

Kydyrbekova, Aliya; Meiramkulova, Kulyash; Tolysbayev, Baurzhan; Kydyrbekova, Assel

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Article

Investigation of Different Water-Related Innovation Aspects within the Past Three Decades: A Case Study of Kazakhstan and Neighboring Countries

Aliya Kydyrbekova ^{1,*}, Kulyash Meiramkulova ², Baurzhan Tolysbayev ¹ and Assel Kydyrbekova ¹

¹ Department of Management, L.N. Gumilyov Eurasian National University, Nur-Sultan 010000, Kazakhstan; tol_b@mail.ru (B.T.); asellya@gmail.com (As.K.)

² Department of Environmental Engineering and Management, L.N. Gumilyov Eurasian National University, Nur-Sultan 010000, Kazakhstan; kuleke@gmail.com

* Correspondence: aliyafromkz@gmail.com

Abstract: The advancement of water sustainability and reliance is highly dependent on the innovative ideas implemented in the sector. However, despite water being a vital resource, the water sector still faces many challenges in terms of innovations in comparison to other sectors. This study investigated different aspects of innovation activities in the water sector in the case of Kazakhstan and neighboring countries. The potential water-related issues calling for more innovation activities in the field are also expounded. Moreover, the potential effect of the COVID-19 global pandemic is also highlighted, based on a questionnaire survey conducted among different water-related firms. The innovation datasets were divided into three different decades to investigate the potential influence of a 10-year period on the characteristics of the innovation activities in the water sector; whereby, a *p*-value of approximately 0.014 was retrieved from the analysis of variance (less than the significance threshold of 0.05). As a result of our findings, it can be stated that there were statistically significant differences in terms of innovation during the three decades investigated in this study. Moreover, a relatively high correlation was observed between wastewater handling tariffs and the number of patented innovations, with a correlation coefficient of 0.868; however, there was a weak correlation between water supply tariffs and patented innovations, with a correlation coefficient of 0.333. Based on the questionnaire survey, it was observed that the innovation disruption caused by COVID-19 in terms of the motivation in water-related innovations has impacted more of the large-scale water firms than the small-scale firms. Therefore, the results derived in this study further reveal that there is a significant need to invest more towards innovation in the water sector, especially regarding large-scale firms.

Keywords: dynamics of innovation; patents; innovation management; water resources management; invention



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1. Introduction

Innovation is among the key tools for improving living standards in the world, including improved access to water and management of water resources in general; that is to say that it plays a great role in addressing water-related challenges (Wehn and Montalvo 2018). Innovation is the application of concepts in a way that results in the creation of new products or services, or enhances the provision of those already existing. The process of creating something new by combining elements in an inventive way is known as invention. Innovation differs from invention in the sense that an invention happens when you create a brand new idea, whereas an innovation involves enhancing an already-existing idea. Unfortunately, currently, running policies and technologies do not seem to be sufficient for solving these challenges; therefore, more innovations are in urgent need. It should also be noted that innovation in the water sector has been of increasing interest to venture capital investors (O'Callaghan et al. 2020). Therefore, it is significant to find new strategies

to hasten the adoption of innovation in the water sector. Among others, implementing creative strategies is essential to provide long-term stability and excellent customer service at a competitive price. Moreover, it is worth highlighting that factors such as climate change and population growth have been increasing the demand for more innovation literacy in the field of water (Moreno-Guerrero et al. 2020). This is because water conservation, preservation, and management remain the key aspects towards ensuring human survival. Moreover, innovation during the present time, in which the entire world is under significant threat from climate change, can be a useful adaptation tool (Niywul 2021; Bauer and Steurer 2014). The implementation of policies to improve innovation in this sector, on the other hand, is still in progress. In particular, there is a scarcity of research on market-based motivational aids (Razumova et al. 2016).

Unfortunately, all over the world, innovations in the water sector are relatively low in comparison to other sectors. Moreover, innovation diffusion in the field of water is known to be a very slow process in comparison to other industries (Goonetilleke and Vithanage 2017). This phenomenon calls for more studies in this field to investigate different factors leading to the current challenges in the link between innovation and water. The significance of linking innovation and water is explained by the fact that water-related issues are becoming a limiting factor for sustainability and economic growth in particular (Compagnucci and Spigarelli 2018). Moreover, it is a known fact that the innovation processes in the water sector face more significant uncertainties that are also poorly understood in less developed regions, especially in developing countries (Hyvärinen et al. 2020; Imonikhe and Moodley 2018).

Despite more efforts being applied in recent years to improve the general impact of water innovation in less developed countries, the field still lacks sufficient knowledge of the problems and appropriate methodologies needed to investigate and work towards proper management of water resources and improvement of water services provision (Mvulirwenande and Wehn 2020a). There are already many initiatives all over the world implemented to promote water innovation (Mvulirwenande and Wehn 2020b). The European Innovation Partnership on Water (EIP Water) stands among the good initiatives designed to facilitate the development of more innovative solutions to our water challenges. EIP Water has directed its focus on eliminating the persisting barriers to water innovation in Europe, regarding the entire phenomenon as an issue requiring agency through restructuring the funding system (Schmidt et al. 2018). This kind of approach can also be highly useful in developing countries where the problems of innovation in water are more evident. Apart from knowledge, lack of funding is another significant challenge to innovation adoption; whereby, more funding sources are needed in the field to address the issue. The Trial Reservoir is an example of a new source of funding that can help to accelerate the adoption of technologies in the water sector (Isle Utilities 2021). Additionally, data availability is another challenge in many countries to investigate problems related to innovations in water. In that matter, the use of patent records becomes a useful approach to understanding the trends in both invention and innovation (Huang et al. 2020).

Technological growth has been significantly increasing the potential applicability of patent records, which are a useful tool for investigating and measuring the trend of innovative activities in the world. Patents provide a good picture of the innovation trend in several ways (Pavitt 1985), including: the general international patterns and distributions of how innovative activities progress, as well as their effects on trade and production; the interaction among firms, and their effects on firm performance and industrial structure in terms of innovative activities; the extent of growth and focus of innovative activities in different technical fields and industrial sectors, as well as providing links between science and technology. On the other hand, organizations, institutions, and governments spend billions of dollars on improving water access issues. However, to increase social welfare through improved access to water, the results of research and development must be properly commercialized so that consumers can benefit from improved water-related products and lower prices (Svensson 2015). However, research has revealed that in order to

undergo effective transitions towards a circular economy, all social factors must be taken into account. Institutional diversity and a range of delivery mechanisms—market, public, and communal—provide a framework for water innovation and circular economy research that is not confined to markets (Ziegler 2019). Additionally, participation from end users, investors, policymakers, and frequently the water society, is important in order to speed the adoption of innovation.

According to Margaret Ayre et al. (2016), if the alignment of research towards practice and policy is to be enabled, then adequate starting conditions are essential in the process; a scoping effort is necessary to establish this alignment, and it must include those persons and institutions who are interested in the research. Nevertheless, the challenges in water innovations can only be dealt with appropriately if there are strong partnerships between companies and research centers (Borges et al. 2020; Franco and Haase 2020). Therefore, water innovation must apply not only to new sustainable technologies, but also to new partnerships extending across private and public administrations, research, and industries towards fostering new business models and new forms of water governance (European Commission 2015).

Unfortunately, as previously mentioned, innovations in the water sector are relatively lagging behind; this phenomenon can be linked to limited awareness resulting from a lack of sufficient studies in the field (Sousa-Zomer and Cauchick Miguel 2018). The government of Kazakhstan in particular has been heavily investing in technological advancements through innovations. However, as is the case in many other countries, the water sector is still lagging behind in terms of innovations. It has also been difficult to quantify the extent of the problem due to the lack of sufficient studies (Koshebayeva and Alpysbayeva 2015; Sadyrova et al. 2021; Issayeva et al. 2020). Therefore, the current state of the water sector makes water-related innovations of high interest on the global policy agenda. However, the systemic complexity that typically surrounds such contexts in the water sector call for more significant and actionable knowledge of how to empower and compose innovative activities towards more innovative solutions by connecting different players through organized networks (Gabrielsson et al. 2018).

