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Changes in water demand patterns in a European city due to restrictions caused by the COVID-19 pandemic

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ABSTRACT

A COVID-19 pandemic in early 2020 has significant impact on socio-economic systems worldwide, which are strongly connected with the use of natural resources. Restrictions introduced in many countries changed the daily habits of society and set hygiene standards to support public health. This study aimed to define how water demand patterns have changed during the lockdown, covering both the amount of consumed water resources as well as its location within the city. The study uses a visual analytics approach for detecting changes in water use patterns in the period from January 2018 to April 2020 for the case of a regional European city (Wrocław, Poland). The results of the study showed that the total water consumption in April 2020 did not change significantly, therefore, it did not impact available water resources in the water supply system. However, the amount of used water in different water intake points changed comparing to the previous month mostly in housing buildings (+13.2%), commercial objects (–17.2%), and education facilities (–38.1%). The relatively similar structure of groups of users within the city is a favorable factor, as it results in stable water consumption in each urban district, which is beneficial from the point of view of the urban water supply system. The results of the research might be useful for emergency preparedness in urban water and wastewater utilities in case of unexpected events.

Keywords: SARS-CoV-2; Coronavirus; COVID-19; Pandemic; Urban water management; Water consumption

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1. Introduction

Despite scientific reports regarding the potential threats associated with the new coronavirus [1], global socio-economic systems were not prepared for the COVID-19 pandemic, which became a global threat in early 2020 [2]. Such a situation is a result of complicated risk management where hazard, vulnerability, and exposure have to be taken into account [3]. Without such an approach, socio-economic systems could be paralyzed due to constant preparations for many possible threats. Another obstacle to forecast the potential future influence of some elements is still too few interdisciplinary studies searching for linkages between different components between humans and the environment. However, the rapid worldwide spread of SARS-CoV-2, a virus that causes COVID-19 disease [4], showed how pandemic situations can influence our systems. There is a significant impact not only on physical public health [5,6] but among others also on mental health [7–12], economy [13–15], and environment. As usual, the game-changing shift has both positive and negative effects, while still, one group of factors outweighs the others. In relation to the environment, COVID-19 has led to the generation of massive amounts of medical wastes, but at the same time reduction in economic activities improved air and water quality across the globe [16,17]. Based on the remote sensing data, pollution in some of the epicenters of COVID-19 such as Wuhan, Italy, Spain, and USA, etc. has been reduced up to 30% [18]. In some cases concentration of some pollutants (PM_{10}, NO_2, and SO_2) was reduced even by more than half [19]. Lockdown led also to cleaner beaches and environmental noise reduction [20]. Similar to other components of the environment, the COVID-19 pandemic influences water resources.

In terms of water resources, there is a significant difference between water stored in waterbodies and urban water used by citizens. On the one hand, lockdown due to the COVID-19 spread improved adjacent lake water quality in India [21] and impact on water transparency in the Venice Lagoon in Italy [22]. On the other hand, combating COVID-19 resulted in reports proving the presence of SARS-CoV-2 in wastewater [23]. Therefore, there are recent review studies that conclude the state of knowledge on SARS-CoV-2 detection in wastewater and needs for future research on wastewater surveillance [24,25]. Despite recent studies on relations between COVID-19 and water quality, the aspect of water quantity seems to be omitted. However, considering new habits and routines of citizens influenced by some restrictions or even a lockdown caused by the COVID-19 pandemic, it is crucial to investigate how this situation influenced water consumption. More stringent sanitary requirements could possibly increase water demand. The other point is the different distribution of water consumption due to working from home or new procedures applied in medical facilities.

Therefore, the aim of this research was to define water demand patterns within the city due to the restrictions caused by the COVID-19 pandemic. The study enables us to define the amount of consumed water as well as its distribution comparing types of water recipients and their location in the urban structure. The study area presented in this research is Wrocław, the 4th biggest city in Poland (around 650,000 citizens), located in Central Europe [26]. This manuscript has a documentary character of the extremely unusual phenomenon as global lockdown and corresponds to the direction of quantitative studies describing the impact of significant modifications in socio-environmental systems, like publications quantifying the impact on air [27,28] or water quality [29,30] in other parts of the world. The paper is structured as follows: section 2 (Materials and methods) describes data and methods that were applied in the research; section 3 (Results) contains the results of the research presenting statistical as well as the spatial distribution of water demand; the discussion and conclusions of the obtained results are presented in section 4 (Discussion).

2. Materials and methods

For the purpose of analyzing changes in water demand patterns data on water consumption was obtained from the Municipal Water and Sewage Company S.A. in Wroclaw (MPWiK). Available data present water consumption per month in the period from January 2018 to April 2020. The used data are not included in publicly available registers, therefore, it was obtained from MPWiK datasets and aggregated at the level protecting corporate non-disclosure. The amount of used water within the city was divided by 10 groups of users (different categories of water intake points: churches, commercial, education, health care, housing, industry, military, penitentiary, public institutions, sport, and leisure) as well as 23 District Metered Area (DMA) zones[1]. DMA zones do not cover the whole city equally, however, are basic units used in management by local water supply company. The structure of water consumers divided by their type in each DMA zone as well as distances of geometrical centroids of DMA zones from the city center are presented in Table 1. Moreover, within the study legal regulations influencing pandemic restrictions were analyzed to characterize periods when major limitations to the regular socio-economic activity were applied.

The obtained data were analyzed in the visual analytics approach which enables to discover patterns in datasets [31]. Visual analytics as a field of science of analytical reasoning facilitated by interactive visual interfaces evolved directly from information visualization and automatic data analysis [32,33]. This method combines data visualization, human factors, and data analysis. Visualization is a data presentation on an interactive interface. Human factors (interaction, cognition, perception, collaboration, presentation, and dissemination) play a crucial role in communication and decision-making. Data analysis includes statistical analytics, data exploration, and management, knowledge representation. The visual analytics methodology includes data visualization and exploration as well

1. Four DMA zones are divided into sub-zones (zone 15 divided into 5 sub-zones; zone 19 divided into 5 sub-zones; zone 23 divided into 4 sub-zones; zone 27 divided into 4 sub-zones). However, due to the relatively small area of sub-zones, in this research values are aggregated at the level of 23 DMA zones.

