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Demand Changes by the SARS CoV-2 Virus Pandemic in Selected Water Supply Systems – Poland case study

Analiza zmian zapotrzebowania na wodę w kontekście pandemii SARSA CoV-2 w wybranych jednostkach osadniczych w Polsce

Alicja Bałut, Jędrzej Bylka and Michał Januszko*)

Keywords: *Water Distribution System (WDS) management under unusual conditions (lockdown), SARS-CoV-2, Variability of water demand, pandemic, COVID-19, Emerging Hot Spot, Space Time Cube, Esri, Space Time Pattern Mining, Spatial Data Mining, Space-Time Analysis.*

Abstract

This work presents the results of the analysis of changes in water demand for two selected water companies in Poland caused by the SARS-CoV-2 virus pandemic (first wave). Literature that's been published so far has been broadly cited in this work, together with selected evidence collected worldwide. The aim of this article is to evaluate the impact of this type of event on the spatial distribution and variability in water demand using GIS software for two selected samples. The resulting geo-statistical analysis allowed to show areas of greatest variability in water demand using measurements from water meters. In order to achieve this the following research tools developed by ESRI were utilised: 'Space Time Cube', 'Emerging Hot Spot Analysis' and 'Local Outlier Analysis'. Indicators of space-time trend were calculated by category using the ArcGIS Pro software. Additionally the knowledge base was expanded with results of a survey conducted in Poland on hundreds of water utilities concerning impacts of the pandemic related changes in how they function, their financial liquidity, threats, and challenges. Interesting conclusions from the obtained results were presented and directions of future research in connection to further development of the situation in the world were considered. Given the lack of possibility to reference events of this type from the past, this analysis should be treated as an introductory research of this issue in Poland.

Słowa kluczowe: *Zarządzanie systemem dystrybucji wody (WDS) w nietypowych warunkach (kryzysy), SARS-CoV-2, Zmienność zapotrzebowania na wodę, pandemia, COVID-19, Emerging Hot Spot, Space Time Cube, Local Outlier Analysis, Esri, Dane przestrzenne, data maining, analizy czasoprzestrzenne*

Streszczenie

W pracy przedstawiono wyniki analizy zmienności zapotrzebowania na wodę dla dwóch wybranych przedsiębiorstw wodociągowych w Polsce spowodowanych pandemią wirusa SARS-CoV-2 (pierwsza fala). Omówiono dotychczas opublikowaną literaturę oraz badania w tym zakresie realizowane na całym świecie. Celem artykułu jest ocena wpływu pandemii na rozkład przestrzenny i zmienność zapotrzebowania na wodę, przy wykorzystaniu oprogramowania GIS. Analizę wykonano dla dwóch jednostek osadniczych. Analiza geostatystyczna pozwoliła na wskazanie obszarów o największej zmianie zapotrzebowania na wodę, na podstawie analiza danych pomiarowych z wodomierzy. Do celu realizacji badań wykorzystano następujące narzędzia badawcze w pakiecie oprogramowania ESRI: „Space Time Cube", „Emerging Hot Spot Analysis" i „Local Outlier Analysis". Wskaźniki trendu czasoprzestrzennego obliczono według przy użyciu oprogramowania ArcGIS Pro. Dodatkowo baza wiedzy została poszerzona o wyniki badania przeprowadzonego w Polsce wśród setek przedsiębiorstw wodociągowych, na temat skutków zmian związanych z pandemią na ich funkcjonowanie, płynność finansową oraz zagrożenia i wyzwania związane z tego typu zjawiskami. Zaprezentowano ciekawe wnioski z uzyskanych wyników oraz rozważono kierunki przyszłych badań, w związku z dalszym rozwojem sytuacji na świecie. Ze względu na brak możliwości odniesienia się do tego typu wydarzeń z przeszłości, niniejszą analizę należy traktować jako wstępne badania tego zagadnienia w Polsce.

INTRODUCTION

Supplying water at an appropriate pressure and quality is a priority task for every water distribution system (WDS). An unprecedented scale of SARS CoV-2 virus pandemic, as well as blockades and restrictions implemented in many countries around the world, made people realise how important this aspect is. In particular the task of supplying as many people as possible with running and clear water not only for the consumption needs, but primarily due to sanitary requirements in this special time. For network operators the last year was certainly also a test of the commonly used methods and tools, which are meant to support the decisions associated with optimal resource usage with simultaneous delivery of the highest quality of service while keeping the costs as low as possible. By using the billing data as well as the software and available functionality of GIS, an attempt was made to evaluate the impact of this phenomenon on the spatial variability of water demand for two, radically different, case studies.

The paper is organised as follows. After the present section of Introduction, a brief background on the first lockdown in Poland and

* **Alicja Bałut**, Faculty of Environmental Engineering and Energy, Poznan University of Technology, Poznan, Poland, alicja.balut@put.poznan.pl,
Jędrzej Bylka,Faculty of Environmental Engineering and Energy, Poznan University of Technology, Poznan, Poland, jedrzej.bylka@put.poznan.pl,
Michał Januszko, bESRI Polska, Warszawa, Poland

restrictions associated with it is presented. Additionally the information sourced from literature and the so far delivered speeches during virtual conferences describing impacts of SARS-CoV-2 pandemic in the water and sewage industry for selected countries is collected and analysed. In the next section of this publication, two case studies are presented in detail. In the Results section a visualisation of changes in water demand over the analysed period from January to August 2017-2020 is presented. The following section describes the methodology and obtained results, which then in turn allowed to asses the methodology. The most interesting observations are described in the Discussion section, namely the potential causes of changes in water demand stemming directly from the executed analysis. Additionally the available literature and recently carried out studies and observations are described and summarised. Finally the conclusions, future workflow and further research direction of the present work are drawn.

Background

For the first time in Europe the World Health Organization (WHO) on the 30th of December, 2019 announced the appearing cases of "lung inflammation of unknown etiology" constituting possibility of public danger [33]. Due to new reports of the rapid spread of virus in 114 countries around the world, on the 11th of March, 2020, WHO announced that COVID-19 disease, caused by the arrival of the new virus, could be described as a pandemic. In Poland the first case of disease occurred on the 8th of March, 2020. In Poland, from the 14th to the 20th of March, 2020, the state of epidemic emergency has been implemented. From the 20th of March, 2020, in accordance with the ordinance of the Minister of Health, in Poland the state of epidemic has begun, the so called hard lockdown.

In this period, there was a series of changes in the use of water not only for living purposes but also in sectors of the economy where restrictions were placed on the operations of enterprises that were so far significant recipients in the water systems. The research regarding the impact of COVID-19 on water demand in Poland that has been carried out by IGWP on a group of 101 water utilities has shown that 15.8% of them experienced unusual water demand, 60.4% did not notice significant changes, all other did not respond. Main changes that have been identified include: significant reduction in water, demand for industrial plants, miniscule increase of 2% in the housing sector, significant reduction in water demand for sport centres, cultural centres, dining, hospitality.

