Study of Freshwater Resource Availability for Socio-Economic Sustainability in the World

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Abstract: - Fresh water supply is one of the most pressing global problems nowadays since the availability of sufficient fresh water influences all areas of human activity, especially the vital spheres of power generation, household life, and agriculture. Densely populated countries, especially in the arid zone of the Mediterranean, North Africa, the Middle East, and Central Asia, are already faced with an excessive demand compared to available resources, which can be a cause of humanitarian and political risks in those regions. The renewable freshwater resources per capita are constantly decreasing; the allocation of these reserves is extremely uneven, and in several countries the annual water intake many times exceeds its renewable resources. This fact may have negative social and political outcomes. Therefore, the research into the issues associated with water supply is topical for contemporary science. This article presents the findings of data analysis of the water consumption dynamics in different countries around the world, which made it possible to obtain a detailed picture of water problems at a global scale. Water withdrawals are expected to continue to increase in the future, placing even greater strain on the economy's available freshwater resources. This fact can lead to negative socio-economic and political consequences. Therefore, strict monitoring and development of directions for preventing the problem of freshwater shortage are necessary at all levels of management.

Key-Words: - water resources availability, renewable resources, international comparisons, resource security, patent activity, consumption, socio-economic sustainability.

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1 Introduction

As far back as 50 years ago the problem of water scarcity seemed a distant prospect. However the growth of the world's population and economic shift towards more resource-intensive consumption patterns have led to an increase in global freshwater use approximately sixfold since 1900, [1]. Nowadays the continued growth of the world population, accompanied by increased production and consumption of food, energy, and industrial products bring water consumption closer to the natural limit of existing sources, [2]. On average the annual consumption growth amounts to 80-100 cubic kilometers, [3]. In a number of countries, freshwater consumption already exceeds its reproduction within their borders. This is especially true in the densely populated countries of the Northern Hemisphere with an arid climate, where it is impossible to farm without irrigated agriculture, [4]. Due to this fact, to date, according to [5], about 72% of fresh water is consumed by the agro-industrial complex.

For example, Central Asia is one of the regions with the most water scarcity in the world. According to a study carried out by [6], in fact, four countries - Uzbekistan, Kyrgyzstan, Tajikistan, and Turkmenistan – are provided with fresh water from the Amu Darya and Syr Darya, the commutative runoff of which is 110 cubic kilometers per year. Over the past 20 years, despite the significant population growth of these countries, their annual water consumption is 100-105 cubic kilometers. i.e. the consumption "ceiling" has been reached, and there is simply nowhere to get water from. The obtaining of water from outside through canals is practically impossible due to the fact that the region is locked by mountainous areas and the Caspian Sea from almost all sides except the north, where lies the arid Kazakh steppe. The further increase in water consumption, which accompanies the growth of industrial, energy, and agricultural production, is significantly limited without strengthening the efforts aimed at rational economical use of water resources, [7]. In particular, as [8] notes up to 80% of water in the region is wasted (evaporation, washing irrigation systems). All this significantly limits the countries of Central Asia in their further development.

If Afghanistan increases its water intake for its own energy and agricultural purposes, this will lead to a humanitarian disaster throughout the region, [9]. Recent cases confirm the likelihood of such scenarios.

For example, according to [10], water shortage was one of the causes of the «Arab Spring» and the conflict in Syria started in 2011. We also observed such an adverse situation in 2014 in Crimea when the North-Crimean Canal was blocked, which led to a large-scale water shortage in most regions of the peninsula [11], although in some cities there had been freshwater shortages before that [12]. The problem has been basically solved through both a more rational use of resources and an increase in groundwater intake, [13]. As can be seen in the above-mentioned cases, the problem of water scarcity is not only typical of desert arid regions. Globally, the states around the world are also facing water shortages. Yet this problem is more common in the Old World because of the greater population in this territory, [14]. Therefore, research into water issues is highly relevant to modern science.

2 Problem Formulation

2.1 Background of the Study

Water is the chemical and physical basis of life on Earth. At the same time, it is one of the most valuable economic resources, so it is at the center of economic and social development. Today, this resource, regardless of the economic conditions of the world, is becoming increasingly scarce, and the demand for it is growing rapidly.

The problems of water stress are interdependent with the dynamics of economic growth within the framework of the dichotomy "economic development - environmental protection". Water shortage is an obstacle to sustainable socio-economic growth of countries, the lack of development and resources is an obstacle to solving water problems of water shortage.