Table 1
Structure of water consumers in DMA zones in Wrocław (April 2020)

DMA	Share of the user group in each DMA (%)										Distance of DMA's centroid from the city center (km)
	Churches	Commercial	Education	Health care	Housing	Industry	Military	Penitentiary	Public institutions	Sport and leisure	
0	0.75	10.84	2.49	0.60	80.69	1.15	0.16	0.03	3.06	0.22	1.5
8	0.49	3.37	1.38	0.16	93.10	0.09	–	–	1.27	0.13	4.7
10	0.20	3.08	0.25	0.20	95.15	0.81	–	–	0.25	0.05	6.6
13	0.21	6.53	0.43	0.17	91.25	0.55	–	–	0.85	–	4.8
14	0.13	4.94	0.30	0.03	93.74	0.46	–	–	0.33	0.07	6.5
15	0.22	6.37	0.17	0.10	92.08	0.49	0.02	–	0.54	–	8.2
16	0.06	2.12	0.21	0.24	96.41	0.62	–	–	0.27	0.09	10.4
17	–	1.37	–	–	96.59	2.05	–	–	–	–	12.2
18	0.11	2.97	0.27	0.02	95.01	1.11	–	–	0.36	0.14	9.4
19	0.57	8.86	1.20	0.32	87.92	0.25	–	–	0.89	–	4.7
20	0.23	3.41	0.45	0.23	93.18	0.91	0.23	–	1.36	–	4.7
21	–	1.23	–	–	98.77	–	–	–	–	–	7.9
22	0.52	3.14	–	–	94.76	0.52	–	–	1.05	–	10.8
23	0.25	5.91	0.42	0.25	91.47	0.67	0.25	–	0.74	0.04	4.7
24	0.21	13.29	0.62	0.14	82.16	2.27	0.07	–	1.24	–	5
26	0.07	2.62	0.07	0.13	95.37	1.48	–	–	0.20	0.07	8.4
27	0.29	5.19	0.64	0.16	92.37	0.67	–	–	0.51	0.16	7.7
28	0.29	5.77	0.29	0.29	90.71	1.56	0.35	–	0.75	–	13.6
29	0.10	5.22	0.20	0.40	92.97	0.20	–	–	0.60	0.30	6
32	0.13	4.81	0.18	0.04	93.82	0.64	0.04	–	0.27	0.07	5.8
33	0.15	5.18	0.62	0.31	92.12	0.85	–	0.08	0.70	–	3.9
38	–	66.67	–	–	33.33	–	–	–	–	–	13.9
41	–	–	–	–	100.00	–	–	–	–	–	15.2

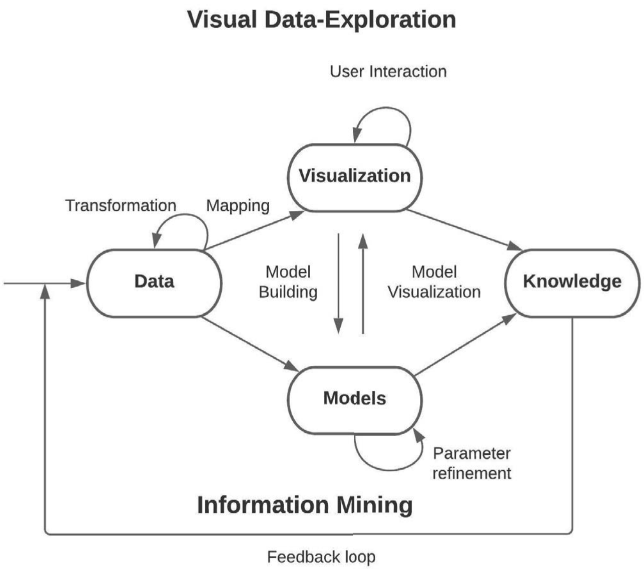

Fig. 1. Visual analytics process (based on the study of Keim et al. [33]).

as human interaction in order to discover knowledge from data (Fig. 1).

The main advantage of visual analytics is that researchers or decision-makers operate within a loop where data can be interactively manipulated and explored. The iterative process provides to gain knowledge. Visual analytics helps to transform abstract data into graphical representation (marked as length, position, shape, color, and orientation), which is more attractive for visually oriented humans [34]. This method is especially useful for big dataset exploration as well as finding trends and patterns in collected data [35]. Visual analytics can be performed with the use of Business Intelligence systems, which combine data gathering, data storage, and knowledge management with analytical tools [36]. Therefore, this study was carried out with the use of business intelligence software, namely Tableau 2020.2, which is a suitable tool for visual analytics of statistical and spatial data [37,38], aiming to conduct data discovery and communication process supported by dynamic and interactive visualizations [39]. The assessment covered both relative and absolute data on water use. The approach of using geo-spatial visualizations in water management studies is commonly used by the scientific community of environmental engineers [40,41]. Restrictions due to the COVID-19 pandemic were analyzed by the use of the Gantt chart [42].

3. Results

3.1. Polish restrictions due to COVID-19 pandemic

On March 2nd, 2020, the Polish government adopted the Act on special solutions related to preventing, counteraction, and eradication of COVID-19, other infectious diseases, and crises caused by them [43]. The law introduced several solutions aimed at preventing the spread of the SARS-CoV-2. Among the most important were the legal solutions related to the possibility of delegating employees to perform their professional duties outside the place of permanent work (remote work), rules for the payment of parental benefits for the time of care and educational institutions' closure, Public Procurement Law exemptions for the procurement of goods and services necessary to counteract COVID-19 and other specific public management solutions at risk. All restrictions are presented below in a graphical way (Fig. 2).

An epidemic emergency was declared on March 14th, 2020, while an epidemic state was introduced on March 20th, 2020. It was a key moment to introduce some restrictions to prevent the spread of the virus. The restrictions have been successively introduced and abolished.