The American water company AWWA [3] on the basis of USA experiences, difficulties similar to those stated for Poland are listed: suspension of water supply shutdowns, increase in water payment arrears, reduction of revenues from commercial activities, maintenance delays, increase in personnel and other external companies expenses, reduction in system development fees, decrease in customer number growth.

Similar surveys were also carried out in the United Kingdom by the Chartered Institution of Water & Environmental Management – CIWEM [10]. The aim was to analyse the challenges facing the British WDS's as well as to capture the best practices and to define the possibilities and utilised solutions in order to provide resilience of water supply systems, as defined by Butler [8]. The results of changes in the organisation, communications, in financial problems as well as in providing work safety were described in detail in Cotterill [10]. In the United Kingdom Waterwise has published a report which indicates in certain regions a 35% increase in peak daily consumption during the lockdown [2]. In Brazil, analysis of data from 26 days pre-lockdown and 26 days during lockdown has revealed an 11% increase in household water consumption attributable to the lockdown [21]. Similar studies were conducted in the northern part of Germany [22]. The paper investigates hourly and daily water consumption volumes of a utility in northern Germany for the first wave of the pandemic. They performed a linear mixed model to compare the 2020 daily water consumption volumes with previous years before the first wave of the pandemic. It turns out that about a 14.3% (3968 m3) higher residential water consumption per day, with higher morning and evening demand peaks during the day, were observed. The German city of Karlsruhe investigated their WDS's with a similar goal in mind. They have used an AI (artificial intelligence) system to analyse how COVID-19 lockdowns are affecting water consumption and demand forecasting [34]. Interesting observations were also made by Clarke [9] in England and Wales, who via surveys, in albeit small, but very diverse group of 21 randomly selected people, described the impact of the first wave of the COVID-19 pandemic in England and Wales on experiences in consumption changes and new water usage practices in households [25,32].

Factors which can influence solidification of new patterns of water demand inequality over the week and longer periods, even after the pandemic subsides in the other parts of the investigated region, have been classified and composed into a list, which has been also described and expanded by Lüdtke [22]. Another important factor impacting the changes in water demand during the pandemic was a type of the settlement units, in which up until pandemic most inhabitants commute to work or study in nearby towns. Such a case study has been analysed in the work [5] for five towns in a Puglia region in southern Italy. It is also worth mention the fact that the greatest fluctuations, observed for towns in which population commuting to work was predominating, were overlapping with the electrical energy consumption [3,29].

The latest article, at the time of writing of this publication [6], which also takes a look at these issues from a very broad and general perspective, indicates that the pandemic situation can be impactful for the waterworks industry, especially where water resources are small or non existent. During a situation such as a lockdown, managing the entirety of WDS's assets is certainly a challenge that has been faced not only by the described city of Auckland in New Zealand [28] but many other cities in the world struggling with such problems.

To study changes in water demand during COVID-19, clusterization analysis was used. [12] who describede methdolodgy for preparing water consumption histogram. For this purpose the analysis of hourly water consumption for selected apartment buildings was performed. Grouping by means of k-means clustering was applied.

The stay-at-home effect on water demand was also analyzed by Irwin et. Al. [20] This interesting case sudy described water consuption changes on the desert area. The effect of pandemic in water-scarce areas in the desert city of Henderson, Nevada was analyzed. Data from March 17 2020 to May 9 2020 were analyzed.

The literature review has shown that most of the studies on water demand changes only consider quantitative aspects. There is no reference to the spatial distribution of changes. In the geostatistics science a number of methods are available to analyze the changes of trends in spatial terms. The starting point of the study is that these methods can be used to analyze changes in water demand, especially in the case of extramural events such as pandemics. In this paper two geostatistics methods were tested: Space Time Cube and Emerging Hot Spot. These methods have already been used for analysis in environmental and urban planning studies [26, 1, 20, 22, 35, 18, 7] and in the analysis of COVID-19 geostatistic [27, 23].

The motivation for studying this subject, within the frame of conducted analysis, was primarily the expansion of the scope of the fundamental research on factors such as pandemic which, at such a large scale, has been experienced for the first time by many countries in the world.

The main goal of the article is to demonstrate that it is possible to analyze and identify geospatial trends in data on changes in water demand during the COVID epidemic. To achieve this, three tools were used: Space Time Cube, Emerging Hot Spot,

Materials and Methods

In the following article, as a case study for the analysis of spatial variations in water demand over the period of the first wave of the pandemic, data from water meters from two water utilities of different size in Poland was collected. Both subjects carry out the task of water supply to two settlement unit with population of 10 thousand and 100 thousand inhabitants accordingly. The described below examples of WDS's were chosen primarily to include in the analysis the impact of the type of the settlement unit: rural and urban.

CASE 1

The analysed service area is located in the northern part of Poland, its coverage spans approximately 131.5 km^2 which constitutes about 27.7% area of the district. The number of inhabitants is 11943. The area has been divided into parts in accordance with the existing administrative division. The entire network consist of 223 km of pipes carrying drinking water to installed 3126 connections. According to 2019 data 96.3% of inhabitants is connected to the water supply network. This municipality is rural. The confirmation of this fact is that according to the statistics for the year 2019, 1102 of the inhabitants commute to work to other municipalities. Approximately 33.3% of the workers are in the agricultural sector, about 19% in the industry and construction and 11\% in the service sector. The population density is about 89 inhabitants per km^2. The average area per inhabitant is 27.5 m^2. The number of people per 1 household is 3.43.

CASE 2

The second settlement unit chosen for the analysis is the area within the borders of the city also located in Poland with a population of about 70 thousand inhabitants. The area of the city is about 42 km^2 and it includes 28 thousand real estates within the limits of the city. This area has been divided in accordance with the existing administrative divisions. For the analysis, only readings from the water meters within the administrative borders of the city were used. According to the statistics it is estimated that among the professionally active inhabitants about 3020 commutes to other towns, up to 7012 of the working commutes from outside the municipality. About 22% of the workers operates within the construction industry and only 1.5% within the agricultural industry, with the rest in other activities. The city does not have many industrial plants, the vast majority of the enterprises are micro and small businesses (BDL) [4].

Data

Moving onto more detailed description of the utilised data in the 1st case an area was chosen for which it was possible to collect readings remotely and export them directly. Additionally several readings of significant demand size, which were obtained via the collector visit, were utilised. The readings were collected using Kamstrup Multical 21 water meter, which based on the verifications tests, has a measurement error of 1-2%. In general, based on conducted consultations, in the WDS from the case 1 during the pandemic, when the local readings were limited, estimated data on the consumption to date and readings from area water meters were used. The real, factual analysis of the entirety of the profits from communal services, is truly difficult to realise in conditions such as these i.e. full coverage of the recipients with the remote readings is not available. The spatial presentation of water meters used for the analysis within this publication can be seen in Fig. 1.