Water shortage will become one of the main challenges of the 21st century, and in the coming decades, water problems will increase throughout the globe. Freshwater reserves are unevenly distributed across continents and water basins. There is a constant increase in its consumption. The aggravation of problems of access to water caused problems in the distribution of water resources in various regions of the world and the growth of human demands for high living standards. The water problem in 20-30 years will inevitably lead to structural changes in the world, including in the global economy. Water deficit potentially creates dangers and consequences that are devastating for all of humanity: armed conflicts and social cataclysms, climate change, and mass migration from regions suffering from water shortages to coastal regions. Over the past 50 years, there have been more than 500 territorial disputes over water, [15].

The problem of water discourse as an acute scientific agenda arose in the 1990s. Today, the availability of resources and consumption of fresh water in the world for socio-economic sustainability are actively studied. Specialists in various scientific fields are developing water use scenarios, [16]. The work [17] presents a framework for understanding the changing approaches to the assessment, distribution, and management of water resources, and examines the policy of distribution of this important element of ecological capital in the context of the concept of sustainability. Recent studies of water availability data reveal globally significant threats associated with inefficient water use, extreme climate change, population, and economic growth, and a general inability to effectively protect waterscapes, [15]. Researchers discuss ways to address water stress and analyze various factors affecting the problem of water scarcity in the world, [17].

Provision of clean fresh water is becoming the focus of sustainable development policies. Today, in scientific discourse, we can talk about the formed understanding: fresh water scarcity is becoming one of the structural factors affecting global economic development.

2.2 Materials and Methods

The purpose of the study is systematic and dynamic analysis of historic series in order to obtain an objective view of the situation with the provision of global needs of mankind in fresh water.

The object in our study is the process of retrospective analysis of availability and consumption of freshwater resources in different countries of the world.

The subject of the study is the World Bank's historic series on water resources in the context of world countries.

The hypothesis of the study is to justify the importance of dynamic assessment of availability, consumption and sufficiency of freshwater resources to develop timely measures to stabilize the severity of the water problem both globally and regionally.

The key data source is the World Bank's statistical database on the availability and consumption of water resources in various countries. A historic series of sufficient completeness for our study began in 1961.

The following indicators were used for the analysis:

- volume of annual freshwater consumption (fairly complete historic series since 1980);
- renewable domestic freshwater resources per capita (since 1970);
- the volume of freshwater intake compared to their available domestic resources (since 1975 partially, the full historic series for all countries - only since 2015).

The latter indicator appears to be the most complete and comprehensive reflection of the freshwater situation in each countries. Therefore, this indicator was reflected in our study also in the cartographic material.

2.3 Empirical Analysis

The scientific research in the field of water resources is reflected as the quantification of patent activity. The increasing attention to the water issue is illustrated in Figure 1 which shows the data on patent activity at a global scale according to the data of Espacenet – patent search.

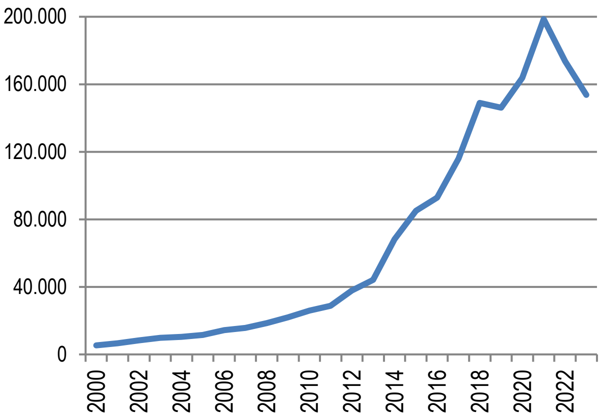

Fig. 1: Annual number of patents received in the field of “water resources”, 2000-2023, units [18]

Figure 1 shows that until 2021 there had been an exponential increase in the number of granted patents where the phrase “water resources” appeared in the title or text of the patent. We attribute some "cooling" after 2021 to the coronavirus crisis, which had a noticeable impact on R&D activities (primarily in China), shifting its main focus to medicine and pharmaceutics. However, we expect a return to the previous trend in the coming years. Nevertheless, even despite the drop in the number of granted patents in 2022-2023, the volume of their annual execution remains very high - dozens of times higher than 20 years ago, which emphasizes the importance of the "water problem" in scientific and applied spheres.