In this study, different aspects of innovative efforts in the water for Kazakhstan and a few cases from the adjacent countries are discussed. The research questions in the study are: 1. In a scenario of an emerging market, how have water-related innovations changed over the previous three decades? 2. How is the pandemic influencing an emerging market's overall view of innovation? Based on these research questions, the potential for water-related concerns regarding the need for additional innovation in the industry is also presented. Furthermore, based on a questionnaire survey conducted within several water-related firms, the possible impact of the COVID-19 global pandemic is emphasized. The innovation datasets were divided into three decades to determine whether a 10-year period could have an impact on the characteristics of water industry innovation. The patterns of innovation activities amongst firms, and their general effects on field performance and industrial structure, are clarified; this includes a description of the changes and focus of innovative activities over time in the water sector. The nature of data distribution within the data series was investigated using box and whisker graphs. The graphs mostly depict data based on medians and quartiles. To determine whether the differences between groups of data are statistically significant, ANOVA was performed; this method analyzes the levels of variance within the groups by taking samples from each group.

2. Methodology

2.1. Case Study Description

Kazakhstan, officially the Republic of Kazakhstan, is a country located in Central Asia. In the northwest and northern region, Russia borders the country; China borders the east; Kyrgyzstan, Uzbekistan, the Aral Sea, and Turkmenistan border the south; as well as the Caspian Sea to the southwest. In terms of size, Kazakhstan is known to be the largest country in Central Asia, making it the ninth largest country in the world. The country

covers about 2930 km from east to west, and 1545 km from north to south. The capital city is Nur-Sultan, previously known as Astana, Aqmola, and Tselinograd, located in the north-central region of the country.

Kazakhstan has more than 7000 streams, which are mainly located in the east and southeast. However, in the northwest, there are the Irtysh, Ishim (Esil), and Tobol rivers, which are described as large transboundary rivers crossing Russia, ultimately draining into Arctic waters. The Irtysh River discharges approximately 28 billion m³ of water every year into the vast West Siberian catchment area. The Caspian Sea is among the largest inland body of water in the world, and forms Kazakhstan's border for 1450 miles of its coastline. However, there are some other large water bodies associated with this country, including Lake Balkhash, Zaysan, Alaköl, Tengiz, and Seletytengiz. Kazakhstan also wraps around the entire northern half of the shrinking Aral Sea, which underwent a major decline during the second half of the 20th century: freshwater inflow was diverted for agriculture, thus the salinity of the sea increased sharply, and the receding shores became a source of salty dust and polluted deposits that ruined the surrounding lands for animal, plant, and human use.

In terms of climatic conditions, the country is characterized as sharply continental, and hot summers alternate with equally extreme winters, especially in the plains and valleys. There is also strong variation in terms of temperature. Average January temperatures in northern and central regions range from -19 to -16 °C, while in the south, temperatures are warmer, ranging from -5 to -1.4 °C. During summer, especially in July, average temperatures in the north reach 20 °C, whereas in the south, they rise to 29 °C. The most extreme temperatures recorded in this country are more than 45 °C. Light precipitation falls, ranging from 200 to 300 mm annually in the northern and central regions, to 406.4 to 508 mm in the southern mountain valleys.

2.2. Data Collection and Analysis

To analyze the water-related issues (wastewater generated with time, the total amount of wastewater discharged into water bodies that have not been treated, water use, and pricing), a list of documents with data were collected from the Bureau of National Statistics of the Agency for Strategic Planning and Reforms of the Republic of Kazakhstan ([Bureau of National Statistics 2020](#)).

Patents are the main source of data used in this study, for which patent information recorded from 1991 to 2020 (30 years) was retrieved. The mission of Kazakhstan's patent system is aimed toward the provision of necessary and sufficient legal, informational, and institutional conditions for a favorable innovative climate for manufacturing products and services in Kazakhstan, with protected rights of intellectual property and ratification of the country as an equal and competitive partner of international economic relations in the context of globalization ([National Institute of Intellectual Property of the Ministry of Justice of the Republic of Kazakhstan 2021](#)). The main body responsible for the patent issues in Kazakhstan is the office of the National Institute of Intellectual Property of the Republic of Kazakhstan (National Patent—Kazpatent). Kazpatent was established on 23 June 1992, a year after the country declared independence from the USSR. The study also captured trademarks (a form of intellectual property that consists of a recognizable sign, design, or expression used to identify goods or services as coming from a specific source, and set them apart from those offered by other parties), utility models (registered property that allows the holder to use a technological invention only in a specific manner), as well as industrial designs (product's artistic and design solution, which decides how it will look). Figure 1 summarizes some of the innovation objects discussed in this study.

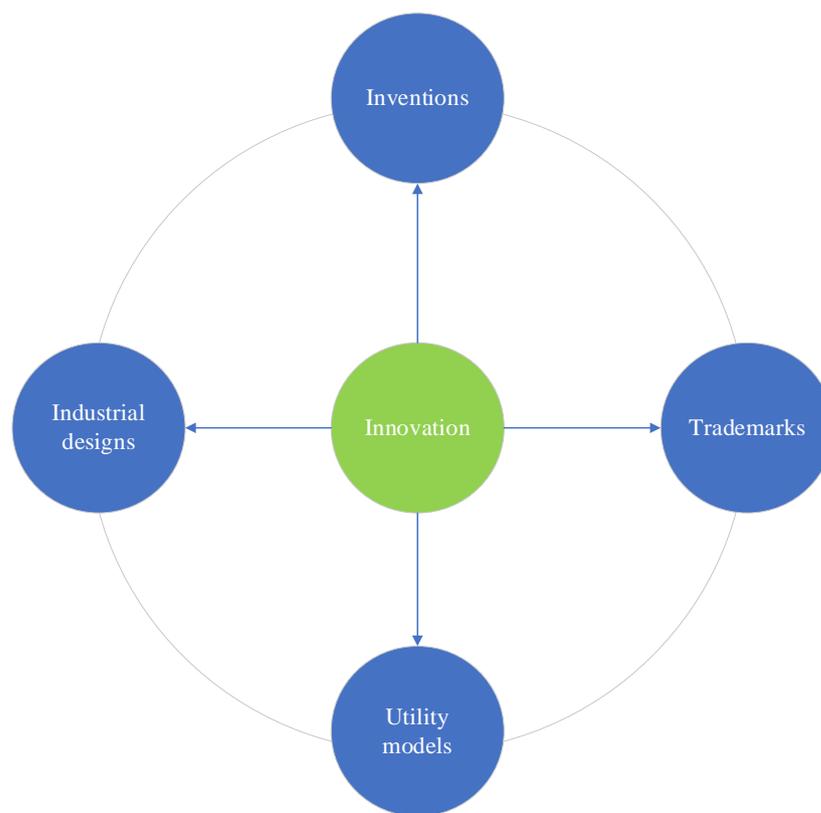


Figure 1. Innovation objects.

In general, the focus of the current work is a quantitative-based analysis of water-related innovations in a developing country, in this case Kazakhstan, with a strong emphasis on the 30 years from 1991 to 2020. It should also be noted that one of the significant challenges in the analysis of innovation trends has always been to find an appropriate study approach and data availability (Courtney and Powell 2020; Palinkas et al. 2019). The phenomenon makes it difficult to accurately analyze innovation trends. In this study, we used patents as a proxy for the trend of water-related innovations with time. The approach of using patents was selected due to the fact that they are available at a highly disaggregated level in terms of field and the type of water technology. The approach simplifies the process of categorizing the water-related innovations with respect to their specific technologies. This is also useful in terms of understanding the innovative activities in different fields of the water sector.