Firstly, on March 10th, mass events were canceled. On March 12th, education at all levels and childcare centers and kindergartens were suspended, as well as the functioning of cultural institutions, restaurants, and bars (take-away option only), shopping malls (excluding grocery stores, hygiene products, and pharmacies), clubs, and discos. Gyms, fitness clubs, entertainment parks, and playrooms were closed on March 13th.

On March 15th, a prohibition on gatherings of over 50 people was introduced (it was tightened in the following days), border controls were established and locked up for foreigners. International air travels were suspended, as well as internal flights the following day. On March 15th, there was also an obligation to undergo quarantine after returning to Poland from other countries, and from April 1st, people living together with a person under quarantine also had to be quarantined. Moreover, on March 15th sports training prohibitions were introduced, both in the Olympic Preparation Centers and individual training in professional sports, all sports facilities were closed, and from March 31st sports competitions were suspended.

On March 25th, a restriction on moving outside the place of residence without a valid reason was introduced, and from April 1st to April 19th, the use of parks, forests, beaches, boulevards, promenades, and city bikes was prohibited. The obligation to cover mouth and nose (e.g., with a scarf, bandana, or by wearing masks) was introduced on April 16th, which was alleviated from May 30th to the obligation to wear masks if it is not possible to keep the distance of 2 m and in closed spaces (shops, post offices, etc.).

In the period from March 25th to April 11th, the restriction was introduced concerning the religious cult. During this period (Easter period and holidays) the biggest limitation was introduced – maximum of 5 people were allowed to stay in the church. Until May 16th the limit was changed to 1 person per 15 m^2 and from May 17th to the end of May – 1 person per 10 m^2, respectively. After that time there were no restrictions on the number of people in the religious buildings.

On March 31st, the so-called "anti-crisis shield" was introduced to protect workplaces in enterprises. The most important solutions were the subsidizing of employees' salaries in connection with the reduction of working hours and the subsidizing of salaries in connection with the economic downturn. An additional care allowance for parents was also introduced in connection with the closure of educational institutions.

As of April 1st, it has been prohibited to carry out activities in the "beauty" sector. The hairdresser's and

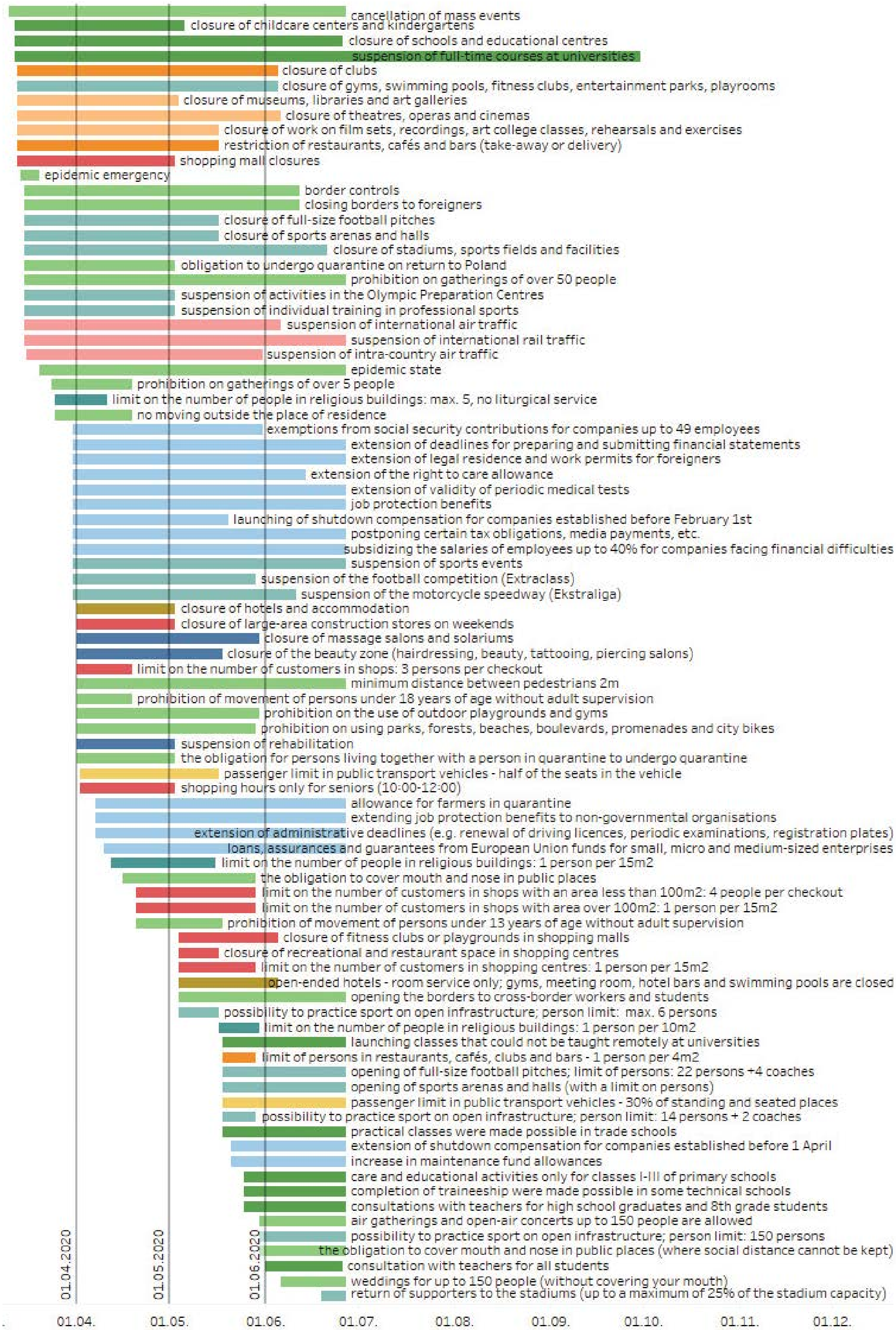

Fig. 2. Gantt chart presenting Polish restrictions due to the COVID-19 pandemic.

beauty salon remained closed until May 18th, solariums and massage salons were closed until the end of May, the possibility of rehabilitation treatments was brought back sooner (from May 4th). From April 1st, hotels and accommodation facilities could only be provided to persons on business trips. A passenger limit for public transport was introduced on April 2nd. Initially, until May 17th maximum of half of the seats could have been occupied by passengers of public transport, and from May 18th the maximum number of passengers corresponds to 30% of standing and seated places.