Figure 2 shows that the vast majority of water patents granted in 2023 belong to the People's Republic of China. The US, Japan, and the World Intellectual Property Organization (WIPO) lag behind China by a huge margin (Figure 2).

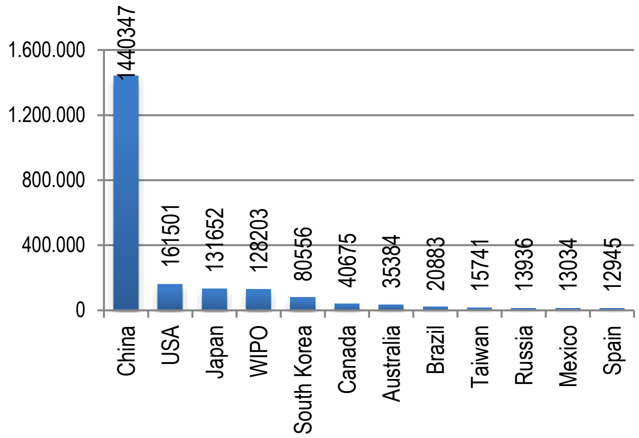

Fig. 2: Number of water-related patents granted in 2000-2023, country-specific (unit, cumulative total), [18]

Table 1 shows the evolution of the share of water-related patents in the past two decades.

Table 1. Number of granted patents in the sphere "water resources" in 2000-2023, % of their total number, [18]

Countries	2000	2005	2010	2015	2020	2022	2023
Japan	53,9	33,5	14,7	4,5	2,8	2,6	1,7
USA	27,8	28,6	19,3	8,8	6,4	6,2	4,3
China	25,6	34,6	65,8	87,8	92,4	91,9	89,3

China took a leading position in patenting the results of applied research in water use as early as the mid-2000s while relative shares of other countries did not have a significant weight by 2023. In the early 2000s Japan, as one of the world’s major scientific centers, played a leading role in this sphere. According to the World Intellectual Property Organization , China's patent activity has grown 20 times in 20 years, [19]. Some researchersconfirm this trend, [20].

Thus, there is a significant exponential growth of attention of the world scientific community to water issues, which is illustrated by Figure 1, Figure 2 and Table 1.

3 Problem Solution

Annual global freshwater withdrawals have nearly doubled over the past 40 years, from 2,188 billion cubic kilometers to 3,896 billion cubic kilometers. At the same time, global per capita water consumption is a stable value over time, approximately equal to 500 cubic meters per year, as illustrated in Figure 3.

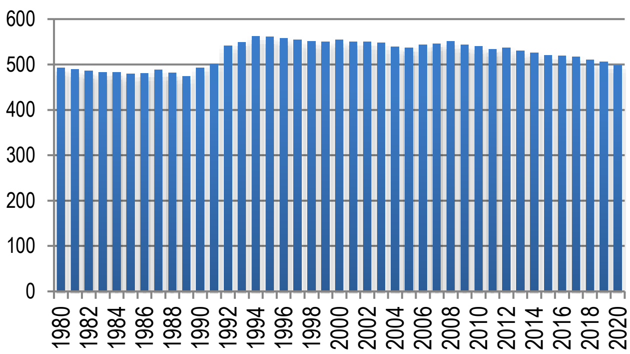

Fig. 3: Global volume of freshwater consumption in the world in 1980-2020, cubic meters per capita, [21]

It is noteworthy that in developed industrialized countries as a whole, water consumption has gradually decreased in 2020 compared to 1980, for example in the USA (from 518 to 444 billion cubic meters), and Japan (88.2 to 78.4 billion cubic meters) (Table 2). This is not primarily due to the greater rationality and efficiency of water resources use, but mainly due to de-industrialization, which led to a reduction in consumption. According to the World Bank data, in countries such as Japan, Finland, France, Israel, France and the United States, the decline from 1980 to 2020 was 10-20%. In Spain and Italy, it was about 30% in the same time period. In England, Switzerland and Sweden it was 40%. In Romania, Bulgaria, the drop in water consumption was 50-65%, which is associated with the negative consequences of the Soviet bloc collapse and the subsequent decline in industrial and agricultural production. The main increase in consumption in recent decades is provided by emerging countries due to their rapid economic growth, as in the cases of some world communities shown in Table 2.