The case 2 on the other hand includes the entire city area, within which, thanks to capability of the working network, it was possible to get readings from all water meters, without the need to collect readings locally at the customer's site. The spatial presentation of the locations of the water meters used in the further parts of the analysis can be seen in Fig. 2.

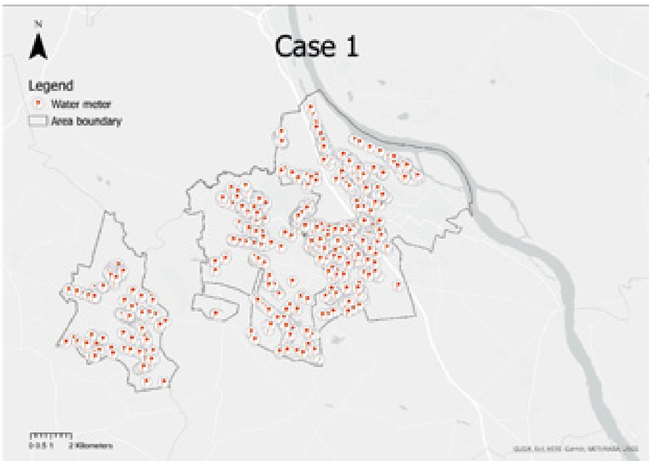

Fig. 1. Water meter distribution for Case 1
Rys.1. Rozmieszczenie wodomierzy dla pierwszego przyp.

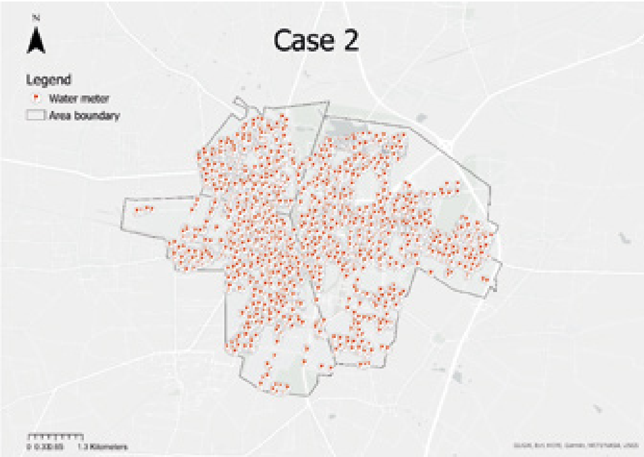

Fig 2. Water meter distribution for Case 2
Rys.2.Rozmieszczenie wodomierzy dla drugiego przyp.

Because of the characteristics of the operation area, the number of active water meters as well as the periods over which the readings were taken varies diametrically between the analysed cases. The details about the number of used readings as well as the time of measurements and important notes regarding the data were compiled in Tab. 1

Billing data analysis

Considering both of the cases, using only the water meters that had full scale of the readings could have been not sufficient to model the changes occurring across time and space. Therefore before the calculations were done, water meters that did not provide at least 50\% of the readings in every year of the considered period were rejected. The missing readings were filled in by averaging the bordering values. Below is the description of the method used to average the values together with the adopted variable names used for Case 2.

For $m = 1$:

$$Vn = \frac{V_{n-1} + V_{n+1}}{2} \quad (1)$$

For $m > 1$:

$$Vn = V_{n-1} + \frac{V_{n0+m+1} - V_{n0-1}}{m+1} \quad (2)$$

Where:
V_n – Volume of water metered in the n'th water meter,
n – number of water meter,
m – number of meter reading .

Table 1. Compilation and comparison of the measurements data from both analysed cases

Tabela 1. Zestawienie i porównanie danych pomiarowych z obu analizowanych przypadków

Case 1					
Data	Period	Meters #	Readings #	Data source	Notes
Readings taken	02.2017 – 08.2017 02.2018 – 08.2018 02.2019 – 08.2019 02.2020 – 08.2020	2310	42 089	Water utilities	
Readings used	02.2018 – 08.2018 02.2019 – 08.2019 02.2020 – 08.2020	2017	42 357	Water utilities	Greater number of readings taken is due to need to average the values.
Case 2					
Data	Period	Meters #	Readings #	Data source	Notes
Readings taken	01.2017 – 08.2020	13 202	342 268	Water utilities	
Readings used	01.2018 – 08.2020	6085	194 720	Water utilities	Water meters that did not provide at least 50% of the readings in every year of the considered period were rejected.

Following these operations, the readings collected for case 2 were ready for further analysis. The data collected from the area in case 1 were a sum of the total consumption over the entire function cycle of a given device. In this form, the readings did not fulfil the requirements of the used analytical tools and required an averaging as well. Next the results normalisation was carried out. As a starting value for the reading from 02.2018 a 0 was taken, with next values being calculated according to the pattern below.

For periods: 03.2018 – 08.2018,03.2019 – 08.2019,03.2020 – 08.2020

$$V_n = V_{Tn} - V_{Tn-1} \quad (3)$$

For periods: 02.2019, 02.2020

$$V_n = \frac{V_{Tn} - V_{Tn-1}}{6} \quad (4)$$

Analytical Methods

Space Time Cube

In order to visualize and analyze spatiotemporal data 'Space Time Cube' has been used. It is a feature built-in ESRI ArcGIS Pro software. The output of this tool is a cube which contains a series of attributes for a given period of time, which are grouped into bins. Fig. 3 presents a theoretical structure of this tool. Bins are composed of the number of the observation as well as the value of the chosen variable. For them a trend value is calculated over the investigated period based on the Mann-Kendall trend test statistic

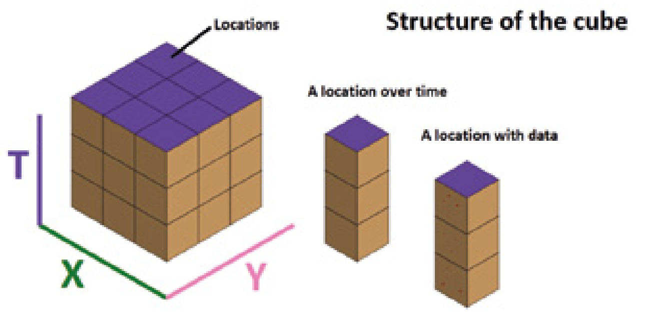

Fig. 3. Structure of the space-time cube (where T – analysed time period, X – width of the space-time cube, Y – length of the space-time cube)

Rys.3. Budowa sześcianu czasoprzestrzeni (gdzie T – analizowany okres czasu, X – szerokość sześcianu czasoprzestrzeni, Y – długość sześcianu czasoprzestrzeni)

The Space-Time Cube construction consists of three dimensions. Dimensions X and Y characterize the geographic coordinates of the water demand point. The size of each cube represents the quantity of water taken at a given point. Coordinate T characterizes the time for conducting the analysis. Creating space-time cube allows for: visualisation and analysis of time-space data in the time series form, integrated analysis of space and time patterns, visualisation of data using 2D and 3D methods.