From April 20th, a gradual phase of abolishing restrictions began. More people were allowed to stay in commercial and religious facilities, and the possibility to move in open areas for sports and recreation was restored.

On May 3rd sports activities were resumed, initially, professional sports training was made possible, from May 4th it was possible to practice sports in open-air sports facilities with a limit of six people, which was changed into 16 people from May 18th. On May 4th, interior sports halls and shopping malls were opened (with a limit of persons and without a catering zone). At this stage, the possibility of opening hotels and accommodation was restored, as well as the possibility of serving meals to hotel guests. Some cultural institutions were also reactivated (the opening date was decided by the authority). From May 4th, it was also possible to use city bikes.

On May 18th, restaurants (keeping the appropriate distances) and hairdressing and cosmetic businesses were opened.

Education facilities (childcare centers and kindergartens) resumed their work on May 6th, and from May 25th care activities were introduced in classes I–III of primary schools (children in approximately 7–9 years old). The remaining education is still conducted on a remote level. Students graduating from primary school and secondary school from 25 May could benefit from direct consultations with teachers (for all students – from 1st June). Since 25 May, higher education institutions were able to provide teaching classes for students of the last years as well as subjects that could not be taught remotely.

Since May 30th in Poland there are no limits in the trade and catering industry (the distance between tables remains), it is possible to organize meetings and weddings in open spaces up to 150 people. Since June 6th, cinemas, theatres, operas, saunas, solariums, and swimming pools have resumed their activity.

3.2. Urban water use in COVID-19 pandemic period

3.2.1. Total water consumption in the city

The share of water consumption among different kinds of users did not change significantly over the 2 years before the COVID-19 pandemic in Europe. After restrictions connected with economy lockdown were introduced in mid-March 2020, noticeable differences are noticed in April (Fig. 3). A major increase can be seen in the case of housing where the share changed from 75.8% (March) to 81.6% (April). On the contrary, water consumption by commercial buildings dropped from 9.1% to 6.8% and by education buildings from 3.4% to 1.9%, respectively. These are the three main changes in the whole structure of water consumption in the city.

Focusing on specific categories of users, more changes can be observed. Data was prepared in three sets where February, March, and April in 2018, 2019, and 2020 are compared, respectively (Fig. 4). Comparisons of February, March, and the first two values for April (2018 and 2019)

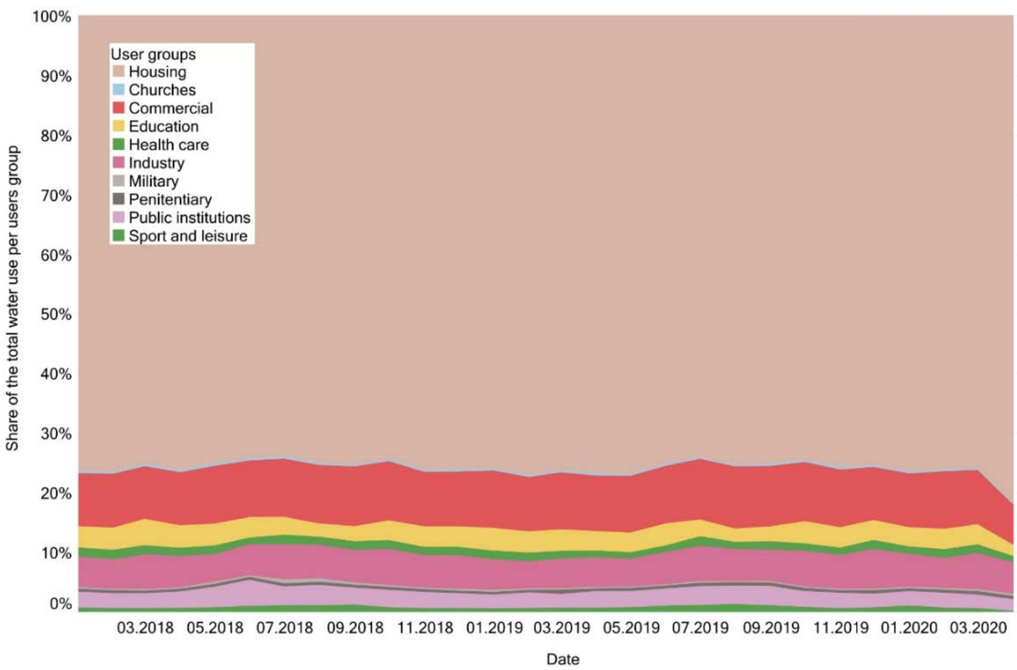

Fig. 3. Structure of water consumption per group of users in a period from January 2018 to April 2020.