As Table 2 shows, since 2010, the increase in water consumption has occurred at a much slower rate than in earlier periods. This is largely explained by the lack of statistics from India and Argentina – the figure has remained the same since 2010, indicating a lack of primary information from some countries.

Table 2. Annual freshwater consumption, total (billion cubic meters). Top 15 countries, [21]

Countries	1980	1990	2000	2010	2015	2020	Per capita, m3	2020 to 2000, %	2020 to 1980, %
World	2188	2606	3405	3762	3849	3896	498	114	178
India	438	500	610	648	648	648	464	106	148
China	444	500	551	587	592	568	403	103	128
USA	518	465	474	419	444	444	1341	94	86
Indonesia	ND	74	113	182	216	223	819	197	…
Pakistan	154	155	173	185	197	190	834	110	123
Iran	52,0	65,9	88,5	93,0	93,0	93,0	1065	105	179
Mexico	56,0	62,1	68,2	79,6	85,7	89,5	711	131	160
Philippines	ND	ND	ND	83,3	86,4	85,9	765	…	…
Vietnam	37,9	51,5	71,8	81,9	81,9	81,9	847	114	216
Japan	88,2	91,0	90,4	81,0	79,9	78,4	621	87	89
Egypt	50,1	53,9	57,0	73,8	60,9	77,5	721	136	155
Brazil	ND	41,7	56,1	74,8	63,9	67,2	315	120	…
Russia	ND	ND	75,9	69,7	62,4	64,8	450	85	…
Türkiye	ND	ND	42,0	47,0	53,7	61,5	738	147	…
Uzbekistan	ND	ND	53,4	49,9	55,1	58,9	1721	110	…

Data have not been changed since 1998 from Afghanistan, since 2008 from Bangladesh and Chile, and since 2004 from Iran. But quasi-stability in reality hides the higher rates of consumption.

Of those states for which complete series are available, we can repeat the above-mentioned: since 1980 and 2000, the increase in freshwater consumption has been mainly at the expense of developing countries against a background of a slight decrease in water consumption in developed countries. China and India are the undisputed leaders in terms of water consumption; they had surpassed the USA by 1990. The Top 5 countries account for 53% of global consumption (and 47% of the world's population).

As for per capita volumes, the spread is quite large. While China, Russia, and India demonstrate roughly similar volumes of consumption per capita, for example, the difference between Uzbekistan and Brazil is more than 5 times. This is due to a significant difference in the humidity in these countries (Brazil's equatorial climate and droughty arid climate in Uzbekistan).

The next important indicator of water availability is the per capita value of renewable domestic resources. Moreover, it is the internal resources that matter, which do not depend on water inflow from neighboring countries.

Table 3. Renewable domestic freshwater resources per capita, thousand cubic meters.Top 15 countries, [21]

Countries	1970	1980	1990	2000	2010	2020	2020 to 2000, %	2020 to 1980, %
World	11,3	9,3	7,8	7,0	6,2	5,5	78	59
Iceland	832	745	667	605	535	464	77	62
Guyana	342	310	323	318	322	302	95	98
Suriname	261	264	240	207	181	163	79	62
Bhutan	318	229	170	138	111	101	73	44
Papua New G.	322	258	207	145	106	82,2	56	32
Canada	134	116	103	92,9	83,8	75,0	81	65
Gabon	275	219	167	129	95,8	71,5	56	33
Norway	98,6	93,5	90,1	85,1	78,1	71,0	83	76
Solomon Islands	259	191	138	104	82,7	64,7	62	34
New Zealand	116	105	98,2	84,8	75,2	64,2	76	61
Peru	121	94	74,2	61,6	56,1	49,3	80	53
Chile	90,1	77,2	66,3	57,6	52,0	45,9	80	59
Colombia	103	81,9	65,8	54,7	47,9	42,1	77	51
Liberia	137	104	90,5	69,1	49,8	39,3	57	38
Congo Republic	159	121	93,1	70,8	50,0	38,9	55	32

As it follows from Figure 3, the average annual freshwater consumption per 1 person in the world is about 500 cubic meters. Accordingly, in 2020 this norm at a global scale is provided about 11-fold. Although, of course, there is a great diversity among countries, and in 31 countries of the world this norm is no longer provided by their own resources – these are the countries of the Sahara zone, the Middle East, Uzbekistan, and Barbados. Renewable inland freshwater resources in Bangladesh, Holland, Hungary, Moldavia, Azerbaijan, South Africa, and Cyprus (about 600-800 cubic meters) are very close to critical indicators. That is, the water problem is no longer characteristic only of the arid zone and is expanding. Most countries in Asia and Africa, and some countries in Latin America and Europe will face severe shortages of their own freshwater resources in the coming decades. Table 3 illustrates these concerns – resources are steadily declining even in the most water-rich countries. Table 4 shows the level of annual water withdrawals compared to the availability of domestic freshwater resources, clarifying Table 3 on the availability of water to countries. Expand the list of countries here to 21.

