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Dynamics of innovation in the use of water resources in emerging markets

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A B S T R A C T

The advancement of water sustainability and reliance highly depends on the implementation of innovative ideas. However, despite being a vital resource, the water sector still faces many challenges in innovations compared to other industries. This study investigated three different aspects of innovation activities in the water sector in Kazakhstan, which represents a typical developing country. First, the potential water-related issues calling for more innovation activities were investigated. Second, the trend of innovation activities over 30 years was investigated with the help of patents. Third, the disruptions rendered by COVID-19 to innovation activities in the water sector were investigated through a questionnaire survey. The analysis results showed that the total volume of contaminated wastewater generated in Kazakhstan has generally increased with time. The number of water enterprises, patented water-related innovations, and total general patents showed a strong association, with correlation values ranging from 0.66 to 0.99. In all firms, regardless of the scale investigated in this study, the availability of local expertise, the culture of local organizations toward innovation, and the country's business environment are all considered to have a significant impact on water innovation processes.

1. Introduction

Innovation is one of the most important tools for raising global living standards, including greater access to water and water resource management; it plays a significant role in tackling water-related issues (Baehler and Biddle, 2018). Unfortunately, current policies and technologies do not effectively address these issues, necessitating the urgent need for further breakthroughs. It is also worth noting that venture capitalists are increasingly interested in water-related innovation. Climate change and population growth have increased the requirement for more innovative literacy in the water industry (Arnell, 2004). Water conservation, preservation, and management remain critical elements in guaranteeing human survival.

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Innovation can be a beneficial adaptation strategy when the entire planet is in peril due to climate change (van Genuchten et al., 2019).

Unfortunately, in comparison to other industries, water innovation is rather low worldwide. Water innovation diffusion is slow (O'Callaghan et al., 2020). This situation necessitates greater research into the various aspects contributing to the current link between innovation and water challenges. Water-related concerns are becoming a limiting factor for sustainability and economic growth, highlighting the importance of combining innovation and water (Wehn et al., 2021).

Furthermore, it is a fact that water sector innovation processes face greater uncertainties, which are also poorly understood in less developed locations, particularly in developing countries (Mvulirwenande and Wehn, 2019).

Despite recent efforts to improve the general sense of water innovation in less developed countries, the field still lacks sufficient knowledge of the problems and appropriate methodologies to investigate the problem toward proper water resource management and improved water service provision (Wehn and Montalvo, 2018). In many nations, data availability is also a problem in investigating problems associated with water innovations. In this case, looking at patent data can help you understand both invention and innovation (Huang et al., 2020). Furthermore, technical advancements have increased the potential applicability of patent records as a tool for investigating and measuring the global trend of innovative activity. In various aspects, patents provide a good picture of the innovation trend, including (Schankerman, 2003):

- The overall international patterns and distributions of how innovative activities progress and their consequences on commerce and production.
- The implications of interfirm interactions on firm performance and industrial structure in creative activities.
- The scope of innovation in various technical domains and industrial sectors and its focus.
- Providing scientific and technology connections.

On the other side, billions of dollars are spent every year by organizations, institutions, and governments to improve water availability. However, to attain social welfare through increased water access, research and development findings must be successfully monetized so that consumers can benefit from improved water-related products at lower prices (O'Callaghan et al., 2019). The issues of water innovation can only be addressed effectively if significant cooperation between businesses and research institutions exists (Song et al., 2019). As a result, water innovation must encompass new sustainable technology and new alliances across commercial and public sectors, research, and industry to create new business models and forms of water governance (Bunch et al., 2014).

Unfortunately, as previously mentioned, water sector innovations lag, which can also be attributed to a lack of knowledge caused by a lack of sufficient studies in the field. Kazakhstan's government has made significant investments in technological advancements through innovation. However, like many other sectors in the world, the water sector is still lagging in innovation. Due to a lack of sufficient investigations, it has also been difficult to quantify the scope of the problem (He and Ortiz, 2021; Yi et al., 2020). As a result of the current status of the water sector, water-related innovation is a hot topic on the international policy agenda. The systemic complexity that typically surrounds such contexts in the water sector necessitates a deeper and more actionable understanding of empowering and composing innovative activities toward more innovative solutions by connecting different players through organized networks (Charry et al., 2016).

The trends in water-related inventions are studied using patent data from Kazakhstan. The possible water-related challenges are emphasized, highlighting the urgent need for increased innovation initiatives. The patterns of creative activities across enterprises, and their overall consequences on-field performance and industrial structure, are elucidated; this includes descriptions of how innovative activities alter and focus over time in various scientific domains.

2. Materials and methods

2.1. Case study description

Kazakhstan is a Central Asian republic formally known as the Republic of Kazakhstan. The country is bordered on the northwest and north by Russia, on the east by China, on the south by Kyrgyzstan, Uzbekistan, the Aral Sea, and Turkmenistan, and on the west by the Caspian Sea. Kazakhstan is the largest country in Central Asia and the ninth largest country globally in land area. From east to west, the country is 2930 km long, and from north to south, it is 1545 km long. The country's capital, Nur-Sultan, is in the north-central area. Astana, Akmola, and Tselinograd were the past names for the city.

There are around 7000 streams in the country, most of which are in the east and southeast. The vast Irtysh, Ishim (Esil), and Tobol rivers are all located in the northwest and are considered big transboundary rivers that penetrate Russia and eventually spill into Arctic waters. The Irtysh River dumps 28 billion m^3 of water into the enormous West Siberian catchment area every year.