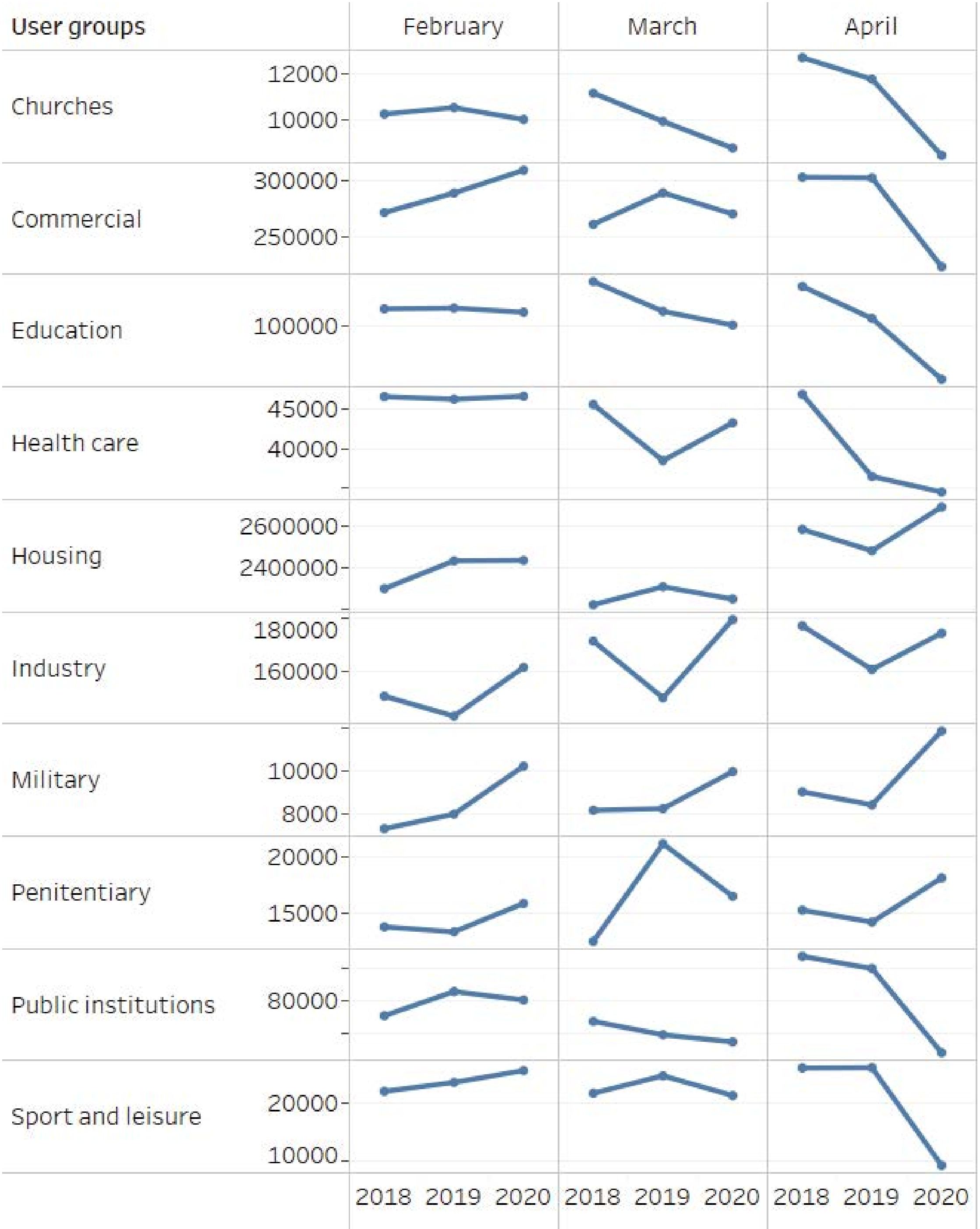

Fig. 4. Comparison of water (m³) in a group of users between the selected months (February, March, and April) in the period 2018–2020.

show how stable water consumption in each group is. Based on these reference levels it was possible to distinguish relative changes that draw change of trajectory. Comparing April 2019 to April 2020 water consumption increased in housing buildings from 2,481,709 to 2,693,333 m³ (8.5%). Trajectories in the case of the industry present an increase in all 3 months in 2020, therefore, it does not allow to relate it directly with COVID-19 restrictions. A similar situation can be observed in the case of military objects. Penitentiary users do not allow to define any regular pattern on this data visualization set. When it comes to decreases between April 2019 and April 2020 (comparison including seasonal aspect of specific sectors), the most visible change is noticed in sport and leisure facilities from 26,132 to 9,286 m³ (–64.5%), education buildings from 105,121 to 62,168 m³ (–40.9%), public institution from 89,878 to 64,156 m³ (–28.6%) and commercial objects from 301,864 to 223,649 m^3 (–25.9%). In all these cases drop in water use is observed also comparing march to April in 2020.

Besides relative data analysis, absolute data also characterize important features of the water demand pattern. Available data do not show an increase in total water consumption in the city in the whole period of 28 months (January 2018–April 2020). Values of water use in months January–April 2020 aggregated at the level of groups of users are presented in Table 2. More detailed data on water consumption in the DMA zone in this period are presented in Appendix (Figs. A1–A4).

3.2.2. Water consumption within the spatial structure of the city

Despite total water consumption, this section focus on the spatial distribution of water sources within the urban structure. Relative changes between a month-to-month comparison in subsequent years (Table 3) do not allow to distinguish any specific pattern. In case of many zones, relative change between 2018 and 2019 even exceed the same differences for months from 2019 to 2020. Some significant changes which cover also years before the COVID-19 pandemic proves that there are other reasons than recent restrictions that influence that change. These changes may be caused by different reasons, including both changes in a number of water consumers (for instance construction of new houses; establishment or closure of commercial or production units) as well as changes in water consumption per consumer (for example modernization or replacement of the equipment into the one meeting more efficient standards including water-savings; savings in water use caused by the price of water). However, the available data does not allow to verify that is the key factor for recorded differences.

Considering the structure of types of water intake points it can be noticed the central DMA zone has a significantly higher share of non-housing users than other zones (Fig. 5). Unfortunately, the central part of the city is covered by one DMA unit (zone 0) which does not allow for more detailed analysis. Therefore, it is possible that within DMA zone 0 sub-units do not guarantee similar water distribution. However, the obtained data shows that the rest of the zones present more similarities in the structure of different water consumers (pie-charts are located in centroids of DMA zones). More patchwork urban structure (by avoiding urban districts with mono-functions) has an impact on the more stable distribution of water sources among the city.

4. Discussion

The COVID-19 pandemic creates a situation that requires adjustments of many elements into the new reality. The technological approach used in this research is coherent with the findings of Zhou et al. [44] who tested the use of geospatial analyses with big data provides valuable information to fight COVID-19. However, they highlighted that there are still some challenges in data aggregation, knowledge discovery, and dynamic expression [44]. Business intelligence software used in this research is complementary with a new paradigm of data-driven urban management [45] and the use of modern technologies in communication and surveillance in the COVID-19 pandemic situation [46].