Emerging Hot Spot

As part of the measurement data analysis an Emerging Hot Spot Analysis tool was also used, given that the data in the GIS system provides an ability to identify trends within. This tool allows for automatic labelling of new, rising, falling and sporadic values, the so called hot spots and cold spots. As an entry parameter it accepts the time space cube in NetCDF format. The analysis is performed for every bin. As a result value we receive, assigned to every bin, a value of z-score and p-value as well as so called hot spot classifier. Next, using the Mann-Kendall statistical method, trends in dataset are evaluated. The curve depicting values that define data relevance is shown in Fig. 4. below.

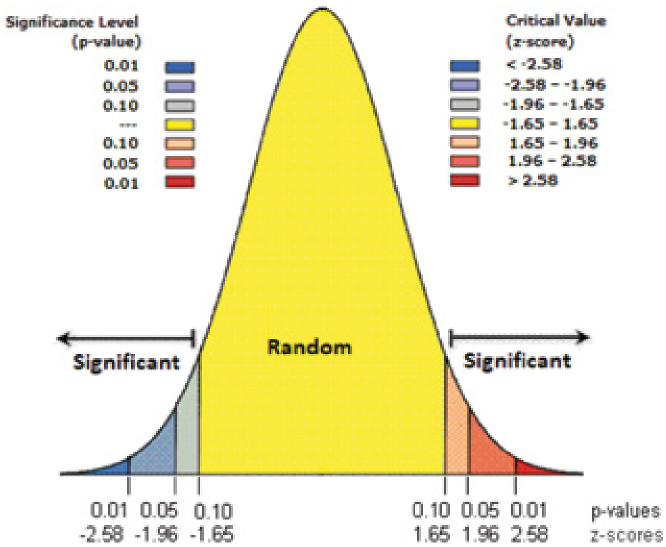

Fig. 4. Normal distribution with p-value and z-score outlined

Rys.4. Rozkład normalny z zarysem wartości p i z-score

Based on this, further visualisation of the trends is carried out using one of seventeen categories which are assigned based on the value of: z-score, p-value as well as z-score and p-value from Hot Spot analysis for every bin. Results categories are: No Pattern Detected (cannot find any trends in water demand changes), New Hot Spot (the place with significant water demand increasing was found), New Cold Spot (the new place with significant water demand decrease was found), Consecutive Hot Spot (the place with consecutive water demand increase was found), Consecutive Cold Spot (the place with consecutive water demand decrease was found), Intensifying Hot Spot (the place with intensifying water demand increase was found), Intensifying Cold Spot (the place with intensifying water demand decrease was found), Persistent Hot Spot (the place with persistent water demand increase was found), Persistent Cold Spot (the place with persistent water demand decrease was found), Diminishing Hot Spot (the place with diminishing water demand increase was found), Diminishing Cold Spot (the place with diminishing water demand decrease was found), Sporadic Hot Spot (the place with sporadic water demand increase was found), Sporadic Cold Spot (the place with sporadic water demand decrease was found), Oscillating Hot Spot (the place where in the past water demand significantly decrease but in the year of analyses become significantly increase), Oscillating Cold Spot (the place where in the past water demand significantly increase but in the year of analyses become significantly decrease), Historical Hot Spot (the place which in the past was hot spot was found), Historical Cold Spot (the place which in the past was cold spot was found)

Definitions of each of the trend categories can be found [14].

Local Outlier Analysis

In order to identify statistically significant clusters for the two cases and to observe outlier values within the time and space context, a Local Outlier analysis was used. This tool is a time space implementation of the Aneslin Local Moran I statistics [15].

This function allows to compare neighbours with each other, thanks to which areas that use more or less of a given resource e.g. water can be identified. This allows an implementation of good practices that help managing water resources within detected areas. Local Outlier analysis workflow has been presented at Fig. 5.

As a result of this tool we get objects divided into 6 classes:

- Never Significant (location where has never been significant change of water demand),
- Only High-High Cluster (location where the only statistically significant type was High-High Cluster of water demand increase),
- Only High-Low Outlier (location where the only statistically significant type was High-Low Outlier of water demand increase),
- Only Low-High Outlier (location where the only statistically significant type was Low-High Outlier of water demand increase),
- Only Low-Low Cluster (location where the only statistically significant type was Low-Low Cluster of water demand increase),
- Multiple Types (location where has been multiple types of statistically significant Outliers)_.

GIS integration with WDS model of demand

All of the descriptive data used of the analysis were processed using programming language Python 3. Following libraries were used: Pandas, Numpy, ArcGIS API for Python, OS, Arcpy. Given that the raw imported data did not have spatial context, geocoding was carried out. For this purpose address points data was downloaded from Geoportal [16], using which a geolocator was built. This was done using a geoprocessing tool called Create Locator from the ArcGIS Pro software. As a result a point layer with water meter locations was achieved. From this object class a class relation of 1:M (one to many) was created, which relates to records from nonspatial table of measurements. In accordance with the contracts with the data providers all information concerning water consumption and personal or otherwise identifiable data were for the purpose of this publication anonymised.

Limits and assumptions

Main limitations related to carrying out work on this subject were:

- lack of spatial aspect: in both the 1st and case 2 the data was collected without the spatial context, which after processing required geocoding. For the less experienced users or for those not in possession of the address points or the explanations of the imposed assumptions could have made such analysis impossible or to delay it significantly,
- lack of standardisation on the national level: the data is recorded in different schemes in accordance with the internal policies of a given enterprise, this prolongs the processing time due to familiarisation need for every file structure of every enterprise,
- gaps in data: missing data which demands rejection of parts of measurements which can lead to exclusion of significant water consumers,
- errors in readings: each time they require meticulousness, anomaly detection and consultations with the operators,
- unclear water meter labels within one database: they demand additional consultations with the given enterprise,
- necessity to use script languages: due to complexity and volume of the data it could constitute a high bar for inexperienced analysts.

For the purpose of this study, we consider the entire lockdown period as lasting from 4 March to 30 April 2020, starting with the closure of schools and universities. Main comparison date was chosen to be the 16th of March, 2020 due to being directly related to the most severe restrictions of transportation and movement, closures of schools, kindergartens and many public institutions (i.e. commercial, cultural, sport, recreation and entertainment centres). Because of this it was possible to show the impact of families with their children remaining home and that of the adults working remotely on the spatial distribution of water demand.