Table 4. Annual freshwater withdrawals, % of domestic renewable resources. Top 21 countries, [21]

Countries	1975	1980	1990	2000	2010	2020	2020 to 2000, %	2020 to 1980, %
World	ND	ND	ND	ND	ND	9,1	…	…
Egypt	4820	5012	5393	5703	7380	7750	136	155
Bahrain	ND	ND	4873	7218	5019	3878	54	…
Turkmenistan	ND	ND	ND	1767	1990	1868	106	…
UAE	ND	600	1028	1556	1782	1587	102	265
Saudi Arabia	ND	ND	ND	820	915	974	119	…
Libya	171	210	680	615	783	817	133	389
Sudan	ND	ND	ND	ND	ND	673	…	…
Qatar	268	331	342	293	425	446	153	135
Uzbekistan	ND	ND	ND	327	305	360	110	…
Pakistan	279	280	283	314	337	345	110	123
Mauritania	ND	183	404	400	337	337	84	185
Syria	46,8	83,6	157	211	197	196	93	234
Israel	213	220	210	215	179	170	79	77
Yemen	ND	ND	139	161	170	170	105	…
Iraq	115	116	122	187	135	161	86	139
Azerbaijan	ND	ND	ND	135	135	155	115	…
Jordan	66,1	78,4	122	109	131	138	126	176
Oman	ND	ND	ND	92,9	107	117	126	…
Tunisia	25,5	45,3	73,1	62,0	74,3	92,1	149	203
Barbados	61,9	71,3	90,0	101	87,5	87,5	86	123
India	26,3	30,3	34,6	42,2	44,8	44,8	106	148

As can be seen in Table 4, the countries of the arid zone of the Northern Hemisphere, which we have already mentioned, are in the most vulnerable position due to a significant deficit of their own water resources.

Turkmenistan, Egypt, Sudan, Uzbekistan, Pakistan, Mauritania, Syria, and Iraq – these are densely populated countries whose main water sources (major rivers) have their source outside their territories. Water consumption there exceed internal renewable resources by times and even by orders of magnitude, and their further development, agricultural production, and meeting of domestic needs depend on the politics and activities of the states "upriver". I.e. Egypt and Sudan depend on Ethiopia and Uganda (the Nile River), Iraq and Syria – on Turkey (the Tigris and the Euphrates), Turkmenistan and Uzbekistan – on Afghanistan, Tajikistan and Kyrgyzstan (the Syr Darya and the Amu Darya), Pakistan – on India (the Indus), etc.

In the countries listed in Table 4, the water issue is no longer a regional issue, but practically a state one.

Bahrain, the UAE, Saudi Arabia, and other South-West Asian oil-producing countries have long addressed water shortages through desalination plants. However, this is ensured by the availability of fossil fuels (oil and gas) in these states. However, Egypt, Sudan, Central Asia, Pakistan, and several others do not have such significant oil and gas resources so they could relatively cheaply provide desalination in volumes sufficient for industry and agriculture. And the solution in this case will be very costly and perhaps unaffordable for the budgets of these emerging countries. The development of nuclear power would largely solve the water issue in water-scarce regions, [22]. But it is constrained by international nuclear energy policy, the unstable political situation in the Middle East, and a number of other factors.

Figure 4 illustrates the situation with the level of water withdrawal compared to the volume of renewable freshwater resources.

Fig. 4: Annual freshwater withdrawals by country in 2020, % of domestic resources, [21]

As we can see in Figure 4, indeed, the countries in the Mediterranean, Northern Sahara, the Middle East, South and Central Asia, as well as Transcaucasia are in the most difficult situation. It is noteworthy that Turkey is already approaching the deficit of renewable freshwater resources to a certain extent, which will cause an avalanche-like increase of water problems in the countries downstream of the largest rivers (the Kura, the Arax, the Tigris, and the Euphrates). Central European countries, Haiti, South Korea, Thailand, and some countries in South Africa, Haiti, South Korea, Thailand and some countries of South Africa are already at risk. Table 3 and Table 4 depict a constant trend of increasing consumption and decreasing renewable freshwater resources, indicating that water issues will increase across the globe in the coming decades. So, water security is a key factor in international competitiveness, its provision is extremely important for each state.