The fact that spatio-temporal water consumption patterns are non-stationarity and may change due to many social, urban, and physical environmental drivers is well-known [47]. Despite these factors, there are some undesirable drivers that also impact water consumption, like pollutants or diseases that may be spread by water (including COVID-19) [23,48]. It may be especially dangerous for public health, as in some cases poor-quality water is not perceived locally as a health risk [49]. All these elements may lead to household water insecurity [50]. In order to prevent such situation, stakeholders should be informed about water consumption patterns to be able to guarantee sustainable water management [51]. As the COVID-19 pandemic does not have a comparable event that occurred at the moment when water management systems are developed as nowadays, there are no similar studies that can be compared to the obtained results. It is assumed that half of the world population was under some form of lockdown

Table 2
Total water use per month per group of users in a period from January 2020 to April 2020

Group of users	Water use (m^3)			
	January 2020	February 2020	March 2020	April 2020
Churches	10,815	10,037	8,803	8,487
Commercial	313,905	308,573	270,066	223,649
Education	112,351	109,512	100,437	62,168
Health care	43,139	46,672	43,298	34,503
Housing	2,660,436	2,435,166	2,247,829	2,693,333
Industry	190,957	161,720	179,668	174,574
Military	10,135	10,209	9,957	11,833
Penitentiary	16,168	15,835	16,476	18,134
Public institutions	83,736	80,244	67,454	64,156
Sport and leisure	40,953	25,627	21,326	9,286
Total	3,482,595	3,058,047	2,965,314	3,300,123

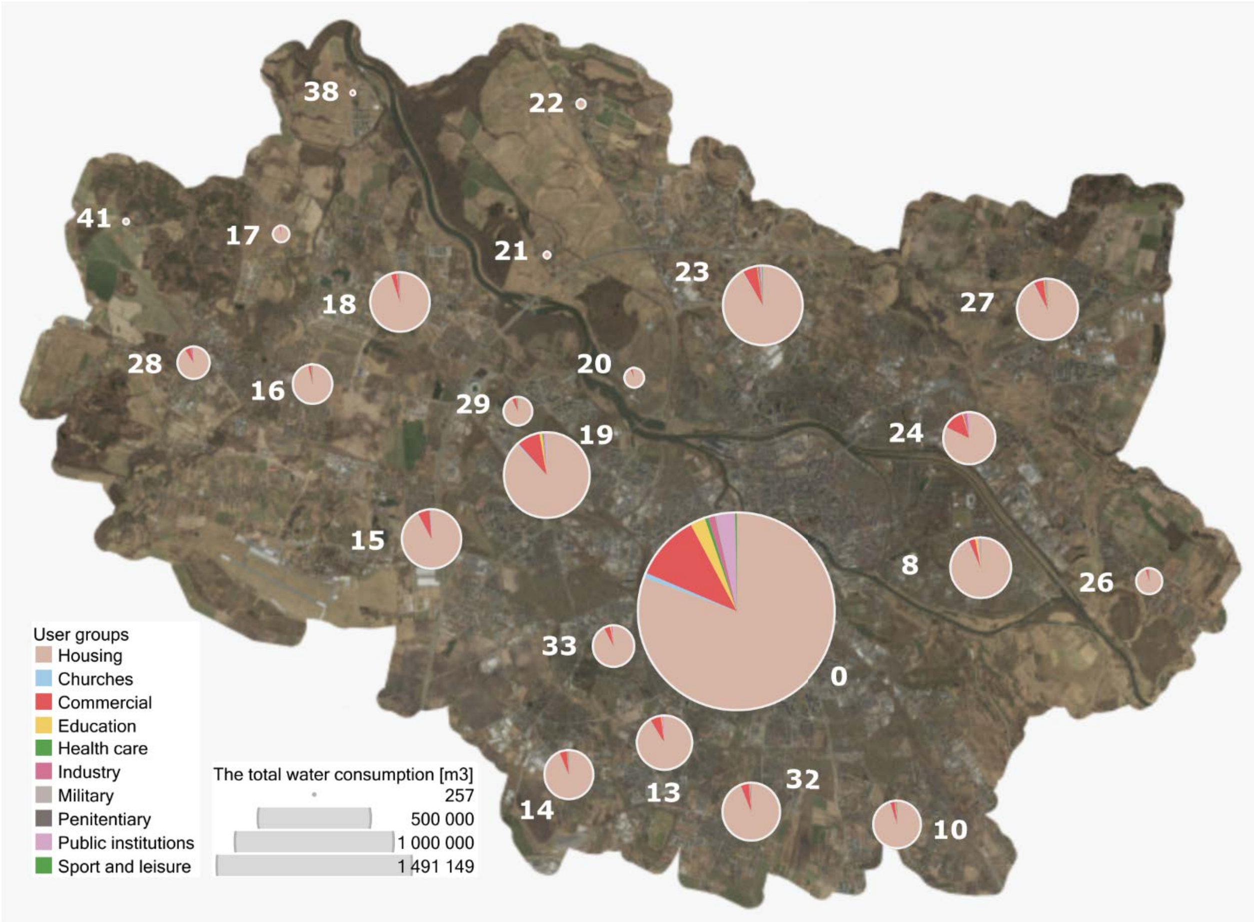

Fig. 5. Spatial distribution of water consumption among DMA zones.

due to COVID-19 in early 2020 [18]. Therefore, the outcomes of this study may constitute a valuable insight for further studies on water consumption patterns and their impact on techno-economic aspects of water management systems, which were already a topic of recent studies [52–60].