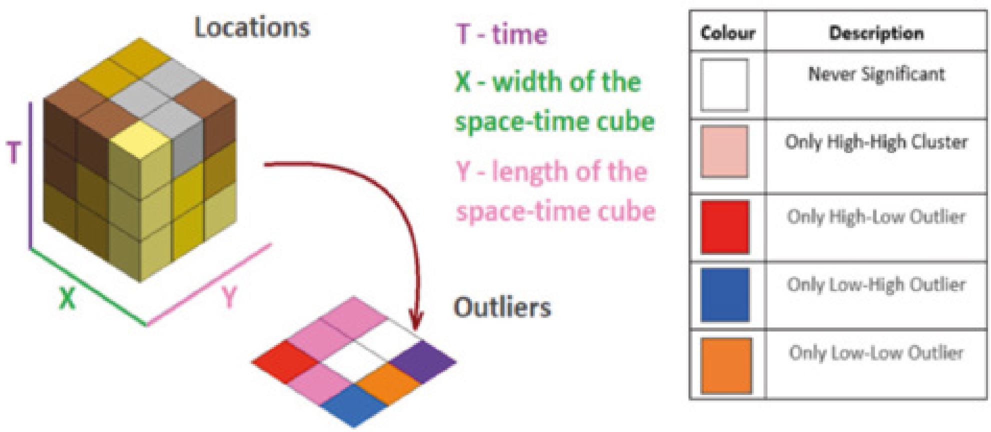

Fig. 5. Local outlier analysis workflow, 3D cube to 2D feature class

Rys.5. Proces analizy lokalnych wartości odstających, przekształcenie kostki 3D w klasę elementów 2D

Statistical Analysis

The final list of all statistically relevant measurements for every case was presented in Tab. 2. At the bottom of the table the number of measurements, for both cases, was given. Only those classified as statistically significant, that is those for which for 90% of the analysed period it was possible to determine the characteristic properties of the Hot Spot analysis, were considered. The difference in years is due to only averaging values and different number of measurements for each year,presented also in tab. 1.

Sensitivity analysis

Analysed spatial changes in water demand are greatly varied, which are influenced by a number of different parameters [19, 30, 24, Gornicka 2020). On the basis of the analysis done for case 1 and 2 the parameters, which are the most important for this type of analysis that uses the GIS system, were listed in tab. 2,3,4.

Table 2. Space Time Cube sensitivity for both cases and adopted values

Tabela 2. Czułość Kostki Czasu Przestrzennego dla obu przypadków i przyjętych wartości

Parameter	Impact on the results obtained	Parameter value
Time Step Interval	High	1 Months
Time Step Alignment	Medium	End time
Variables	High	Fill Empty Bins with: Temporal Trend (Case 1) Fill Empty Bins with: Space-time neighbours (Case 2)

Table 3. Emerging Hotspot sensitivity for both cases and adopted values

Tabela 3. Czułość Emerging Hotspot w obu przypadkach i przyjętych wartościach

Parameter	Impact on the results obtained	Parameter value
Conceptualization of Spatial Relationships	high	Fixed distance
Neighbourhood Distance	medium	699 meters for Case 1 342 meters for Case 2 calculated based on the spatial distribution of water metres
Neighbourhood Time Step Define Global Window	high	7 for Case 1 12 for Case 2 Neighbourhood time step

Table 4. Local Outlier Analysis sensitivity for both cases and adopted values

Tabela 4. Czułość lokalnej analizy wartości odstających dla obu przypadków i przyjętych wartości

Parameter	Impact on the results obtained	Parameter value
Conceptualization of Spatial Relationships	high	Fixed distance
Neighbourhood Distance	high	699 meters for Case 1 342 meters for Case 2 calculated based on the spatial distribution of water metres
Neighbourhood Time Step	medium	7 for Case 1 12 for Case 2
Number of Permutations	low	499
Define Global Window	medium	Neighbourhood time step

Their influence on the achieved results was presented in the next tables. For each of the three tools a three step method of assessing the impact on the obtained results in the dictionary form was adopted: high, medium, low. In the Space Time Cube analysis following parameters were used, which together with the adopted values are presented in Table 2.

Results

Based on the Emerging Hot Spot results which has been presented shortly in tab. 5.

The Emerging Hot Spot analysis revealed that in the case of Case 1, in the years 2018-2019, a large number of New Cold Spots appeared, whereas between 2019 and 2020, a large number of Sporadic Cold Spots were registered. In the year 2019 – 2020, a large number of Oscillating Hot Spots were not observed, indicating the absence of local increases in water demand. In the case of Case 2, no significant change was noticed in the Emerging Hot-Spot analysis between the years 2018-2019 and 2019-2020. Space Time Cube and Local Outlier analysis it was possible to collect following visualisations of changes in water demand values for selected areas for both case 1 and 2, which constitute the results of this study. In figures 6-9 the select sub areas for each of the analysed cases are presented in detail.

In the southern part of the analysed area an intensification of the studied phenomenon was reported. It can be identified through higher values which are statistically significant. Locations in the east central sector can be also described as statistically significant but with lower values, which appeared during the period of pandemic.

Table 5. Results of Emerging Hotspot for Case 1 and Case 2

Table 5. Wyniki pojawiającego się hotspotu dla przypadku 1 i przypadku 2

	Case 1				Case 2			
Analysed period	**2018 – 2019**		**2019 – 2020**		**2018 – 2019**		**2019 – 2020**	
Category	Hot	Cold	Hot	Cold	Hot	Cold	Hot	Cold
New	6	397	2	8	3	0	8	9
Consecutive	11	87	11	0	240	898	278	1164
Intensifying	0	0	47	1	862	2846	919	2807
Persistent	0	0	100	5	88	191	0	11
Diminishing	0	0	2	0	14	16	0	0
Sporadic	0	15	35	470	40	104	31	119
Oscillating	239	738	7	889	1	3	0	0
Historical	0	0	0	0	0	0	0	0
Locations with hot or cold spot trends	1493 of 2017		1577 0f 2017		5306 of 6019		5346 of 6051	