The Caspian Sea, one of the world's largest inland bodies of water, runs along Kazakhstan's shore for 1450 km. Lake Balkhash, Zaysan, Alaköl, Tengiz, and Seletytengiz are some of the greatest bodies of water. The country also includes the entire northern half of the shrinking Aral Sea, which experienced a catastrophic decline in the second half of the twentieth century as freshwater inflow was diverted for agriculture. This caused the sea's salinity to rise dramatically and the receding shores to become a source of salty dust and polluted deposits, destroying the surrounding lands for animal, plant, and human use.

The nation's climate is distinctly continental, with hot summers and equally brutal winters, particularly in the plains and valleys. The country's temperature fluctuates widely, with average January temperatures ranging from -19 to -4 °C in the northern and central portions. The south has milder temperatures than the north, ranging from -5 to 1.4 °C. Average summer temperatures in the north, particularly in July, exceed 20 °C, whereas, in the south, they reach 29 °C. Temperatures as high as 45 °C have been recorded in the country. The northern and central parts receive light precipitation, ranging from 200 to 300 mm per year to 406.4–508 mm in the southern mountain valleys.

2.2. Data collection and analysis

A list of documents with data was collected from the Bureau of National Statistics of the Agency for Strategic planning and reforms of the Republic of Kazakhstan to analyze water-related issues (wastewater generated over time, total amount of wastewater discharged into untreated water bodies, water use, and pricing) (Bureau of National Statistics of the Agency for Strategic planning and reforms of the Republic of Kazakhstan 2020).

Patents were the primary data source for this study, with information obtained from patents filed from 1991 through 2020 (30 years). The mission of Kazakhstan's patent system is to provide the necessary and sufficient patent legal, informational, and institutional conditions for a favorable innovative climate for manufacturing products and services in Kazakhstan with protected intellectual property rights, as well as ratification of Kazakhstan as an equal and competitive partner in global economic relations (National Institute of Intellectual Property of the Ministry of Justice of the Republic of Kazakhstan, 2021). The National Institute of Intellectual Property of the Republic of Kazakhstan's office is the main organization in charge of patent matters in Kazakhstan (National Patent – Kazpatent). Kazpatent was founded on June 23, 1992, after the country gained independence from the Soviet Union. The following is a list of database information that can be retrieved:

- Invention
- Utility models
- Industrial designs
- Selection invention
- Well-known trademarks
- Trademarks
- Geographical indication

The current research focuses on a quantitative analysis of water-related innovations in a developing country, especially Kazakhstan's 30-year period between 1991 and 2020. Finding the right study approach and data has always been one of the most difficult aspects of researching innovation trends (Courtney and Powell, 2020). As a result, precisely assessing innovation trends is difficult. Patents were employed as a proxy for the trajectory of water-related advances in time in this study. Patents were chosen as a technique because they are easily available in field and water technology at a disaggregated level. The technique makes it easier to categorize water-related accomplishments into several groups based on their technologies. This likewise aids in understanding creative activity in a range of water-related areas.

To be more specific, we used the national patent database (National Patent – Kazpatent) to gather the data and analyze water-related innovative activities. Unlike many other databases, where retrieving data necessitates a high level of knowledge, the National Patent – Kazpatent database is straightforward. Patent data can be correlated with other organized data in the database, and different codes and years can sort data. Only files from the Republic of Kazakhstan's National Institute of Intellectual Property were utilized in this situation. Using the National Patent – Kazpatent database, linking each patent to the assignee code, name, location, abstract, and application and registration dates was simple. The retrieved patents estimate innovative water activity as previously indicated. The investigation began with a sample of water-related International Patent Classifications (IPC) from 1991 to 2020, yielding a dataset of over 56,000 patents (Fig. 1). The patents were categorized into distinct water technology areas and applications using conventional IPC codes in addition to the overall study. To December 31, 2020, Fig. 1 summarizes Kazakhstan's trademarks, inventions, utility models, industrial designs, selection achievements, and appellations of origin (including rights of use).

2.3. Analysis of water-related issues

The nature of data distribution within the data series was investigated using box and whisker plots. They can consolidate data from various sources and display the conclusions in a single graph; box and whisker plots are particularly effective and easy to understand. The graphs mostly depicted data based on medians and quartiles (Larsen, 1985).

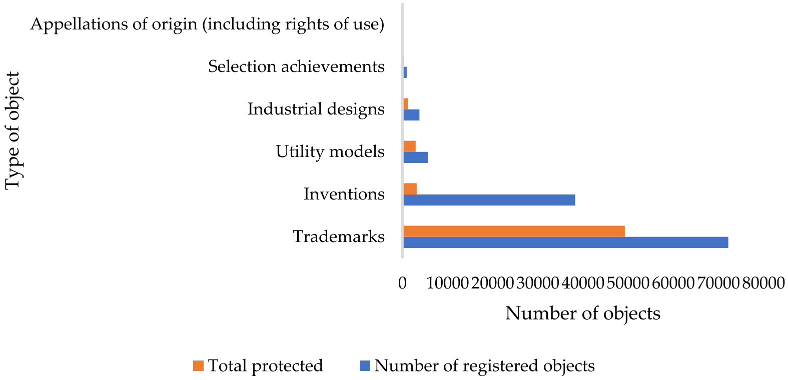

Fig. 1. The total number of registered items for the patent office's entire history as of December 31, 2020.