To be more specific, we used the national patent database, National Patent—Kazpatent, to retrieve the necessary information and execute the analysis on water-related innovation activities. Contrary to many other databases where high-end knowledge is needed to retrieve data, the National Patent—Kazpatent database is relatively simple and it is easy to retrieve data. In the database, it is possible to link the patent data with other regionalized data, as well as sort data based on different codes and years. In this case, only the files at the office of the National Institute of Intellectual Property of the Republic of Kazakhstan were used. From the National Patent—Kazpatent database, it was possible to link each patent with an assignee code, name, location, abstract, as well as the date of application and registration. As previously mentioned, the retrieved patents provide an estimation of water innovative activities. The analysis started with measuring the water innovative activities by selecting the International Patent Classifications (IPC) related to water innovations for three decades from 1991 to 2020; the extracted dataset contains over 56,000 patents (Table 1). Apart from the general analysis, the patents were also divided into different water technology categories and applications based on the standard IPC codes.

Table 1. Total registered objects for the entire period of the patent office (by national procedure) as of 31 December 2020.

Parameter	Number of Registered Objects	Total Protected
Trademarks	72,165	49,251
Inventions	38,262	3152
Utility models	5665	2915
Industrial designs	3763	1257
Selection achievements	946	370
Appellations of origin (including rights of use)	72	53
TOTAL	120,873	56,998

Table 1 provides a summary of the registered and protected trademarks, inventions, utility models, industrial designs, selection achievements, and appellations of origin (including rights of use) in Kazakhstan as of 31 December 2020.

Box and whisker plots were plotted and used to investigate the nature of data distribution within the data series. The plots displayed data mainly based on medians and quartiles (Larsen 1985; Holcomb and Cox 2017).

2.3. Questionnaire Survey

The respondents were grouped into three main categories, namely; small-scale (1–20 workers), medium-scale (21–1000 workers), and large-scale (more than 1000 workers). The estimation of the sample size was accomplished using the formula for single population proportion; whereby, the minimum required sample size of the study was determined (Nyampundu et al. 2020; Metcalfe 2001).

$$n = \frac{N \times Y}{Y + N - 1}$$

where

$$Y = \frac{Z_{\alpha/2}^2 \times p(1 - p)}{d}$$

- $Z_{\alpha/2}$ represents the critical value of the normal distribution at $\alpha/2$ (for instance, with a confidence level of 95%, α is 0.05 and the critical value is 1.96);
- d is the margin of error;
- p is the sample proportion;
- N is the population size.

To determine whether the differences between groups of data are statistically significant, an ANOVA was performed; this method analyzes the levels of variance within the groups using samples from each group. Furthermore, correlation coefficients were computed from different datasets in the study; correlation coefficients are specific statistics that assess the strength of the linear link between two variables (Akoglu 2018). The correlation coefficients ranging from 0 to 0.29 were considered as “weak”, 0.3 to 0.49 as “moderate”, 0.5 to 0.69 as “strong”, and 0.7 to 1 as “very strong”.

3. Results and Discussion

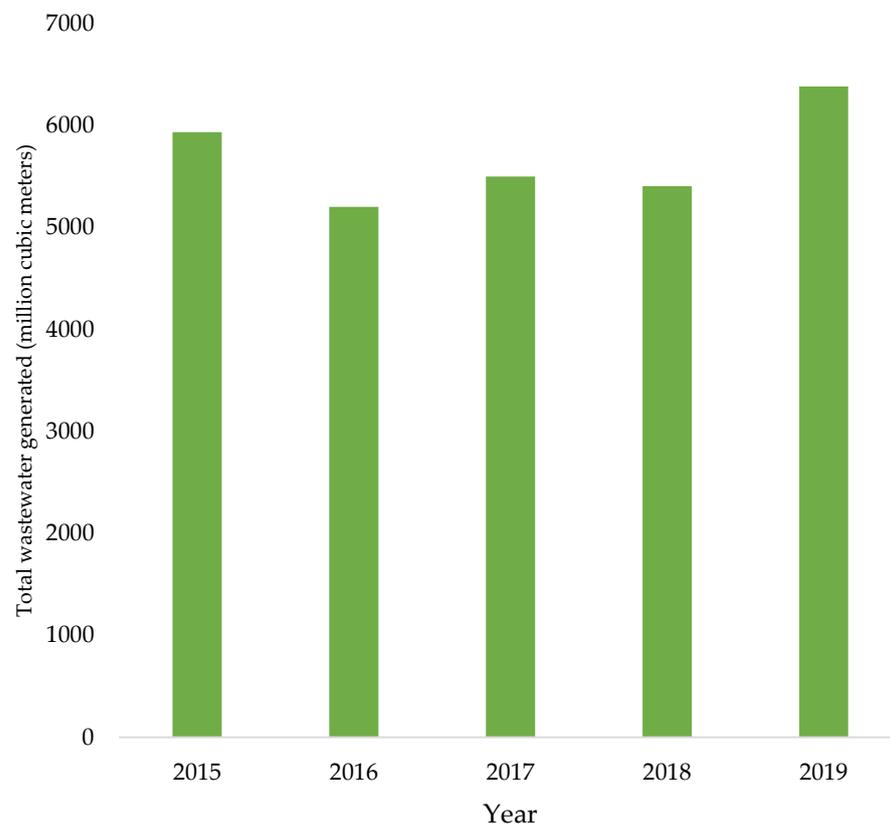
3.1. Characterization of Water-Related Issues

3.1.1. Water Use and Wastewater Management

The collected datasets from 1991 to 2020 were successfully analyzed based on the existing water-related challenges and innovation perspectives in water. Figure 2 presents the total volume of wastewater and the total amount of wastewater discharged into water bodies that have not been treated in Kazakhstan. From Figure 2, it can be observed that the total amount of polluted wastewater generated in Kazakhstan decreased by 12.3% from 2015

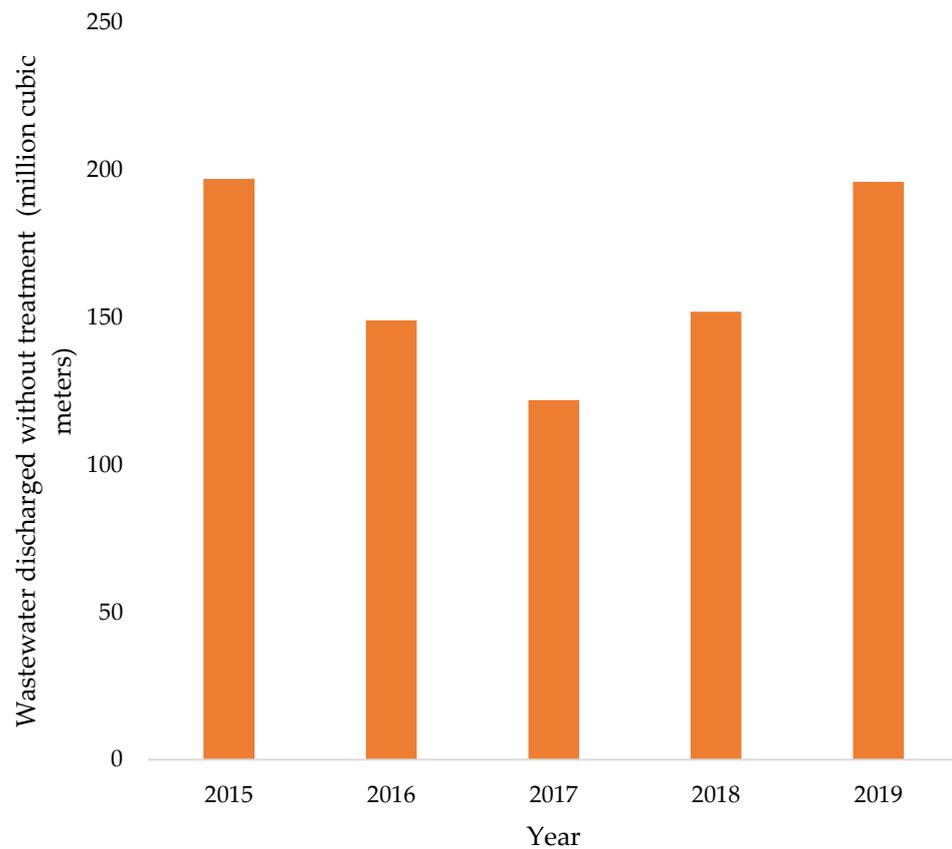
to 2016, and then increased by 5.7% from 2016 to 2017. The phenomenon suggests that there is a significant potential for the wastewater generated in the country to increase in the future, mainly caused by population growth. In general, all over the world, population growth has been observed to significantly affect the levels of wastewater generated, and increase the need for more sewerage network systems. According to the study conducted by Giorgis Z Teklehaimanot et al. (Teklehaimanot et al. 2015), which investigated the trend of population growth in some regions of South Africa (Sedibeng and Soshanguve) and its impact on the design capacity and performance of the wastewater treatment plants, Soshanguve exhibited a 50% increase in the number of households connected to the sewerage system between 1996 and 2001.