In the analyzed case, restrictions caused by COVID-19 did not change total water consumption. Therefore, the first finding of this research is that hygiene requirements promoted by public authorities were not a factor for increased consumption of water resources. At the same time, the lockdown of the economy caused noticeable transfer between different categories of water consumers. From the point of view of total water distribution, the main increase characterizes consumers in housing buildings (+5.8% in the share of total urban water consumption compared to the previous month; +19.8% in the absolute amount of consumed water), while the main decrease was observed in commercial objects (–2.3% in total urban water consumption comparing to the previous month; –17.2% in the absolute amount of consumed water) and education facilities (–1.5% in total urban water consumption compared to the previous month; –38.1% in the absolute amount of consumed water). These values are crucial for the stability of the water supply system to know what are the benchmarks for water demand in case of a lockdown. Based on these figures, which could not be recorded previously on the scale of the whole city, there is a more practical finding useful for the water supply company. Knowledge about the changes in patterns of resource flow in the city may allow assuming potential needs for water pressure in the municipal water supply system. Despite the fact of mixed land use in Wrocław and relatively similar distribution of types of water consumers in different parts of the city, the finding concerning changes in the resource flow might be even more crucial in case of these municipalities where land use in different districts of cities are more homogenous (e.g., typically housing district, mostly commercial neighborhood, or concentrated university campus). Considering specific types of water consumers in seasonal aspect (April 2019–2020), main savings in water consumption were recorded for sport and leisure purposes (–64.5% comparing to the same month year before), education purposes (–40.9% comparing to the same month year before), public institution (–28.6% comparing to the same month year before), and commercial purposes (–25.9% comparing to the same month year before). The finding based on these results is that the fact of crucial limitations of some sectors of the economy (a group of commercial customers: closure of shopping malls and offices, limitations in the operation of construction stores and regular shops) or even total

Table 3
Changes in water use in DMA zones between the selected months (February, March, and April) in the period 2018–2020

DMA zone	February		March		April	
	Δ 2018–2019	Δ 2019–2020	Δ 2018–2019	Δ 2019–2020	Δ 2018–2019	Δ 2019–2020
0	5.4%	0.2%	2.4%	–5.1%	–4.6%	–3.2%
8	–7.7%	9.0%	1.8%	–7.9%	–1.6%	–14.5%
10	–6.8%	13.0%	2.7%	–1.8%	–5.9%	25.2%
13	5.6%	10.0%	6.6%	–9.2%	–14.1%	3.8%
14	–4.2%	17.4%	6.7%	1.0%	10.5%	–1.6%
15	1.1%	13.3%	6.9%	–9.6%	–3.0%	6.6%
16	13.9%	9.8%	9.4%	1.8%	–10.8%	9.3%
17	–12.5%	8.5%	20.3%	3.3%	10.0%	–5.4%
18	13.8%	–1.7%	0.8%	7.2%	–3.6%	28.3%
19	2.4%	–7.0%	7.5%	–7.3%	–12.1%	6.3%
20	0.3%	–15.7%	–1.7%	6.3%	10.9%	–17.2%
21	–3.1%	–2.9%	0.4%	15.7%	–0.8%	2.2%
22	20.1%	–21.1%	3.8%	3.3%	8.7%	–10.1%
23	21.1%	–6.7%	–15.4%	4.1%	–1.5%	4.8%
24	5.5%	3.1%	0.4%	25.3%	–6.0%	0.2%
26	9.1%	9.7%	8.5%	–9.4%	–10.6%	5.7%
27	9.1%	6.0%	–4.5%	11.3%	–3.0%	–6.2%
28	–24.5%	35.4%	4.9%	–2.9%	–6.6%	4.5%
29	3.0%	–2.4%	7.2%	5.0%	–17.3%	12.4%
32	16.5%	–8.5%	2.6%	4.5%	7.2%	16.1%
33	0.7%	1.7%	11.2%	–2.9%	–9.4%	2.5%
38	114.0%	15.2%	77.4%	14.9%	57.3%	94.7%
41	–21.5%	30.6%	3.5%	5.4%	–11.8%	30.0%

lockdown (like in the case of education or sport and leisure facilities) do not imply as significant water demand as it could be expected. The most characteristic value could be the water demand at the level of approximately 60% of regular demand in the case of education facilities, which were under total lockdown in that period. Therefore, potential cases of closure of different purposes objects in the future may require a constant water supply, which should be assumed to maintain the infrastructure of these objects in proper conditions. Knowledge about the scale of water savings might be useful once the economy would be restarted and reorganized after the COVID-19 pandemic. In case some processes proved to be effective in home office mode, the scale of water savings and connected with them economic savings could constitute important information to insight to redesign some sectors of the economy. Moreover, considering current discussions on the potential second wave of COVID-19 cases in some parts of the globe and political scenarios of new protective measures that should be applied, the above findings may enrich these discussions by verified data and knowledge. A similar comparison focusing on energy resources might be also valuable.

When it comes to the spatial distribution of water demand among the city in the analyzed case, the mixed structure of water consumers between different districts of the city did not destabilize the water supply system. Variations of water consumption in urban zones did not exceed the scale of variations that were observed before the pandemic. This information is very optimistic as that influences the stability and efficiency of the urban water supply system [61]. As it is proved, the number of failures in water supply infrastructure is related to the pressure management in the water supply system [62,63]. Therefore, a relative balance in water pressure (there is no extraordinary situation when there is a need to supply much more water resources than usually) allows safe operation of the system. Despite obtained results for Wrocław, similar comparison in cases of cities where land use is not mixed and mono-function land use classes constitute a majority, could support an interesting insight into how land-use planning and urban design might impact the stability of water supply systems. This study corresponds with other research on spatial differentiation of water consumption in this domain [64].

The obtained results may constitute a valuable input to the state of knowledge to build more resilient urban systems supporting a high quality of life [65,66]. As Sowby stated, COVID-19 renews the need for emergency preparedness by water and wastewater utilities. In order to ensure proper hygiene standards to support public health, water-related utilities should learn from COVID-19 to strengthen future preparedness for unexpected events [67]. The knowledge about water demand patterns in case of lockdown supports local authorities in a more effective water resources management process. It stands in line with conclusions from the research of Madurai Elavarasan and Pugazhendhi, who noticed that the technology shift that occurred in society during the COVID-19 pandemic should be used to restructure socio-environmental systems by the use of different technological strategies to control the situation [46].

Author Contributions

JK: conceptualization, methodology, formal analysis, investigation, data curation, writing—original draft preparation, writing—review and editing, supervision, project administration, and funding acquisition. SS: methodology, formal analysis, data curation, writing—review and editing, and visualization. TP: resources. KT-D: resources. KJ: writing—review and editing. MŚ: writing—review and editing, visualization. All authors contributed to the article and approved the submitted version.