2.4. Analysis of the potential disruptions caused by the pandemic

This part of the study investigated different aspects of COVID 19's potential disruption based on a questionnaire survey with 54 firms. The respondents' firms were divided into three categories: small-scale (1–20 employees), medium-scale (21–1000 employees), and large-scale (above 1000 employees). The sample size was calculated using the formula for single population proportion, and the study's minimum required sample size was derived as a result (Nyampundu et al., 2020).

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

where

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

Moreover:

- $Z_{\alpha/2}$ represents the critical value of the Normal distribution at $\alpha/2$, for instance, 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.

3. Results

3.1. Characterization of water-related issues

The retrieved wastewater generation, wastewater discharged into water bodies before treatment datasets, prices, and tariffs for paid services were analyzed to characterize water-related issues in the water sector, calling for innovative ideas.

Table 1
Total volume of wastewater, million cubic meters.

Year	Total volume of wastewater (million cubic meters)	Percentage (%)
2015	5935	20.87
2016	5205	18.31
2017	5502	19.35
2018	5408	19.02
2019	6383	22.45
Total	28433	100

3.1.1. Wastewater generation

Table 1 illustrates that the total volume of contaminated wastewater generated in Kazakhstan has generally increased from 2015 to 2019. As a result of the phenomenon, the amount of wastewater generated in the country is expected to rise due to population growth. According to Varjani et al. (2021), increased population and industrialization result in a high quantity of organic contaminants, posing a threat to the planet. As the amount of available freshwater decreases, humanity is driven to reuse and recycle wastewater. Treatment of industrial wastewater in an environmentally friendly and economically viable manner has received global attention (Mkilima et al., 2021; Skrzypiecbcef and Gajewskaad, 2017). It is also worth noting that the amount of wastewater generated and its overall pollution load is increasing globally due to population increase, faster urbanization, and economic development (Meiramkulova et al., 2021).

3.1.2. Wastewater discharged into water bodies before treatment

Table 2 illustrates that the volume of wastewater discharged into water bodies appears to be highly fluctuating. However, not much improvement has taken place from 2015 to 2019. More developments in terms of wastewater management innovations are required to achieve a nearly 100% closed loop of clean-to-wastewater-to-clean water. When huge amounts of wastewater are discharged, the temperature of the receiving water body might rise, disrupting the natural balance of aquatic life (Jawecki et al., 2017; Mkilima, 2022).

Water use is another good indicator of the growing need for more innovations in the water sector. From Table 3, it can be observed that approximately 51163 million cubic meters of water were used in Russia, followed by 20955 million cubic meters in Kazakhstan. However, the consumption is highly linked to the amount of wastewater discharged to water bodies.

3.1.3. Prices and tariffs for paid services

The price of water-related services is another significant indicator of the need for more innovative strategies in the water business to make critical services more accessible at a reduced cost. As indicated in Fig. 2, prices for hot water, cold water, and sewage services have been steadily rising.

Due to population growth, changing climatic conditions, resolving issues with existing structures, ensuring high-quality water delivery, and minimizing energy use, water supply and wastewater disposal utilities confront several challenges in meeting future demands. As a result, the utility's willingness to invest in and work on innovative solutions to address these challenges is solely determined by the utility, based on a variety of factors, including governance and cultural concerns, the regulatory environment, performing the specific structure, and the availability of funds to address the issues. If these issues are not addressed, there is a major risk that they may exacerbate existing issues such as pollution, environmental degradation, public health hazards, and deterioration of service delivery, resulting in significantly higher charges for the same service (Colby and Isaaks, 2018).

However, service pricing in the water sector might constitute a serious threat to innovation. According to the literature, some studies have found a significant linear association between service pricing and water industry innovation activity (Adams et al., 2020; Hardelin and Lankoski, 2015; Krozer et al., 2010). In addition, inadequate pricing can generate a vicious cycle in which water authorities cannot address the concerns mentioned above, resulting in further revenue losses.

3.2. Innovations patenting

3.2.1. Innovation trend from 1991 to 2020

Producing more with less has never been more important than now, with the world's population predicted to exceed 9.7 billion people by 2050. Although the world has recently encountered various water-related challenges, Fig. 3 demonstrates that the trend of innovative activity in the water industry has been decreasing. There was an exciting spike in patented innovations from 1991 to 1993, followed by a significant drop from 1993 to 1994. Since 2012, the number has been progressively decreasing, underlining the need for immediate action.

While the water supply and sanitation sector continues to face rising challenges, particularly due to changing climatic conditions and population expansion, governments in developing nations must strengthen the water sector's resilience and sustainability. Innovation and technology play a critical role in addressing the difficulties.

Table 2
The total amount of wastewater discharged into water bodies that have not been treated, million cubic meters.