From Figure 2b, it can be observed that there has not been much improvement in the sector in terms of the potential amount of wastewater discharged into water bodies in the region. The phenomenon suggests that the water sector is still in pressing need of more innovations. It has to be noted that drought, flooding, pollution, population increase, and competition from a variety of uses are all increasing strains on our freshwater resources. Technology innovation can assist us in addressing our water issues, and put us on a more sustainable path while also promoting economic growth.

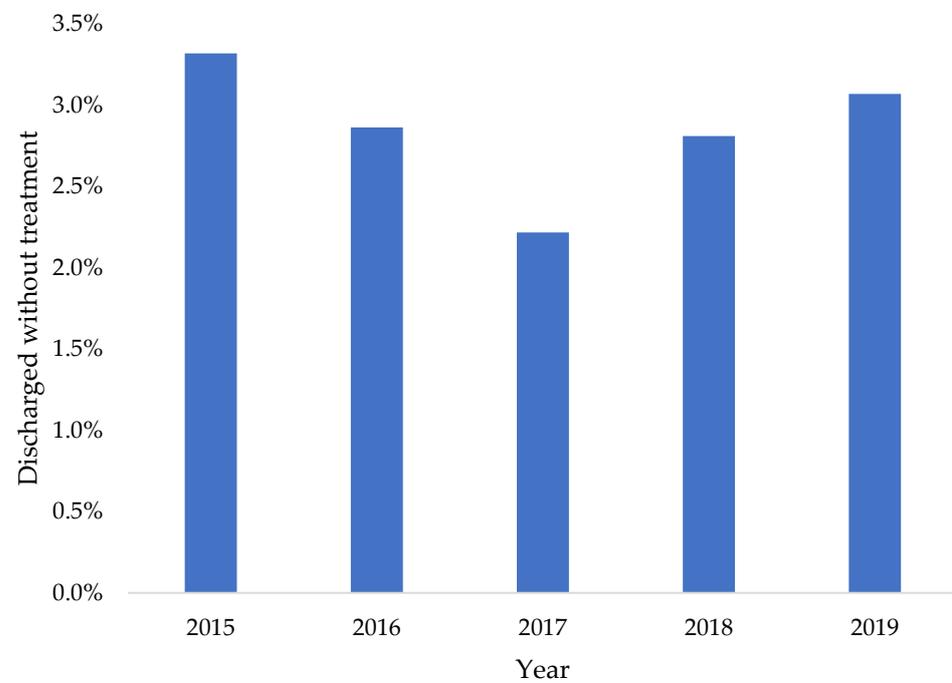


(a)

Figure 2. Cont.



(b)



(c)

Figure 2. Polluted wastewater: (a) total amount of wastewater generated, million cubic meters; (b) amount of wastewater discharged into the environment without treatment, million cubic meters; (c) percentage of wastewater discharged into the environment without treatment.

Moreover, when wastewater is discharged in large quantities, it has the potential to raise the temperature of the receiving water body, which in turn disturbs the natural balance of aquatic life (Vargas-González et al. 2014; Meiramkulova et al. 2020a, 2020b). Furthermore, poor recovery technologies, pollution, and pollutants in water resources can all lead to increased scarcity, environmental deterioration, and potentially irreversible damage. The long-term solution does not lie in substantially reducing water consumption, but rather in innovative wastewater management and treatment technologies and practices.

Water use is another good indicator of the growing need for more innovations in the water sector. From Figure 3, it can be observed that approximately 51,163 million cubic meters of water was used in Russia, followed by 20,955 million cubic meters in Kazakhstan; this discrepancy can be strongly linked to the number of populations within the countries, as well as the economic level that determines innovation activities. Furthermore, the consumption is strongly linked to the amount of wastewater discharged into water bodies. One of the effects of overpopulation is the strain on existing water supplies to meet the demands of an expanding population. By 2030, over half of the world's population will be living in "water-stressed" zones, which are defined as areas where water demand exceeds supply, either owing to a shortage of supply or poor quality (compared to fifteen percent currently). Since 1990, the global population has grown by an average of eighty million people, resulting in a rise in global freshwater consumption of around 64 billion cubic meters per year, according to the United Nations Report (The United Nations World Water Development Report 2015: Water for a Sustainable World 2016) (Amprako 2019). To address these concerns, the water sector must undergo significant reforms. Innovative wastewater treatment technologies (Mkilima 2022; Mkilima et al. 2021), distributed or on-site wastewater treatment, resource recovery (Liu et al. 2021), and institutional and organizational reforms that can render improved wastewater management systems are all promising examples. According to the survey conducted by Cantor et al. (Cantor et al. 2021), it was proposed that improving relationships and communication between utility managers and regulators, as well as additional funding support for increased capacity of both utilities and regulators, would be more effective ways to encourage innovation in the municipal wastewater sector (Cantor et al. 2021). As part of the efforts in the field, The World Bank has developed Utility of the Future, a program designed to ignite, materialize, and maintain transformation efforts in water supply and sanitation services (The World Bank 2022).

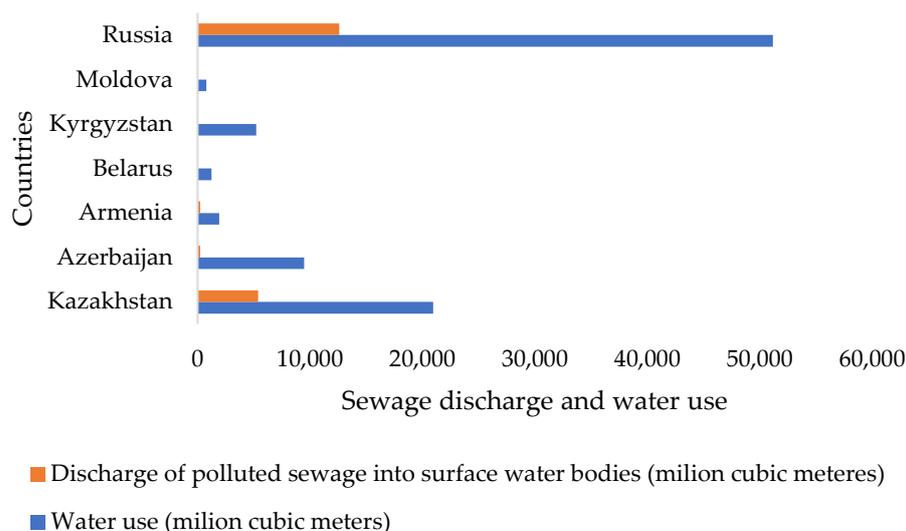


Figure 3. Water use and wastewater discharge in 2019 for Russia, Moldova, Kyrgyzstan, Belarus, Armenia, Azerbaijan, and Kazakhstan.

3.1.2. Water Services Price

Price in terms of water-related services is another good indicator of the need for more innovative activities in the water sector, which would make the vital services readily available at a relatively cheaper price. From Table 2, it can be observed that the prices for hot water, cold water, and sewage services have been generally increasing with time.