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Conflict of Interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Appendix

	User groups									
DMA	Churches	Commercial	Education	Health care	Housing	Industry	Military	Penitentiary	Public institutions	Sport and leisure
0	7 717	153 107	59 987	27 428	1 240 983	90 007	1 238	13 124	37 486	38 397
8	556	3 671	27 214	139	95 202	136			17 774	1 134
10	51	2 122	325	766	65 647	567			2 488	
13	84	6 898	591	54	100 143	1 593			1 135	
14	77	10 787	641	17	74 586	1 959			1 653	1
15	148	14 441	995	67	122 306	1 899	1 595		4 145	
16	67	2 735	928	3 540	47 151	364			386	4
17		59			7 920	104				
18	87	4 345	1 143	31	110 729	322			1 109	749
19	282	8 263	4 219	358	196 252	66			1 501	
20	26	362	132	20	12 169	101	12		474	
21		6			906					
22	12	93			2 128				19	
23	972	22 689	9 991	9 339	195 373	9 957	6 792		6 955	1
24	35	16 346	1 131	20	45 839	40 260	29		697	
26	38	827	79	43	19 331	1 514			38	2
27	113	12 322	2 447	437	123 425	11 940			1 161	30
28	54	7 692	650	21	25 615	12	452		351	
29	77	2 168	209	239	15 632	3 223			823	62
32	342	5 802	747	62	98 316	88	17		340	3
33	75	2 937	542	334	49 363	6 344		3 044	254	
38		251								
41					480					

Fig. A1. Urban water consumption (m^3) in January 2020 in Wrocław (Poland).

	User groups									
DMA	Churches	Commercial	Education	Health care	Housing	Industry	Military	Penitentiary	Public institutions	Sport and leisure
0	7 047	156 373	58 150	27 104	1 141 178	79 550	1 500	12 805	42 266	22 818
8	540	3 819	22 077	208	87 866	77			16 065	1 342
10	72	1 855	273	2 098	58 798	695			1 438	
13	78	8 340	1 378	73	98 912	1 692			1 870	
14	39	13 791	482	10	59 494	2 191			2 314	
15	105	14 945	1 114	74	98 127	1 755	1 999		3 576	
16	73	2 602	1 338	3 688	45 524	484			482	13
17		37			6 458	81				
18	67	5 215	1 740	38	93 629	451			995	679
19	239	11 978	4 036	373	203 084	52			1 589	
20	17	386	82	20	11 607	100	13		452	
21		7			848					
22	12	117			1 920				35	
23	952	19 081	10 052	9 717	161 492	8 326	6 290		3 923	2
24	37	16 533	2 059	25	47 545	23 081	31		536	
26	25	1 579	82	44	19 598	1 266			45	2
27	95	12 508	3 578	1 215	114 279	27 164			961	169
28	49	8 143	1 234	30	25 954	2	364		364	
29	75	2 717	251	401	20 540	1 560			737	128
32	260	4 677	502	48	81 471	117	13		242	3
33	64	2 955	716	360	45 033	6 520		3 030	296	
38		106								
41					448					

Fig. A2. Urban water consumption (m³) in February 2020 in Wrocław (Poland).

	User groups									
DMA	Churches	Commercial	Education	Health care	Housing	Industry	Military	Penitentiary	Public institutions	Sport and leisure
0	6 324	138 440	56 996	26 847	1 068 621	73 914	1 541	12 964	32 900	19 389
8	544	3 364	19 264	150	85 627	51			15 737	733
10	42	1 505	228	997	53 330	500			1 457	
13	75	6 224	559	51	80 940	1 627			853	
14	60	12 360	514	19	55 604	2 311			1 382	
15	84	10 405	671	72	83 059	1 572	2 010		2 675	
16	76	2 541	815	3 286	38 984	347			346	9
17		57			6 674	58				
18	64	4 421	1 099	39	89 260	594			902	640
19	239	10 094	3 189	285	184 833	52			2 159	
20	12	385	100	15	8 599	60	13		306	
21		6			647					
22	7	68			1 451				17	
23	758	15 477	10 337	9 613	148 625	7 434	5 749		3 307	1
24	41	14 878	1 882	34	44 720	56 983	30		515	
26	31	965	295	42	15 953	1 063			37	
27	101	12 390	2 430	397	105 235	13 375			1 010	68
28	41	7 096	383	23	22 225	20	600		397	
29	72	2 803	233	360	18 668	2 034			687	107
32	120	4 026	455	38	79 326	63	14		312	13
33	52	2 258	638	372	42 605	5 980		3 512	227	
38		108								
41					407					

Fig. A3. Urban water consumption (m³) in March 2020 in Wrocław (Poland).

User groups

DMA	Churches	Commercial	Education	Health care	Housing	Industry	Military	Penitentiary	Public institutions	Sport and leisure
0	5 933	98 234	36 246	19 887	1 209 747	68 604	2 697	13 786	29 581	6 435
8	518	2 621	9 299	71	102 575	87			16 218	919
10	60	1 775	67	1 283	74 628	519			1 474	1
13	55	4 648	475	43	102 956	974			710	
14	45	10 356	193	9	69 920	2 242			1 508	
15	79	11 426	546	55	108 533	2 127	2 036		1 752	
16	44	2 146	1 025	3 212	46 542	466			301	7
17		58			7 596	46				
18	67	4 366	591	30	118 573	1 112			1 287	1 050
19	240	7 873	1 521	273	259 023	85			1 732	
20	16	322	9	15	10 973	65	17		326	
21		5			815					
22	9	85			1 807				1	
23	631	14 562	9 155	8 282	183 132	7 081	6 344		3 519	3
24	37	10 611	384	16	48 025	37 377	35		344	
26	17	1 232	55	35	19 193	1 230			31	
27	72	8 310	1 741	345	110 247	12 318			930	79
28	44	7 784	252	18	25 599	14	691		445	
29	46	2 458	18	214	21 269	2 233			656	53
32	411	4 740	61	35	112 759	80	13		939	34
33	51	1 860	214	152	47 749	4 960		4 348	210	
38		257								
41					494					

Fig. A4. Urban water consumption (m^3) in April 2020 in Wrocław (Poland).