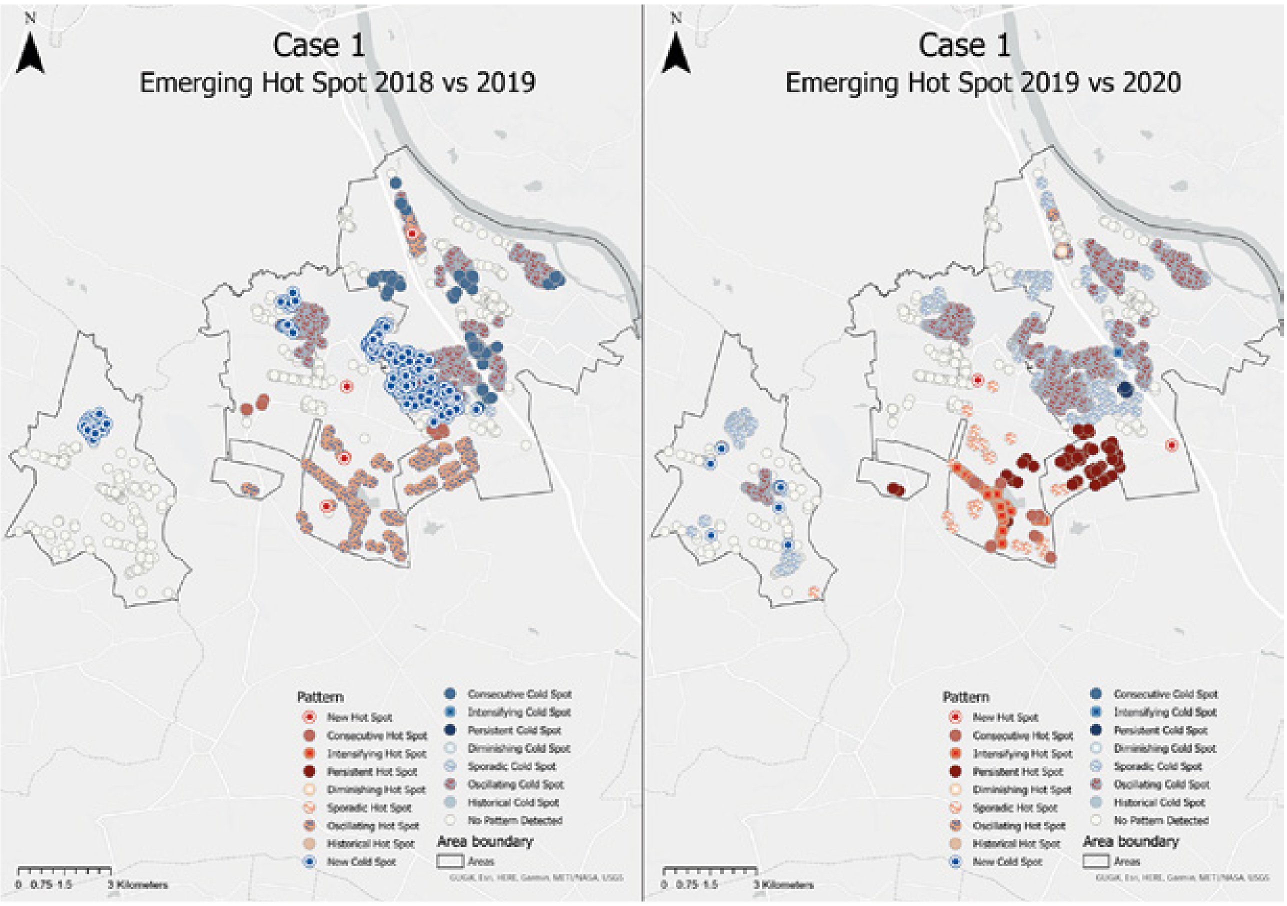

Fig. 6. Emerging Hot Spot results compared for both periods for Case 1

Rys.6. Porównanie wyników Emerging Hot Spot dla obu okresów dla przypadku 1

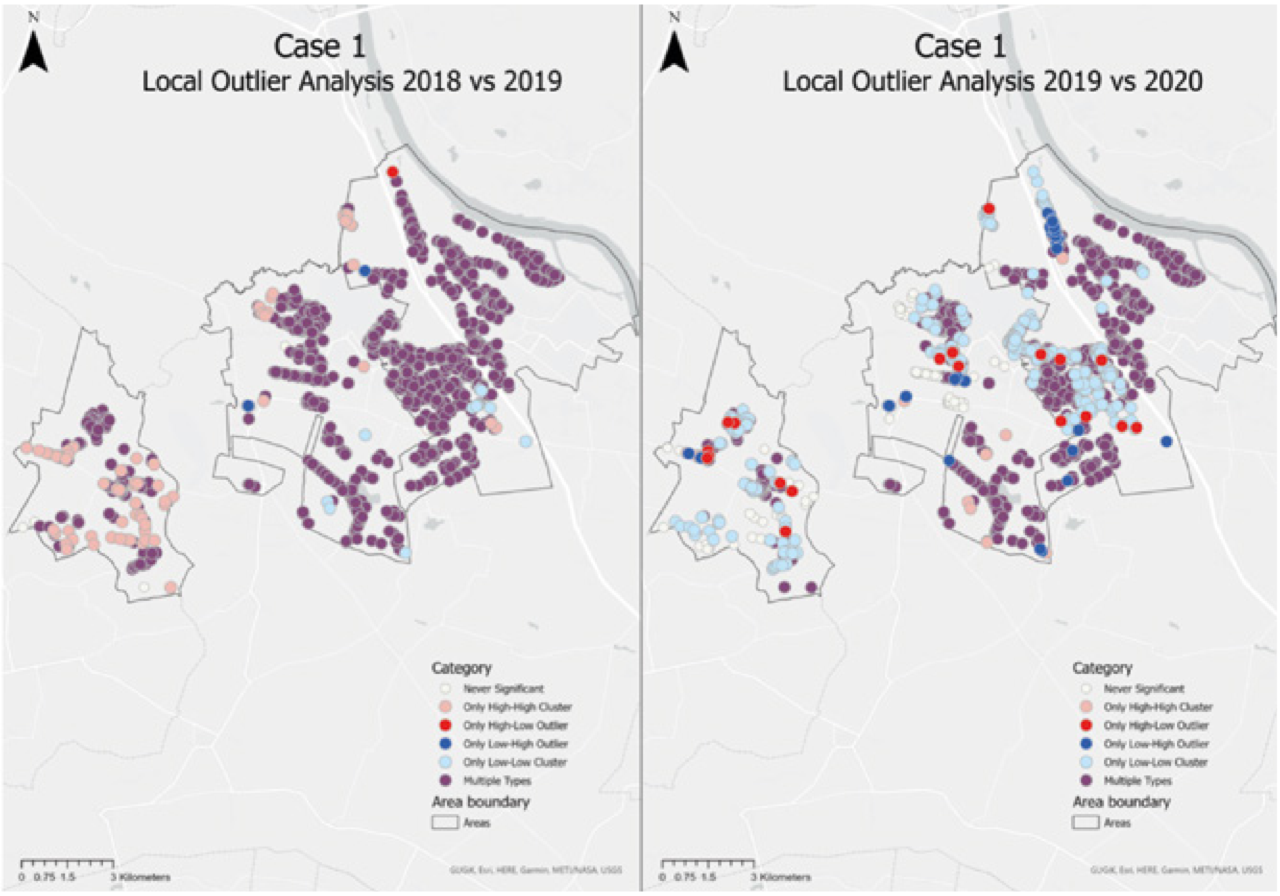

Fig. 7. Local Outlier Analysis results compared for both periods for Case 1

Rys.7. Wyniki analizy lokalnych wartości odstających porównane dla obu okresów dla przypadku 1