Table 2. Average prices and tariffs for paid services for the population, KZT/cubic meter.

Service	Year				
	2015	2016	2017	2018	2019
Hot water	199	218	234	240	232
Cold water	57	65	71	73	69
Sewerage	37	43	46	48	48

Water supply and wastewater disposal utilities are always stressed by a number of challenges towards meeting future demands under population growth, changing climatic conditions, solving issues related to old structures, ensuring that high-quality water is delivered, as well as reducing energy consumption. Therefore, the eagerness of the utility to invest and work on innovative solutions to address these challenges relies solely on the particular utility based on a number of factors, including governance and cultural issues, the available regulatory environment, how the particular structure performs, as well as availability of funds for addressing the issues. In this manner, if these issues are left unattended, there is a significant potential that they may lead to some other issues, such as environmental pollution, destruction of the ecosystem, pose risks to public health, as well as deterioration of service provision; this may, in turn, lead to highly elevated prices for the same service (Speight 2015).

However, it should also be noted that service pricing can pose a significant threat to innovation in the water sector. In the literature, some studies have reported that there is a significant linear correlation between service pricing and innovation activities in the water sector. For instance, according to Ajami et al. (2014), in the United States, water is generally underpriced and the pricing does not comply with the true economic cost of water to society. This has been observed to affect the innovation activities in a number of ways, including revenue reduction making it difficult for water suppliers to invest in innovation. Such a phenomenon often leads to a gap between revenue collected from customers and the total costs to operate these systems, making it very difficult for the authorities to pursue innovation activities in the field of water. Moreover, when the pricing is inadequate there is a significant potential to create a vicious cycle whereby the water authorities are left unable to address the aforementioned challenges, which can further reduce their revenues (Ajami et al. 2014).

3.2. Patenting of Innovation Ideas

3.2.1. Application-to-Registration Ratio

Only about 8.2% of the applied inventions in the water sector were registered by December 2020, according to Figure 4, which shows the ratio of registered innovations to applied innovations in percentage. Generally, people devise many ideas; however, only a small percentage of these become reality. The phenomenon can be linked to a number of factors, as highlighted by Ryabokon' et al. (2019), which include, but are not limited to, a lack of confidence in their ideas' freshness, an overestimation of the required imaginative step, or a fear of sharing their ideas with others. It is also worth noting that patenting allows you to break free from the constraints of thought, and contributes to the discovery of creative potential. Even though many ideas do not reach the application phase, there is also a considerable number of applications that are rejected for several reasons, including failure to meet the predefined requirements.

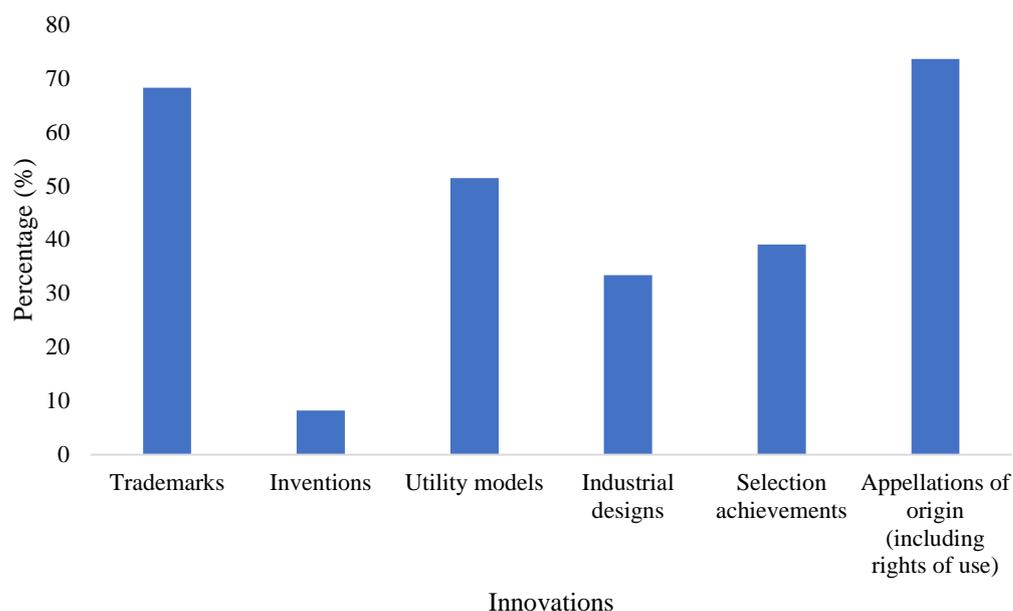


Figure 4. The application-to-registration percentage as of December 2020.

3.2.2. Trend of Innovation within the Three Decades

With the fact that the global population is estimated to reach 9.7 billion people by 2050, it has never been more important to produce more with less. From Figure 5, it can be observed that the trend of innovation activities in the water sector has been decreasing with time, despite the fact that the entire world has recently been under many challenges related to water. There was an interesting increase in terms of patented innovations from 1991 to 1993, which then reduced significantly from 1993 to 1994. Moreover, from 2012, this number has been sharply decreasing, calling for immediate action in the sector. As previously mentioned, as the water supply and sanitation sectors continue to face increasing pressures, especially due to factors such as changes in climatic conditions and population growth, the governments in developing countries need to increase the resilience and sustainability of the water sector. To achieve this, innovation and technology have a vital role in addressing these issues. All over the world, one of the main reasons why innovations fail is due to an unfulfilled commitment and a lack of support for innovation. As a result, numerous resources are wasted due to friction, and innovation activities are not completed to the appropriate standard (Rhaiem and Amara 2021).

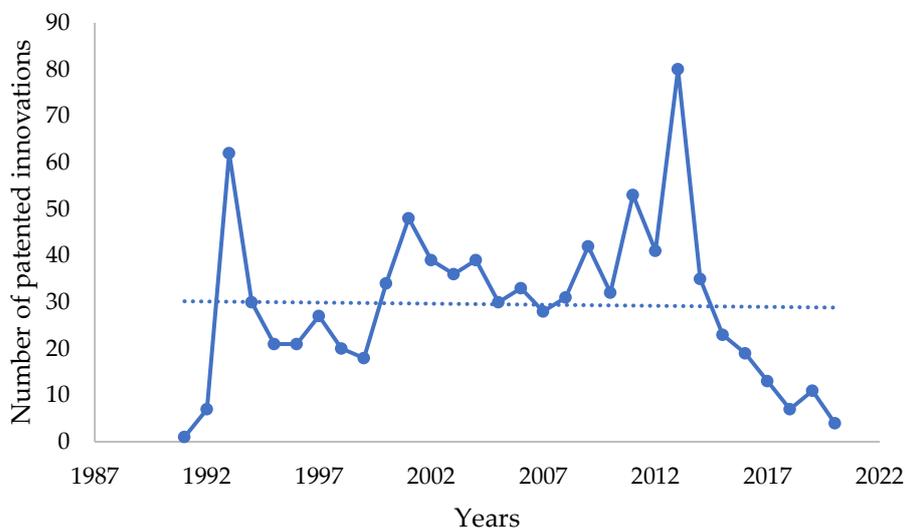
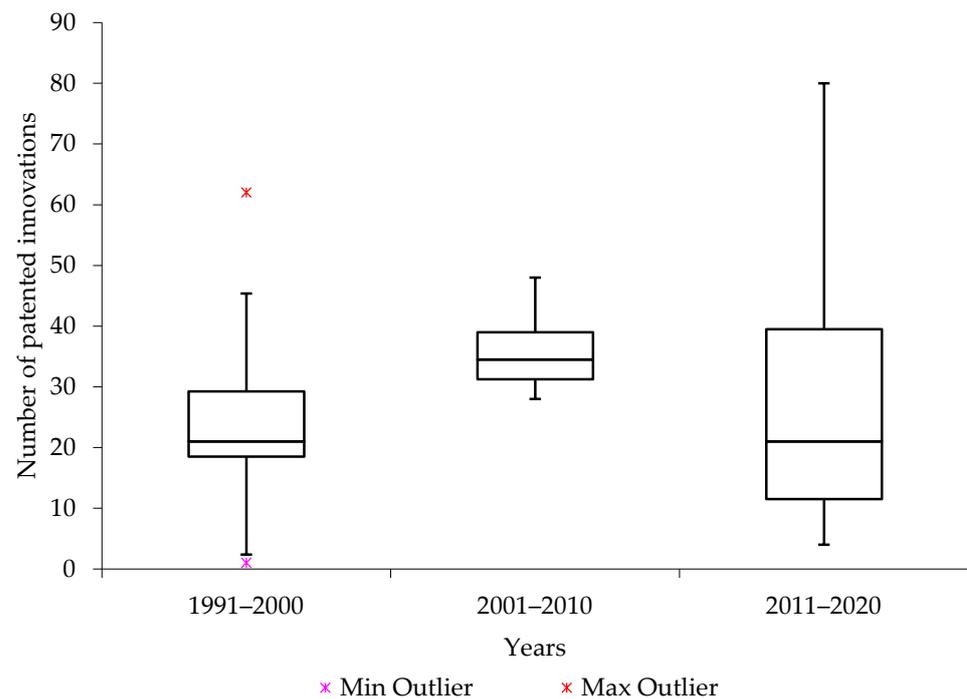