Year	Wastewater discharged into water bodies that has not been treated (million cubic meters)	Percentage (%)
2015	197	26.41
2016	149	19.97
2017	122	16.35
2018	152	20.38
2019	126	16.89
Total	746	100.00

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

Country	Water use		Discharge of polluted sewage into surface water bodies	
	(Million cubic meters)	Percentage (%)	(Million cubic meters)	Percentage (%)
Kazakhstan	20955.00	23.09	5383.00	29.19
Azerbaijan	9472.00	10.44	218.00	1.18
Armenia	1927.00	2.12	222.00	1.20
Belarus	1234.00	1.36	4.00	0.02
Kyrgyzstan	5211.10	5.74	1.90	0.01
Moldova	777.00	0.86	7.80	0.04
Russia	51163.00	56.38	12602.00	68.35
Total	90739.10	100.00	18438.70	100.00

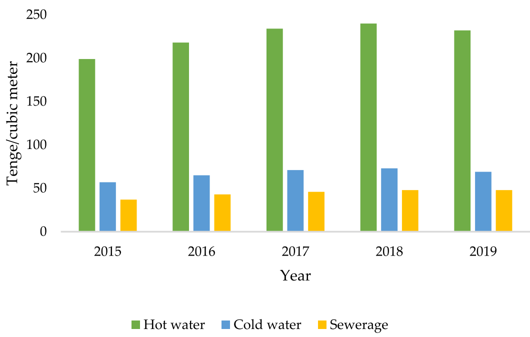

Fig. 2. Average prices and tariffs for paid services for the population, tenge/cubic meter.

3.2.2. Percentage of registered and protected objects

From Fig. 4, it can be observed that trademarks constituted the highest percentage of the total registered and protected objects within the past 30 years. In terms of registered objects, 59.7% were trademarks, while inventions covered 31.7%. Trademarks cover approximately 86.4% of the total objects in terms of protected objects. For a case of open innovation; it is also worth highlighting that many recent studies have found that the patent system can encourage open innovation by encouraging inter-firm partnerships and technology markets (Al Kassiri and Čorejová, 2015; Fica, 2018; Lawson, 2013; Schoellman and Smirnyagin, 2021). Indeed, expanding a company's borders can be dangerous, and patents can often assist in alleviating some risks and challenges of open innovation. Patents may operate as barriers, allowing actors in the invention process to communicate more freely (Pénin and Neicu, 2018).

3.2.3. Water-related innovations based on IPC

The water field categories employed in this research are based on the IPC codes, which typically cover practically all water-related technologies. In this scenario, water and wastewater treatment advancements (Fig. 5), fertilizer extraction from wastewater technologies (Fig. 6), and water collecting and storage technologies (Fig. 7) were examined.

The most important goal of this classification is to check whether more precise innovation patterns in the water sector can be captured. The purpose is to document the overall growth of water innovation trends and the potential rise of technological trajectories for specific water technologies. This aids in determining which water-related field, based on patented technology, is under the greatest stress.

Fig. 5 shows that, among many other categories, only the treatment of water, wastewater, sewage, or sludge is more active in innovation than the others. This tendency also indicates that further innovation is required in the field. Other countries have emphasized focusing on creative activities as a primary driver of economic and social growth in the literature.

It is also worth noting that water-related systems (water supply and wastewater disposal) have traditionally been exceedingly complex-designed systems with long design lives, which has always been a roadblock to water-related innovation. The water sector has been forced toward incremental improvements rather than investing in more inventive concepts and revolutionary technology. The facilities are built to last for decades, if not longer. An excellent example is a technique of supplying recycled water that necessitates regularly building new piping systems, which could be prohibitively expensive. When specific water system elements need to be replaced, the rest is usually operational, making it more likely for authorities to replace the worn piece rather than the complete water system.

From Fig. 6, it can be observed that IPC E02B15/04–10 (devices for separating or removing oil or other floating materials from the surface of open water to clean or maintain it clear) has received no innovation within the past 30 years. Dispersants,

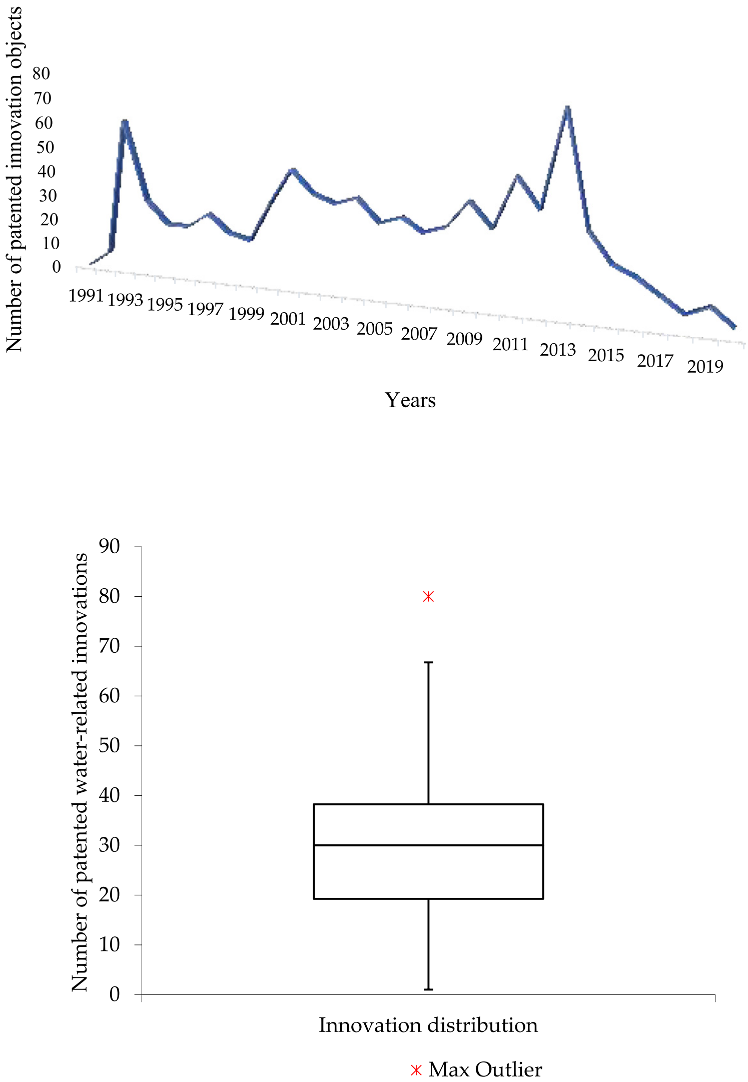

Fig. 3. The trend of innovations from 1991 to 2020.