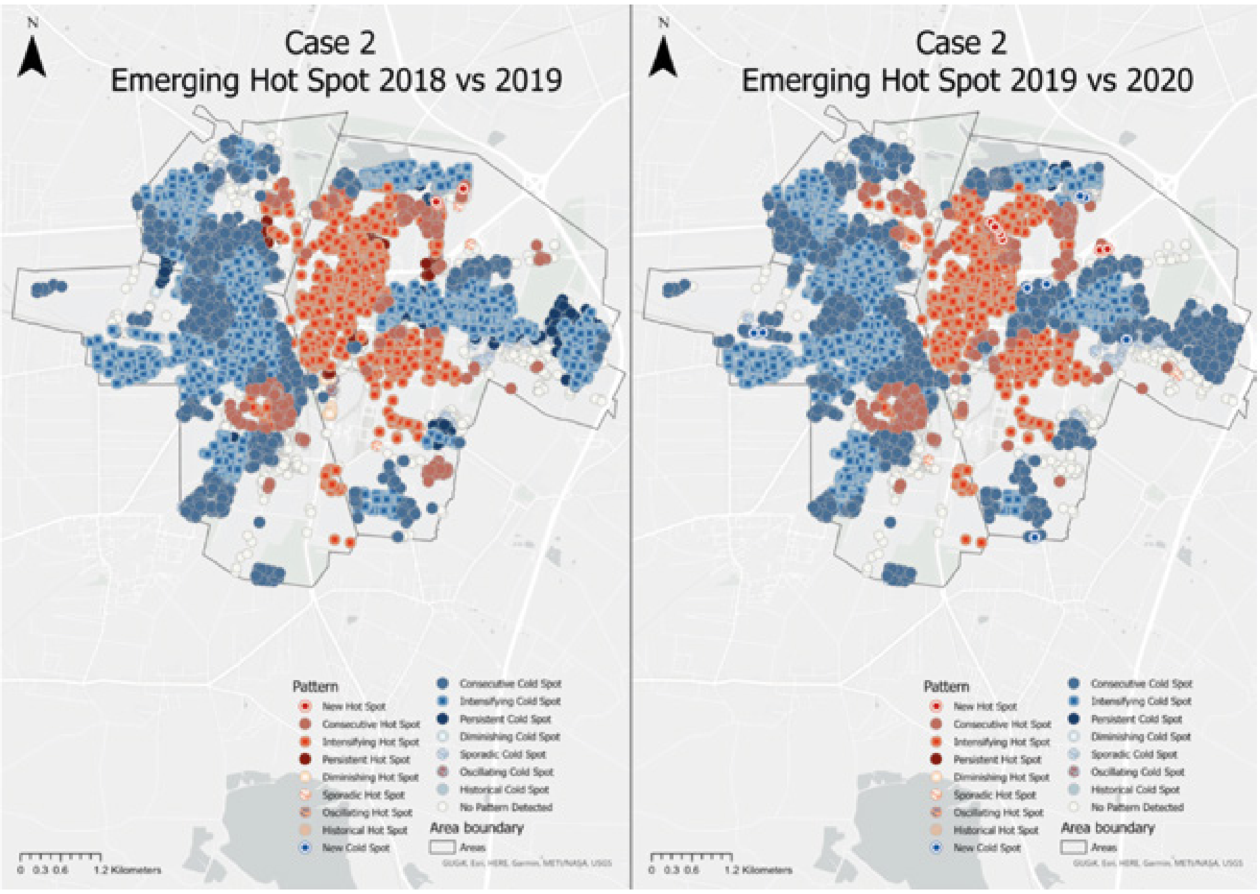

Fig. 8. Emerging Hot Spot results compared for both periods for Case 2

Rys. 8. Porównanie wyników Emerging Hot Spot dla obu okresów dla przypadku 2

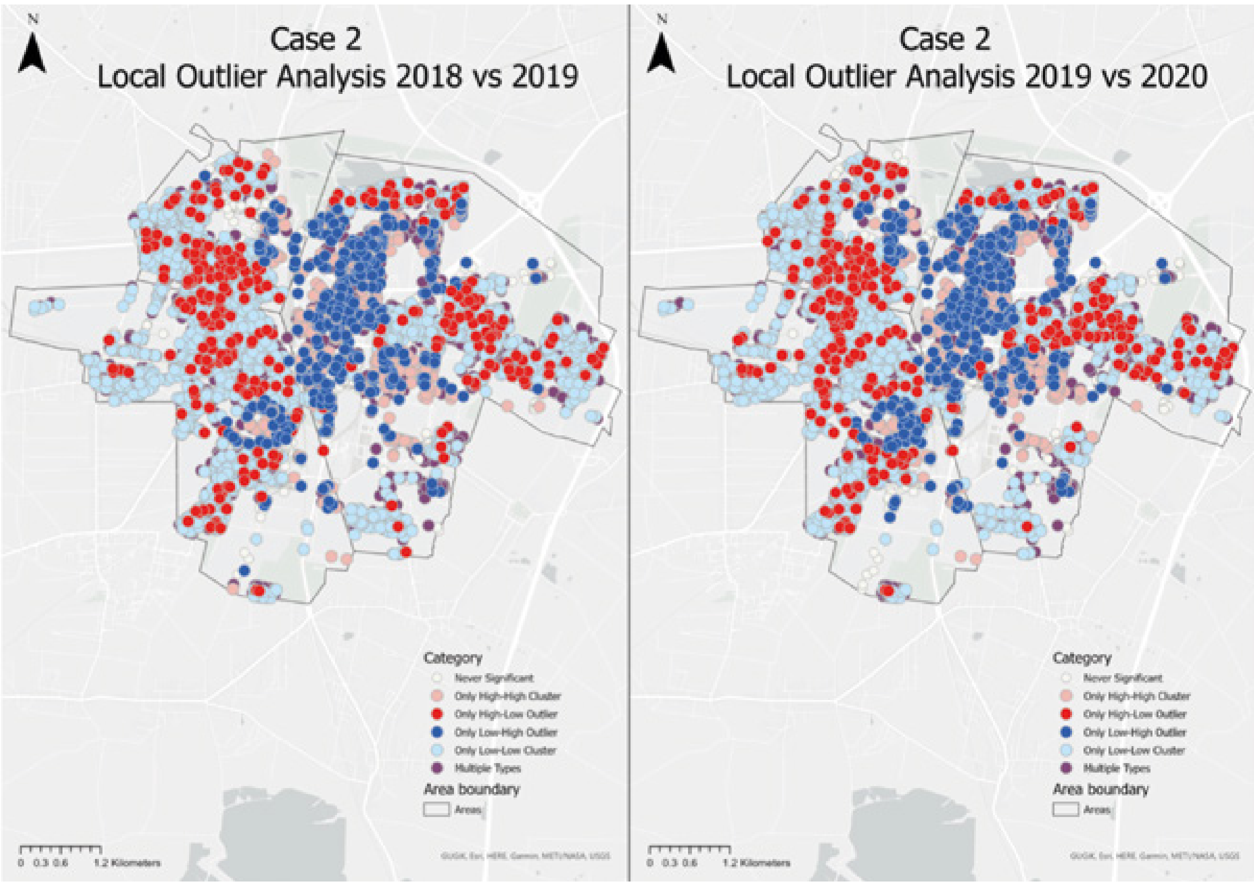

Fig. 9 Local Outlier Analysis results compared for both periods for Case 2

Rys. 9 Porównanie wyników analizy lokalnych wartości odstających dla obu okresów dla przypadku 2

Based on the Fig. 7 it is possible to notice a change in the categories of appearing clusters from High-High to Low-Low which suggests a trend reversal in the water demand. The Low-Low category, which itself is scattered across the entire area of 2019/2020, indicates that this bin reported smaller values than those in its neighbourhood. This indicates a reduction in water demand in many areas of the analysed network. The appearance of the largest number of areas with reduced demand (Low-Low Cluster) was observed particularly in the central part of the analyzed area.