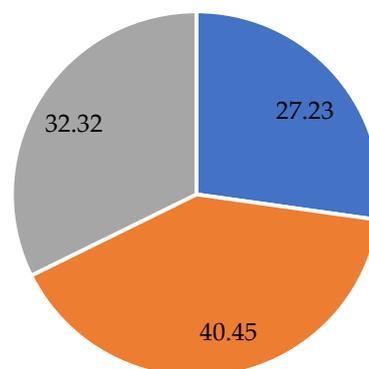
Figure 5. The trend of innovations from 1991 to 2020.

3.2.3. Distribution of Water Innovations over Decades

It was also important to group the datasets into groups of 10 years (decades) to understand how the trend of innovations has been changing within decades. From Figure 6, it can be observed that the 1991 to 2000 decade had relatively fewer patented innovations compared to the 2001–2010 and 2011–2020 decades. Additionally, Figure 5 further reveals that the 2001–2010 decades had more water-related patented innovations than the 2011–2020 decade. The phenomenon shows that there is a decreasing trend in terms of water-related innovations in Kazakhstan. The phenomenon can be highly linked to factors such as social and technological changes that affect the way people use water. Moreover, it can also be a significant alarm of low investment to harness more innovation activities in the sector.



(a)



■ 1991–2000 decade ■ 2001–2010 decade ■ 2011–2020 decade

(b)

Figure 6. Innovations per decade (a) data distribution (box and whisker plot) for the three decades, (b) percentage of innovation within the three decades.

The datasets were grouped into decades because a decade can be sufficient enough for a society to witness a total social and technological change that can significantly affect the trend of innovations. By definition, social change takes into account the way human interactions and relationships transform cultural and social institutions over time, having a profound impact on society's innovation activities including water. In the literature, sociologists term social change as the general transformation in the way human beings interact and relate, which in turn transforms cultural and social institutions; the transformation is also regarded as the cornerstone for the success of emerging countries (Maldonado-Mariscal 2020). These changes take time to occur, and may have significant long-term consequences for the particular society. On the other hand, technological change, sometimes known as technological development, is the overall process of invention, innovation, and diffusion of technology. Technological change, therefore, produces new patterns of social life (Jacobs 2001). The processes are highly influenced by the arrival of new digital tools that affects consumption patterns, types of employment, and working conditions, while acting as a crucial determinant to the trend of innovation activities in different sectors including water (Coron and Gilbert 2020).

3.2.4. Analysis of Variance (ANOVA) with Decades

In this study, it was greatly important to justify whether there is any significant difference in terms of innovation within the three investigated decades. In Table 3, which presents the ANOVA results, it can be observed that the p -value is 0.014039, which is less than 0.05 (alpha value). To determine whether the differences between some of the means are statistically significant, p -values from ANOVA outputs have always been observed to be useful (Rouder et al. 2016). To be more specific, in this study, the ANOVA results were used to examine the null hypothesis by comparing the p -value to the significance threshold (0.05) to establish whether any of the differences between the means were statistically significant. Therefore, based on the results, it can be concluded that differences in terms of innovation within the three decades investigated in this study were statistically significant.

Table 3. Results from single-factor ANOVA.

SUMMARY						
Groups	Count	Sum	Average	Variance		
First decade (1991–2000)	10	241	24.1	275.2111		
Second decade (2011–2020)	10	358	35.8	38.62222		
Third decade (1991–2000)	10	188	18.8	138.6222		
ANOVA						
Source of Variation	SS	df	MS	F	p -value	F crit
Between Groups	1513.267	2	756.6333	5.016846	0.014039	3.354131
Within Groups	4072.1	27	150.8185			
Total	5585.367	29				

3.3. Classification of Water Fields Based on International Patent Classifications

The categories of the water fields used in this study are based on the International Patent Classification (IPC) codes that normally cover almost all water-related technologies. In this case, water and wastewater treatment innovations (Table 4), technologies for extraction of fertilizers from wastewater (Table 5), and technologies for water collection and storage (Table 6) were analyzed. The most significant objective of this categorization is to investigate whether more accurate innovative patterns in the water sector can be captured. The goal is to capture not only the overall evolution of water innovation trends, but also the possible rise in technological trajectories of some individual water technologies. This helps to understand which water-related field based on the patented technologies is under

more stress compared to others. From Table 4 it can be observed that, among many other categories, only the treatment of water, wastewater, sewage, or sludge category is observed to be more active in terms of innovations. This phenomenon also portrays there a need for more innovations in the field. In the literature, some other countries have also been observed to increasingly emphasize the importance of focusing on innovative activities as a major driver of economic and social development. For instance, the Chinese government, which ended 2018 with an economic growth rate of 6.6%, has recently reformed its economy from an investment-driven to an innovation-driven growth model (Qian 2019). Moreover, the significance of water innovative activities has recently captured the interest of Chinese policymakers; and this can be vividly observed from the growing discussions and inclusion in recent policy and research agendas.

Table 4. Water and wastewater treatment innovations in 30 years.

Category	International Code	Number
Water and wastewater treatment		
Arrangements of installations for treating waste-water or sewage	B63J4	0
Treatment of water, wastewater, sewage, or sludge	C02F	629
Chemistry; Materials for treating liquid pollutants, e.g., oil, gasoline, fat	C09K3/32	0
Plumbing installations for wastewater	E03C1/12	0
Sewers—Cesspools	E03F	23

Table 5. Fertilizers from wastewater innovations in 30 years.

Category	International Code	Number
Fertilizers from wastewater		
Fertilizers from wastewater, sewage sludge, sea slime, ooze, or similar masses	C05F 7	2
Oil spill clean-up		
Devices for cleaning or keeping clear the surface of open water from oil or oil-like floating materials by separating or removing these materials	E02B15/04-10	0
Vessels or vessel-like floating structures adapted for special purposes—for collecting pollution from open water	B63B35/32	1
Materials for treating liquid pollutants, e.g., oil, gasoline, or fat	C09K3/32	2

Table 6. Water collection and water storage innovations in 30 years.

