, Al-Ahlia for Publishing and Distribution, Jordan, 1st Edition.

[14]. Ahmed Makki (2023), The Impact of Climate Change on Water Security, Political Orbits Magazine, Issue 2.

[15]. Yazid Boussak (2021), "Egyptian Water Security in Light of the Water Conflict 1990-2020", PhD thesis in Political Science and International Relations, specializing in African Studies, University of Algiers 3, Faculty of Political Science and International Relations, 2021-2022.

[16]. World water development (2024), Water for property and peace, United nations 2024, Accessed on: 10/04/2024**,** https ://www.unesco.org.

[17]. Peter H. Gleick (1999)**,** "The Human Right to Water." *Water Policy***,** 1(5), 487-503, Accessed on: 16/04/2024, https://www.sciencedirect.com

[18]. Ali Abdul Rahim (2014), Virtual Water: A Step to Address the Threat of Water Scarcity, Arab Center for Research and Studies.

[19]. Amani Essam Mohamed (2022), Journal of the Faculty of Economics and Political Science, Cairo University, Volume Twenty-Three, Issue IV.

[20]. Amani Essam (2022), The Role of Virtual Water Trade in Water Challenges in the Middle East, Journal of the Faculty of Economics and Political Science - Helwan University - Faculty of Commerce and Business Administration, Accessed on: 10/06/2024, http://www.asip.cerist.dz

*[21]. (WFN)Water Footprint Network (2024), **Accessed** on: 20/10/2024, https://www.waterfootprint.org*

[22]. UNESCO (2020), Eighth Water and Development Report on the Sustainable Development Goals related to water in the Arab region 2020, Accessed on: 22/10/2024, https://www.unesco.org

[23]. (UN)United Nation (2018), Progress on Transboundary Water Cooperation, Accessed on:25/10/2024, https://www.unwater.org.

[24]. Mohammad Hussain Sayed Hussein (2023), Integrated Management of Transboundary Groundwaters, Journal of the Arab Researcher, Volume 4, Issue 2, Accessed on: 28/10/2024, http://dsper.ul. Edu.lb

[25]. (UN)United Nation (2004), World Water Development Report 2004, Water for prosperity and peace, Accessed on:10/11/2024, https://www.unwater.org.

[26]. Bio Vision Alexandria Reports (2018), Accessed on: 15/10/2024, https://webcast.bibalex.org/Conference

[27]. Mehran Hekmatnia, Ahmad Fatahi Ardakani, Amir Isanezhad, Hamidreza Monibi(2023), A novel classification of virtual water trade for the sustainability of global freshwater resources, Accessed on: 01/12/2024, https://www.researchgate.net

Soumission : **26/12/2024** Acceptation : **28/02/2025** Publication: **31/03/2025**

[28]. Graham, N.T., Hejazi, M.I., Kim, S.H. et al (2020), Future changes in the trading of virtual water, Nature Communication 11, 3632, Accessed on: 15/12/2024. https://doi.org/10.1038/s41467-020-17400-4.