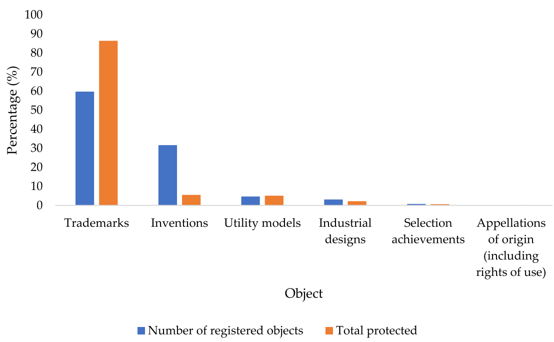

Fig. 4. Percentage of registered and protected objects.

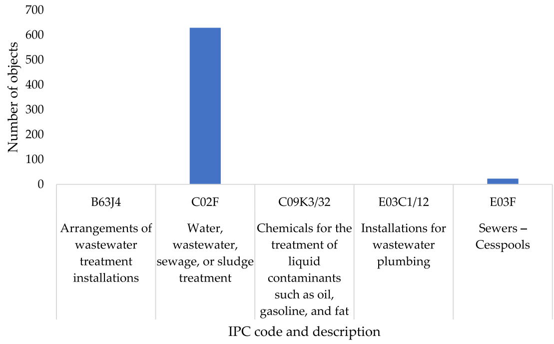

Fig. 5. Water and wastewater treatment innovations over 30 years.

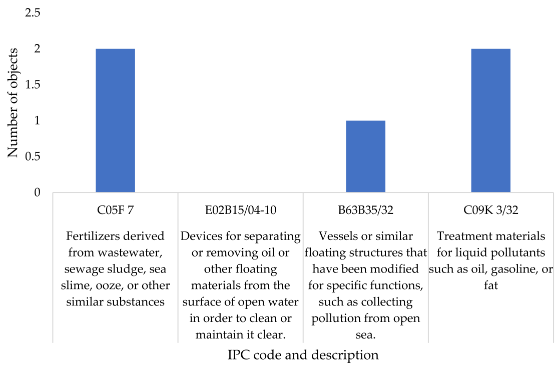

Fig. 6. Fertilizers from wastewater innovations over 30 years.

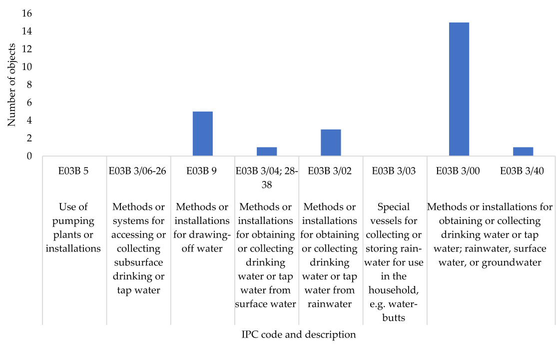

Fig. 7. Water collection and water storage innovations over 30 years.

booms, and skimmers are the most typical ways of cleaning up ocean oil spills. Every method has advantages and disadvantages. The effectiveness is influenced by the amount and type of oil used, ocean currents and tides, and the weather. Skimmers or oil scoops can be put onto boats once the oil has been confined using oil booms to collect contaminants from the water's surface. Skimmers are vacuum cleaner-like equipment that collects oil from the water's surface. They are used to physically separate oil from water to collect and recycle. It should also be noted that the IPC, created by the Strasbourg Agreement of 1971, is a hierarchical system of language-independent symbols for classifying patents and utility models according to the many fields of technology to which they apply (Sasaki and Sakata, 2021).

From Fig. 7, it can be observed that the IPC E03B-5 (use of pumping plants or installations) had no patented innovations within the past 30 years; a pumping station is an electromechanical device that lifts and distributes sewage or wastewater when gravity cannot naturally convey it away from a location. E03B 3/06–26 (methods or systems for accessing or collecting subsurface drinking or tap water) had no patented innovations over the past 30 years. Even though the Millennium Development Goals (MDGs) for drinking water have been reported as being met, water scarcity remains a global issue. Using a better water source is the MDG indicator for quantifying access to water. However, in nations with no on-site drinking water supplies, the time spent fetching water is significant. In 2015, 26.3 percent of the global population did not have access to such services. As a result, it is typical to travel to a water source, queue, fill water containers, and transport them home. Water collection can take a long time and effort. Data on collection time is increasingly being collected through household surveys, and E03B 3/03 (special vessels for collecting or storing rainwater for the household) had no patented innovations over the past 30 years. Rainwater harvesting allows for collecting large amounts of water and reduces drought impacts. Most rooftops provide the essential collection platform. Rainwater is suitable for irrigation since it is normally free of harmful contaminants.