Category	International Code	Number
Water collection (rain, surface, and ground-water)		
Use of pumping plants or installations	E03B 5	0
Methods or installations for obtaining or collecting drinking water or tap water from underground	E03B 3/06-26	0
Methods or installations for drawing-off water	E03B 9	5
Methods or installations for obtaining or collecting drinking water or tap water from surface water	E03B 3/04; 28–38	1
Methods or installations for obtaining or collecting drinking water or tap water from rainwater	E03B 3/02	3
Special vessels for collecting or storing rain-water for use in the household, e.g., water-butts	E03B 3/03	0
Methods or installations for obtaining or collecting drinking water or tap water; rainwater, surface water, or groundwater	E03B 3/00	15
Water storage	E03B 3/40	1
Arrangements or adaptations of tanks for water supply	E03B 11	4

It is also worth pointing out that, among many other factors challenging the innovation activities in the water, is the fact that the water-related systems (water supply and wastewater disposal) have always been extremely complex engineered systems with long design life. The structures last for decades and even more, a phenomenon that has significantly

biased the water sector toward the adoption of incremental upgrades rather than toward investing in more innovative ideas and revolutionary technologies. A good example is a process of delivering recycled water that is always requiring new piping systems, which can be excessively expensive. Additionally, in most cases, when individual elements of a water system need replacement, there is a high potential for the rest of the system to be under operation; this makes it more likely that the authorities will simply opt to replace the worn element rather than fundamentally replacing the entire water system.

3.4. Correlation of Different Innovation Factors in the Water Sector

It is significantly important to highlight that correlation is a statistical term that expresses how closely two variables are related in a linear fashion (meaning they change together at a constant rate). It is a typical way of describing simple relationships without stating a cause-and-effect relationship. In this study, several innovation factors were subjected to the correlation analysis. From Table 7, it can be observed that a relatively high correlation was achieved between wastewater handling tariffs and patented innovations with a correlation coefficient of 0.868. However, a weak correlation can be observed between water supply tariffs and patented innovations with a correlation coefficient of 0.333. This phenomenon presents the reality of the water sector, whereby most of the water supply systems are heavily funded and long-term projects invite fewer individual innovations in the field. That is to say that, systems that rely on large centralized water supply and treatment facilities are unable to meet current or future demand, and prospects for innovation are generally limited in such large-scale systems due to perceived technical, financial, and organizational challenges (Garrick et al. 2020).

Table 7. Correlation among different factors.

Parameter	Water Demand	Water Supply Tariffs	Wastewater Handling Tariffs	Patented Innovations
Water demand	1			
Water supply tariffs	0.781	1		
Wastewater tariffs	0.484	0.620	1	
Patented innovations	0.469	0.333	0.868	1

3.5. Questionnaire Survey

After observing the dramatic fall in terms of patented water innovations, especially in 2020, with only four patented water innovations, we decided to formulate a semi-structured questionnaire to investigate the potential influence of the COVID-19 situation in disrupting the innovation activities in the country (Appendix A); the summary of the firms' distribution in the survey is provided in Figure 7. This is because the COVID-19 pandemic has significantly impacted the world economy, which in turn has resulted in unprecedented disruption to personalities, families, trades, as well as governmental and non-governmental, profit and non-profit organizations. Governments all over the world have been put under pressure when trying to respond to the situation while balancing the health and economic priorities of their citizens. It is only a matter of fact that the catastrophic situation has badly hit even organizations that previously had the strong capability to withstand serious disruptions in terms of investments and devising outstanding innovative solutions (KPMG Digital Delta 2020). The phenomenon makes understanding the trend of water innovation activities even more important.

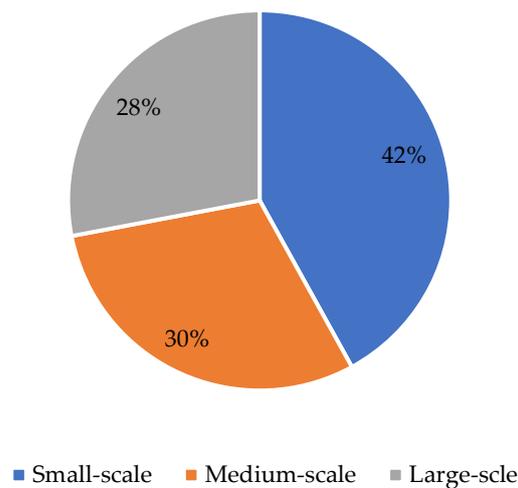


Figure 7. Distribution of firms in the survey.

The COVID-19 public health emergency has brought civilization to the brink of disaster. In such extreme conditions, the need to mitigate COVID-19's full impact by lowering its short- and long-term consequences has prompted governments to implement large-scale and rapid-tracked innovation strategies. This is a dramatic 180-degree turn from earlier assertions that government organizations are not inventive enough (Patrucco et al. 2021). From Figure 8, it can be observed that the innovation disruption caused by COVID-19 in terms of the motivation in water-related innovations has impacted more of the large-scale water firms than the small-scale firms. According to Ronen Harel (2021), who investigated the impact of COVID-19 on the performance of small businesses and innovation, it was observed that despite COVID-19's widespread impact on all aspects of life, the pandemic had no negative impact on the revenues of most small businesses in the industrial sector, and that most of them did not change or adjust their business activities or the extent to which they used open innovation tools or engaged in innovation promotion processes. The findings also suggest that small enterprises, which rely on subcontracting work to other businesses and long-term agreements for the majority of their revenue, will fare better amid economic downturns and uncertainties. This phenomenon also agrees with the findings observed in this study.

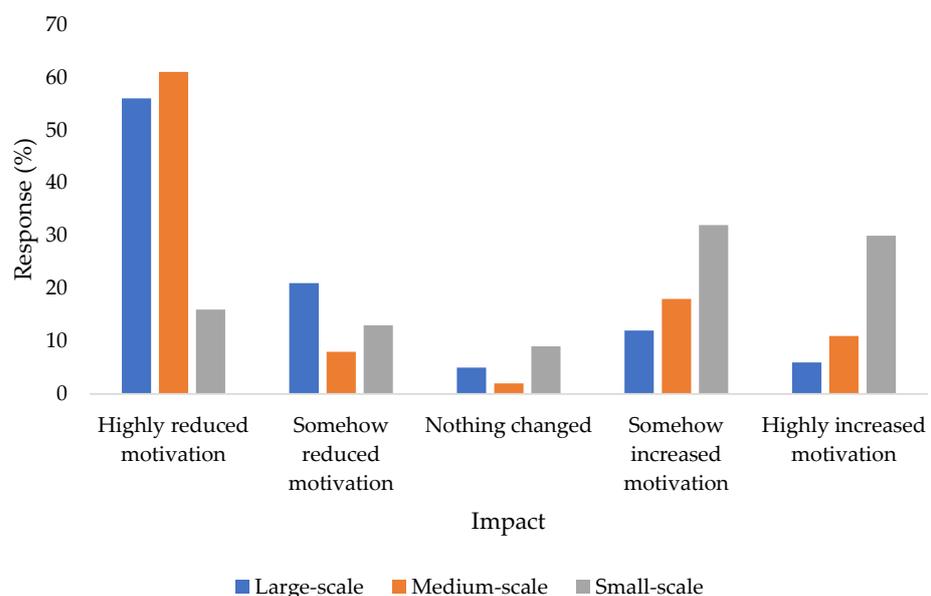


Figure 8. Impact on motivation for innovation.

Countries all across the world fought the COVID-19 pandemic for much of 2020 (Ramalho et al. 2022; Jribi et al. 2020), and continue to do so. This was in order to combat the virus's rapid spread, and many countries went into lockdown. The lockdown's unprecedented constraints and seclusion posed new obstacles in people's daily lives. In such a situation, creativity can help people cope with harsh and difficult conditions since it is based on flexibility, adaptability, and problem-solving. From Figure 9, it can be observed that, similar to how the COVID-19 situation has been impacting the general motivation of the water firms to work more in innovative activities, the level of investment in water innovations, as determined by the level of funding, has also been observed to be more strongly impacting large-scale firms than the small-scale firms. The results derived in this study also agree with the results obtained by Xin Jin et al. (2022), in which, the authors concluded that COVID-19 has a stronger detrimental impact on the innovation quality of state-owned firms than it does on non-state-owned enterprises; while at the company level, COVID-19 has a greater impact on major organizations' innovation than on small- and medium-sized businesses.