The directions for reducing water stress and solving the water problem are seen as increasing the efficiency of water resources management, building "cascade" dams and reservoirs, desalinating salt water, recycling wastewater, new technical alternative solutions, and some "fantastic" ideas: extracting water from aquifers, rain clouds, fog, icebergs, and glaciers.

It is very important to develop international mechanisms for investing in such projects, financing green bonds, and developing EGS mechanisms.

Today, joint efforts of all mankind are required to solve the global problem of water deficit. It is necessary to develop an internationally recognized legal framework and clear legal guarantees of access and consumption of water resources by countries with water deficits, as well as innovative financial mechanisms that would ensure the transfer of capital and water-saving technologies from the North to the South, from the Center to the Periphery, [23]. It is necessary to establish political partnerships and cooperation between different countries and regions in such areas as water pollution control, water resources protection, watershed protection and restoration, creation of irrigation systems, creation of funds for financing water projects, etc.

We need a more integrated policy and mixed "green-gray" approaches of all countries in this area, the formation of a market for "water-saving" technologies, the search for new models of multiple water use, new management models, and new financing models to ensure global water security. Improving environmental management to ensure water security should become a permanent public imperative in all countries.

4 Conclusion

The results of this study showed that the focus of patenting activity over the last 20 years has shifted almost entirely to China (about 90% of patents granted in recent years in the sphere of water resources). This indicates both China's aspiration to take a leading position in the scientific and technological field and the importance of the water resources problem itself for China and for the world community in general. However, countries other than China also demonstrate an increasing of their attention to water issues, judging by the number of patents granted. And this is no coincidence.

The almost twofold (minimum estimates) increase in water consumption over the past 40 years has brought the problem of global freshwater scarcity to the forefront, [24].

As was demonstrated in our findings, while per capita consumption remains stable at 500 cubic meters per year, global consumption grows in line with population growth. And in emerging countries, where population growth is the highest, water consumption grows faster. Whereas developed countries (mainly in the Western world) show a decrease in water consumption. That is caused both by demographic problems (e.g. in Japan and South Korea) and by increasing culture and efficiency of water management.

Renewable freshwater resources per capita are constantly decreasing. Since 1961, they have decreased by 2.5 times and still provide approximately 11 times the “reserve” compared to the average annual consumption of 500 cubic meters per capita. However the allocation of these reserves is extremely uneven, and in a number of countries, the annual water intake many times exceeds its renewable resources. Water withdrawals are expected to continue to increase in the future, placing even greater strain on the economy's available freshwater resources. This fact can lead to negative socio-economic and political consequences. Therefore, strict monitoring and development of directions for preventing the problem of freshwater shortage are necessary at all levels of management.

5 Discussion

The analysis showed a greater increase in water consumption in developing countries, which allows us to conclude that in the future, water security problems will be most severe in developing countries, where the resource, technical, economic, and managerial capabilities to overcome such problems remain limited.

A comparison with the state-of-the-art research papers showed that our results are consistent with the position of several researchers about the dominant factors influencing the growth of water scarcity. To a greater extent than climate change, it is influenced by the constant increase in population and demand for water, [25]. The loss of natural water capital and threats to water security are rapidly growing in the modern world. In response, infrastructure in the form of centralized water purification and distribution systems, as well as large reservoirs and hydraulic structures, began to develop. In the 21st century, water security and the effectiveness of water resources management largely depend on engineering methods and the so-called "green-gray" water infrastructure, [26].

The studies note that the hydro-centric approach should not be the predominant one in solving water problems. Water management problems are associated with complex processes inherent in political and economic factors. Their impact on actual water stress will depend on how water resources will be managed in the future.

Future research directions in the area of water scarcity under consideration lie in the analysis of new forms of international interactions and the potential of trading "virtual" water (water-intensive products, or water used in the production of food or goods). Countries with limited water resources can and should purchase water-intensive products from countries where the relative value of water is lower in order to achieve the greatest efficiency in the use of water resources, [17]. Conducting comprehensive research on this topic can also contribute to the international scientific agenda and efforts to achieve universal and sustainable water security.

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