3.3. Correlation between number of firms, water-related innovations, and general patenting

In this part of the study, the potential influence of the number of water-related firms on the trend of the patented innovations yearly was investigated using correlation analysis. Table 4 presents the correlation matrix number of firms, water-related innovations, and the total number of patents. In correlation analysis, the correlation coefficient is a specific statistic that assesses the strength of the linear link between two variables. It can be observed that the correlation coefficients range from 0.66 to 0.99, indicating a high correlation among the investigated parameters.

3.4. Innovation analysis based on questionnaire survey

3.4.1. Firms distribution

We formulated a semi-structured questionnaire to investigate the potential influence of the COVID-19 situation in disrupting innovation activities in the country after observing the dramatic fall in terms of patented water innovations, especially in 2020 with only four patented water innovations. A summary of the firms' distribution in the survey is provided in Fig. 8. The COVID-19 pandemic has substantially impacted the global economy, causing unprecedented disruption to

Table 4
Relationship among different water innovation factors.

Small-scale firms			
	Number of firms	Water-related innovations	Total general patenting
Number of firms	1		
Water-related innovations	0.816497	1	
Total general patents	0.992052	0.741362	1
Medium-scale firms			
	Number of firms	Water-related innovations	Total general patenting
Number of firms	1		
Water-related innovations	0.927173	1	
Total general patents	0.661457	0.857537	1
Large-scale firms			
	Number of firms	Water-related innovations	Total general patenting
Number of firms	1		
Water-related innovations	0.95626	1	
Total general patens	0.961685	0.857537	1

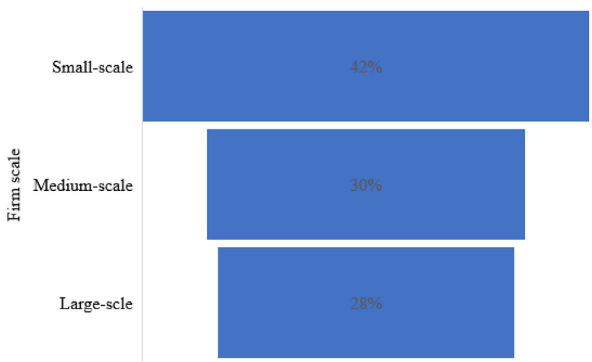

Fig. 8. Distribution of firms in the survey.

individuals, families, businesses, governmental and non-governmental, and commercial and non-profit organizations. Governments worldwide have been under pressure to respond to the crisis while balancing their residents' health and economic objectives. Even firms that previously had the strong capability to tolerate substantial interruptions to invest and generate outstanding innovative solutions have been severely harmed by the catastrophic circumstance (Christa and Kristinae, 2021). Understanding the trajectory of water innovation activities is even more crucial because of this phenomenon.

3.4.2. Potential COVID-19's disruption of motivation for innovation

One of the survey's key objectives was to determine how the COVID-19 disruption's social and economic implications changed water firms' focus on water innovation efforts. Table 5 illustrates that the COVID-19 has impacted large-scale water companies more than small-scale water companies by disrupting innovation in water-related technology. Approximately 56% of large-scale firm respondents said the COVID-19 issue has significantly impacted their businesses, indicating a significant reduction in motivation for innovation. However, the COVID-19 issue had less impact on small-scale water-related enterprises, with just about 30% of respondents reporting an increase in innovation motivation due to the pandemic.

3.4.3. Potential COVID-19's impact on investment level

Another important goal of the survey was to see if there was a link between current innovation trends and the COVID-19 situation, based on how the social and economic effects of COVID-19 challenges have influenced the amount of funding available for pursuing innovation within a water-related company. Table 6 shows that, similar to how the COVID-19 situation has impacted water firms' general motivation to work more on innovative activities, the level of investment in water innovations as determined by funding has also been observed to have a greater impact on large-scale firms than on small-scale firms.

3.4.4. Potential lockdown effect on market dynamics based on analysis of variance (ANOVA)

Out of 54 respondents, 48 (16 for each scale) from various firms were asked to score between 1 and 5 on how the lockdown period has negatively impacted market dynamics and general ways of working inside the water-related firm. This was an important aspect because the COVID-19 pandemic has thrown practically every element of life into disarray, from personal (how people live and work) to professional (how people are treated) (how companies interact with their customers, how customers choose and purchase products and services, how supply chains deliver them). The null hypothesis in ANOVA is that there is no difference between group means; whereby, based on the *p*-value (1.26E-16) in Table 7, it can be concluded that the ANOVA presented a statistically significant result. From Table 7, it can be observed that the lockdown period had more effect on large-scale firms than the small-scale firms.

3.4.5. General analysis of contextual factors influencing water innovation

The respondents were asked to rate how much specific contextual elements influenced their innovation processes in this study. The respondents' responses reveal whether these elements have a good or negative impact (Fig. 9). The availability of local expertise, the mentality of local organizations toward innovation, and the country's business environment are all seen to have a favorable impact on water innovation processes on each of the firm' scales. Fig. 9 reveals further that the impact of the contextual factors was more significant to large-scale firms than small-scale firms. Similar phenomena were also observed in other studies in the field (Choi and Lim, 2017; Mvulirwenande and Wehn, 2020).

Table 5
Motivation for innovation.