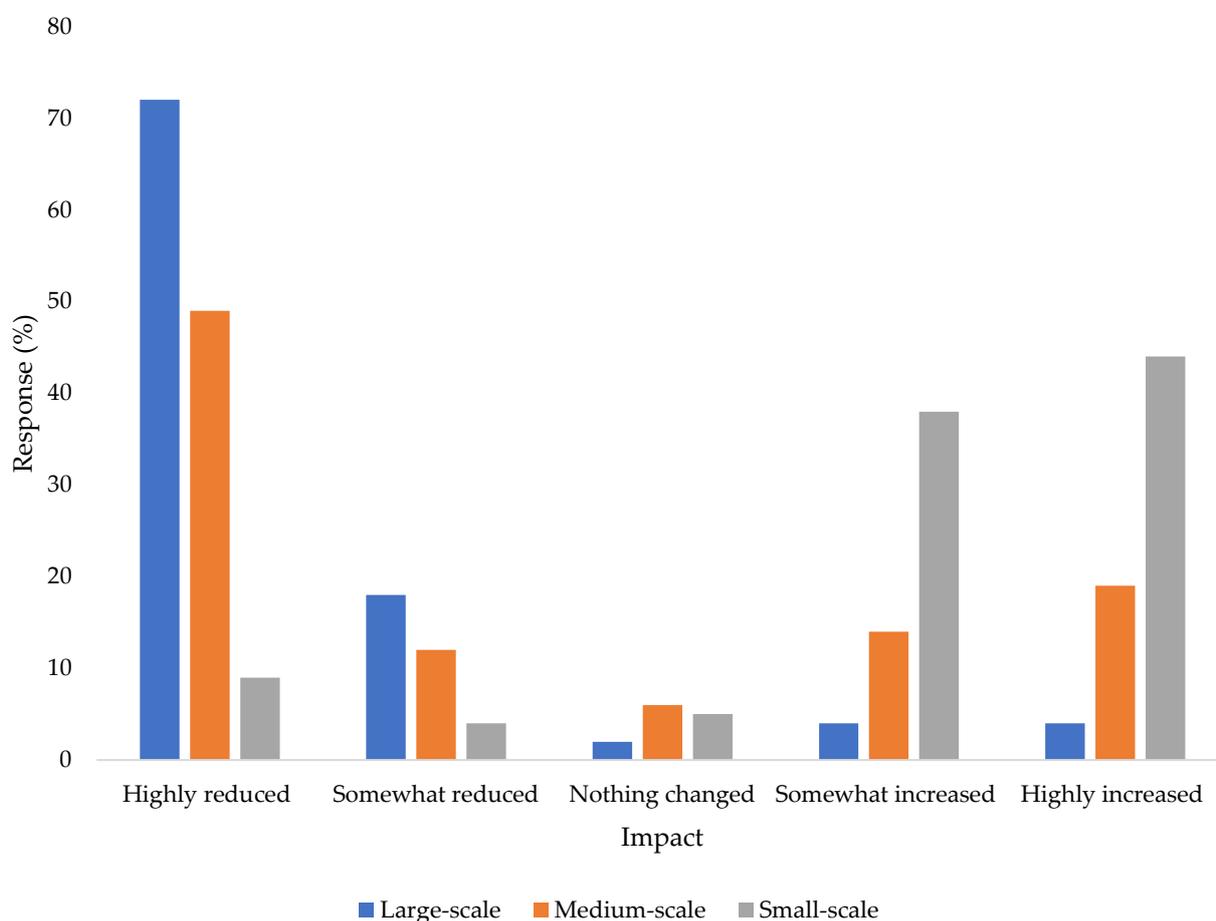


Figure 9. Impact on investment level as influenced by funding.

From Table 8, it can be observed that funding, market availability, transport of goods, and profit-making are innovation factors that are perceived to be highly impacted by the COVID-19 situation in recent years. The phenomenon can be linked to the fact that, as a result of the epidemic, travel by ground, air, and water has plummeted. These changes have occurred as a result of both fear of becoming ill and government regulations. Emergency orders, business closures, online schooling, and reduced social activities all contributed to a 52.4% decline in motorway traffic, and a 40.5% fall in arterial traffic in Florida alone, according to Parr et al. (2020). Many state and local governments across the United States

and the rest of the world imposed social separation orders and limited non-essential travel (Kim 2021).

Table 8. The extent to which COVID-19 has impacted different factors of innovation in the water sector (number of samples = 42).

Factors	Min	Max	Median	Mean	STD
Funding	1	5	5	4.18	1.15
Interest to innovation	2	5	4	3.56	0.79
Cooperation among water firms	1	5	4	3.88	1.23
Training	2	5	4	3.65	0.90
Market availability	2	5	5	4.29	1.07
Transportation of goods	2	5	5	4.71	0.75
Profit making	2	5	4	4.06	1.06
Design of ideas	1	4	2	2.53	0.98

4. Conclusions

Different aspects related to innovation in the water sector were investigated, mainly in the case of Kazakhstan, and a few more cases from neighboring countries. The study started by investigating several water-related challenges, highlighting the crucial need for more innovations in the water sector. From the analysis results, it was observed that the 1991 to 2000 decade had relatively fewer patented innovations compared to the 2001–2010 and 2011–2020 decades. Moreover, it was also observed that the 2001–2010 decade had more water-related patented innovations than the 2011–2020 decade; this phenomenon suggests that there is decreasing trend in terms of water-related innovations in Kazakhstan. The trend of innovation activities in the water sector was observed to be decreasing with time, despite the fact that the entire world has been recently under many challenges related to water. There was an interesting increase in terms of patented innovations from 1991 to 1993, which then reduced significantly from 1993 to 1994. Additionally, the number of patented innovations was observed to decrease from 2012 to 2020. The ANOVA yielded a *p*-value of roughly 0.014 (less than the significance threshold of 0.05). These results allow us to draw the conclusion that there were statistically significant differences in innovation over the three decades studied without any discernible pattern of fluctuation. This type of significant fluctuation suggests that the state of innovation in emerging markets is relatively unstable, making the field as a whole susceptible to collapse. Furthermore, with a correlation coefficient of 0.868, wastewater handling tariffs and patented innovations have a relatively good correlation, meaning that the two factors influence one another. However, with a correlation coefficient of 0.333, it was observed that there is a minor correlation between water supply tariffs and patented ideas. According to the results of the questionnaire study, COVID-19's disruption of innovation in terms of motivation in water-related innovations has harmed large-scale water enterprises more than small-scale water firms. As a result, the findings of this study highlight that there is a substantial need to spend more on innovation in the water sector, particularly among large businesses in the study region and all over the world. Further research into the issue in well-established markets would be interesting.

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Appendix A. Questionnaire

1. Scale of the firm:
 - a. Small-scale (1–20 workers)
 - b. Medium-scale (21–1000 workers),
 - c. Large-scale (more than 1000 workers).
2. How have the social and economic impacts of the COVID-19 disruption influenced your organization’s motivation on water innovation going forward?
 - a. Highly reduced motivation
 - b. Somewhat reduced motivation
 - c. Nothing changed
 - d. Somewhat increased motivation
 - e. Highly increased motivation
3. How will the social and economic effects of COVID-19 impact the level of funding available for pursuing innovation within your organization?
 - a. Highly reduced
 - b. Somewhat reduced
 - c. Nothing changed
 - d. Somewhat increased
 - e. Highly increased
4. The extent to which COVID-19 has impacted different factors of innovation in the water sector (please rate from 1 to 5, where 1 = no significant impact, 2 = less impacted, 3 = neutral, 4 = moderately impacted, and 5 = highly impacted).
 - a. Funding
 - b. Interest to innovation
 - c. Cooperation among water firms
 - d. Training
 - e. Market availability
 - f. Transportation of goods
 - g. Profit making
 - h. Design of ideas

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