Response	Large-scale (%)	Medium-scale (%)	Small-scale (%)
Highly reduced motivation	56	61	16
Somehow reduced motivation	21	8	13
Nothing changed	5	2	9
Somehow increased motivation	12	18	32
Highly increased motivation	6	11	30
Total	100	100	100

Table 6
Impact on investment level as influenced by funding.

Response	Large-scale (%)	Medium-scale (%)	Small-scale (%)
Highly reduced	72	49	9
Somehow reduced	18	12	4
Nothing changed	2	6	5
Somehow increased	4	14	38
Highly increased	4	19	44
Total	100	100	100

Table 7
ANOVA results from the potential lockdown effect questionnaire rating.

ANOVA: Single Factor						
SUMMARY						
Groups	Count	Sum	Average	Variance		
Small-scale	16	76	4.75	0.2		
Medium-scale	16	65	4.0625	0.0625		
Large-scale	16	38	2.375	0.516667		
			ANOVA			
Source of Variation	*SS*	*df*	*MS*	*F*	*p-value*	*F crit*
Between Groups	47.79167	2	23.89583	92.00535	1.26E-16	3.204317
Within Groups	11.6875	45	0.259722			
Total	**59.47917**	**47**				

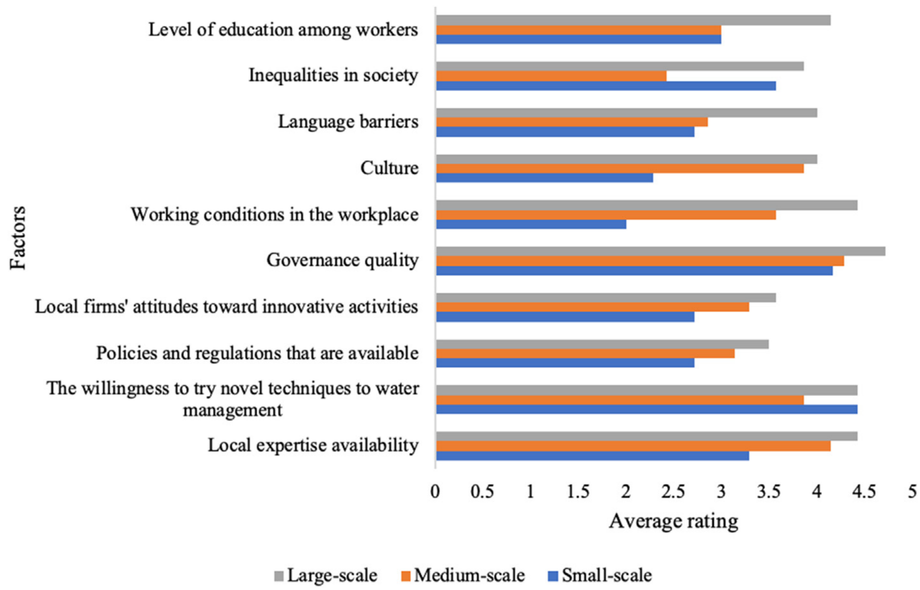

Fig. 9. Contextual factors influencing water innovation (number of samples = 54): Likert scale ranged from 1 to 5, 1 represents a very bad influence, 2 represents a bad influence, 3 represents neutrality, 4 represents good influence, and 5 represents a very good influence.

4. Discussion

This study further revealed that the overall volume of contaminated wastewater generated in Kazakhstan steadily grew, requiring more innovative solutions for proper wastewater management. For instance, from 2015 to 2019, the wastewater generated in Kazakhstan ranged from 18.31% to 22.45% of the total generated wastewater. When you combine such an increase in wastewater generation with ineffective recovery technologies, pollution, and pollutants, freshwater resources are likely to face increased shortage (Boretti and Rosa, 2019), environmental deterioration, and possibly irreversible damage (Schwarzenbach et al., 2010). The long-term solution does not lie in substantially reducing water consumption but in innovative wastewater management and treatment technology and practices (Andersson et al., 2018; Aydiner et al., 2016; Meiramkulova et al., 2020).

The volume of wastewater discharged into water bodies appears to be variable over time, whereby little progress has been made between 2015 and 2019. As previously highlighted, to create a nearly 100% closed loop of clean-to-wastewater-to-clean water, more improvements in wastewater management techniques are necessary (Xu et al., 2018). The significance of devising more innovative technologies to reduce wastewater discharged into the water bodies is linked to the fact that the quality deterioration of the water bodies can lead to many other environmental problems. For instance, when large amounts of wastewater are discharged, the temperature of the receiving water body may rise, thus disturbing aquatic life's natural equilibrium (Asibor et al., 2020). There has been a growing understanding that fresh water is a precious resource because of overexploitation and contamination (Dingemans et al., 2020). According to the literature, wastewater discharge contains several toxic elements or chemicals that can have negative environmental consequences such as changes in aquatic ecosystems, species composition, and biodiversity loss (Tong et al., 2020). These consequences result in a less valuable environment, a less affluent economy, and, as a result, a lower quality of life. Sewage contains several compounds that can affect plant and animal ecosystems (Bhat and Qayoom, 2022).

Based on the correlation coefficients resulting from the correlation analysis among the number of firms from 1991 to 2020, water-related innovations, and total general patents, very high correlations ranging from 0.66 to 0.99 were observed. The highest correlation was observed between the number of firms and the total general patents. The findings reflect reality: the greater the number of enterprises registered, the greater the likelihood of more patented innovations in the water sector. The literature has discovered that as the number of enterprises grows, cost reduction expenditure per firm decreases, while raising the degree of product substitutability (Vives, 2008). In that matter, encouraging the development of new firms in the water sector can significantly impact the level of innovation activities in the sector that would help reduce the growing water-related challenges.

After observing the dramatic fall in terms of patented water innovations, especially in 2020 with only four patented water innovations, a semi-structured questionnaire was developed to investigate the potential impact of the COVID-19 situation in disrupting innovation activities in the country. It is also worth highlighting that countries worldwide fought the COVID-19 pandemic for much of 2020. Many countries went into lockdown to combat the virus's rapid spread (Inegbedion, 2021; Jribi et al., 2020; Ramalho et al., 2022). The lockdown's unprecedented constraints and seclusion posed new obstacles in people's daily lives. It is also important to note that creativity can help people cope with harsh and difficult conditions since it is based on flexibility, adaptability, and problem-solving. The COVID-19 pandemic is already impacting the water system on many fronts, owing to societal behavioral changes that have prompted state efforts to combat the epidemic. The partial economic halt, as well as the resulting changes in water demand and citizen behavior, have immediate consequences (Poch et al., 2020). The analysis results showed that the catastrophic condition has badly impacted even organizations that previously had a great ability to bear significant interruptions to invest and create outstanding new solutions. For instance, while the COVID-19 situation was observed to have less influence on small-scale water-related businesses, with just around 30% of respondents reporting an increase in innovation focus because of the epidemic, the responses showed that during the pandemic period, the large-scale firms were significantly affected. In the literature, a similar phenomenon was observed in the study conducted by Harel (2021), whereby the findings revealed small enterprises would fare better amid economic downturns and uncertainties.

A *p*-value of 1.26E-16 was retrieved from the analysis of variance with an indication that the data differed among the investigated groups (based on firms' scales). It was interesting to learn that the lockdown era had a greater impact on large-scale enterprises than on small-scale firms, based on the scores. Long-term initiatives integrated into and supported by the larger entrepreneurial ecosystem should enable speedy recovery and growth in such a situation (Kuckertz et al., 2020).

Furthermore, the availability of local expertise, the mentality of local organizations toward innovation, and the country's business environment were all seen to have a favorable impact on water innovation processes in each of the firms' scales, according to the contextual factors influencing innovation in the water sector. A similar phenomenon was also observed when different aspects of water innovation were explored in African cities from Kenya, Ghana, and Mozambique in the study conducted by Mvulirwenande and Wehn (2020). When comparing large-scale and small-scale enterprises, the results showed that the impact of contextual factors was greater for large-scale firms. As a result of this occurrence, it is even more important to understand the trajectory of water innovation initiatives (Wehn and Montalvo, 2015). Another purpose of the study was to examine if there was a link between current innovation trends and the COVID-19 scenario, depending on how the social and economic implications of COVID-19 difficulties have altered the amount of financing available for pursuing innovation inside a water-related business. Similar to how the COVID-19 situation has influenced water firms' overall motivation to work more on innovative activities, the level of investment in water innovations as determined by funding has been observed to have a greater impact on large-scale firms than on small-scale firms. Another important point to be highlighted here is that, from technology start-ups to global multinationals, from companies creating individual components to those supplying or building whole solutions, from deep industry specialists to wide generalists, the water supply chain is extremely diverse (Luo and Bai, 2021). We see two major concerns for these businesses: first, keeping their employees safe while safeguarding their manufacturing and supply lines, and second, coping with a potentially big fall in demand.

Water and wastewater systems that are smarter, cheaper, more robust, and ecologically conscious are becoming increasingly popular worldwide. Population increases, urbanization, and conflicting demand from municipal, agricultural, and industrial applications are all regarded to be among the key drivers (Munir et al., 2018).

Also, it is worth highlighting a growing consensus, namely that we should not look for solutions in the past but be more imaginative in achieving the outputs that our infrastructure systems require. New ways of thinking, new processes, and inventive technology are needed (Garner et al., 2021). We should assess the framework in which we operate, including our receptivity to new ideas, our appetite for risk, our processes, and the originality of our sector's people resources. If people are unwilling to change, even the best technology may not be applied. On the other hand, change is not simple; much has been written about the innovation "valley of death," where great ideas fail. This is most often associated with technology, but it can also apply to the deployment of new procedures and processes (Ellwood et al., 2022).

5. Conclusions

For the case of Kazakhstan, three different aspects of water sector innovation have been investigated. The first aspect investigated potential water-related issues that would necessitate more innovation in the field; the second looked into the trend of innovation activities over 30 years using patents. The third investigated the disruptions caused by COVID-19 for water-related innovation using a questionnaire survey. According to the investigation, the entire volume of contaminated wastewater generated in Kazakhstan has steadily increased over time. There was a high correlation between the number of water businesses, patented water-related ideas, and overall general patents. There was a substantial correlation between the number of water firms, patented water-related discoveries, and total general patents, with correlation values ranging from 0.66 to 0.99. While the COVID-19 situation was less impactful on small-scale water-related businesses, with just around 30% of respondents reporting an increase in innovation focus because of the epidemic, only 6% of large-scale firms showed an increase in innovation focus. The availability of local expertise, the culture of local organizations toward innovation, and the country's business environment are all considered to have a substantial impact on water innovation processes in each of the firm scales explored in this study.

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Declaration of competing interest

The authors declare no conflict of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, or in the decision to publish the results.

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