The Emergency Hot Spot analysis for the Case 2 presents, in the Fig. 8 a phenomenon trend that is similar for both of the analysed time periods. The visible collection of the Consecutive Cold Spot pattern for the 2019/2020 period suggests an existence of statistically significant lower values during the lockdown period as well.

The Local Outlier analysis for the above example Fig. 9 indicates that the outlier values for both of the considered periods are similar. It might suggests the identical characteristic of the occurring phenomenon in both of the analysed periods.

Analysing Fig. 8 and 9, it can be concluded that for the 2nd case study, no significant trends in the change of the spatial distribution of water demand in the city were observed.

Discussion

Certainly the pandemic situation forced a swift implementation of various innovative solutions in systems and assets management not only in the water and sewage industry, but in many other sectors as well. Majority of them will remain permanently implemented in the area of exploitation methods and they constitute undoubtedly a benefit, given other negative consequences of this event. Several key activities need to be mentioned here:

- expansion of the visualisation systems that enable remote cooperation of different operators and managers and, based on that, taking key decisions in the ways of pressure and flow management within serviced network,
- retrofitting equipment in the direction of automation, sending and collecting data, electronic documents circulation (especially observed within small businesses),
- retrofitting equipment in the direction of automation, sending and collecting data, electronic documents circulation (especially observed within small businesses),

Based on the analysis done for the two cases of WDS's, differing in size, supplying water to agglomerations it is worth noting what an important factor here is accessing the data via GIS systems, in general as tools with rich functionalities, which can be easily utilised in atypical situations, not only during pandemic but also in all events of disasters, intentional attacks and dangers [13, 17].

The analysis of the results showed that:

- Significant changes were observed in rural areas (Case 1) in terms of the size of demand changes and their location (changes in the volume of withdrawals and the characteristics of their irregularity). This was confirmed by the company. During the lockdown, the company had to change the methods of network control (switching of valves).
- In case 2, changes in water supply during the periods 2018-2019 and 2019-2020 did not significantly affect the spatial distribution of water demand values. This indicates, as also confirmed by conversations with companies, that there were no need to change approach to water supply management.

Conclusions

The paper presents a detailed analysis of two cases of changes in spatial distribution of water demand, which forms a basis for further studies of the impact of COVID-19 on water and sewage industry in Poland. The presented results acquired using GIS sorftware, which include ability to reference every single consumption point on the map, showed key changes in the way the analysed areas of varied characteristics function.

Based on the case study results obtained, the following is concluded:

- Methods such as Emerging Hot Spot, Space Time Cube, Esri, Space Time Pattern can be applied for the purpose of analyzing changes in water demand. The analysis showed that in the case of Case 1 (rural area), there were significant changes in the spatial distribution of water demand. For Case 2 (urban area), no major changes in water demand were observed. The results of the analysis were consulted with companies. This was confirmed by conducting an additional interview with the employees of the companies. In the rural enterprise (Case 1), interventions (changes in valve statuses) were required in the network to ensure its proper functioning. In the case of the urban area (Case 2), no significant changes or problems with network management were observed.
- The results of the analysis done indicate that the patterns of behaviour and ways of functioning of each of the consumer group, constitute one of the dominating factors determining water demand for the household purposes. Certainly the still ongoing pandemic phenomenon should reflect on the complex processes of predictions and prognosis of changes in water demand values in a long term scale (over a dozen years).
- The main aspect that needs to be noticed is the completeness and quality of the acquired data. The assessment of changes and observations should contain full range of data from a given period. This accelerates the analytical process itself and moreover the obtained results better reflect the existing phenomena while the data is not burdened by errors from e.g. averaging values.
- This work is a first attempt to spatially characterise the data collected through traditional billing systems. In this publication, apart from the analytical properties, a spatial side of the collected data was presented, which models the end recipients. The entire process could be simplified and serve for better monitoring if the data collected from local water utilities in the databases was integrated with the GIS system. Such integration would force a unified structure and implementation of data quality control procedures from the GIS system level.
- Based on the analysis, there is certainly a need for reinforcement of financial support and cooperation between WDS's and scientific institutions. It would enable an analysis and research of many WDS's across the country in regards to unusual situations i.e. rise in diseases, restrictions and limitations on water usage.
- The pandemic situation, especially the first wave, was related to a great burden of administrative and organisational changes within the water and sewage industry in Poland and beyond. The data collection methods and difficulties related to geolocation of water meters made the research difficult. The support of scientific institutions as well as the diagnosis and understanding of this dynamic is a very important element, if the water sector – both the utilities as well as the governments – want to plan a more balanced future in water resource planning in a given country.
- The condition for the optimal use of the proposed assessment method of the demand changes is a unified and geocoded water supply points system with values from water meters with properly labelled address points on the map. The need for constant data update in the context of occurring changes (i.e. recipients cut-off, new connections, regular need for device replacement, damage and problems related to data collection methods) constitutes key aspect in the reliability assessment of the obtained analysis results.

Future work on further improvement of the proposed method includes:

- Research and comparison of consumed water changes in garden (sub-meters) and main water meters in the single family households with recreational plot,
- Expansion of research into settlement units which noted a decrease in water usage of 30-40\% and which have strictly tourist characteristic (seaside, mountainous) but which were not analysed in this study,
- Study of changes in the management of pressure and flow in the network, integrated with the hydraulic model in the context of possibly using the aforementioned tools to asses changes in the management of the analysed waterworks systems,
- Research into demand on a multi year scale based on data collected over the period of more than a dozen of years or determination of periodic water demand based on data collected over shorter intervals. Applied Space Time Cube methodology allows for using data with a daily, weekly time step if available.

In general it is worth mentioning that the pandemic situation causes still many changes which affect not only the water supply sector but also sewage and rainfall management and therefore the changes in quality of natural water sources. Such a rapid growth in disinfectants usage (detergents), number of single use packaging, personal protection equipment is not without an impact. The currently undertaken research within this area, by many groups, makes for a very important subject in the context of natural resource managements in a nearest future all around the world.

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Data Availability Statement: Some or all data, models, or code generated or used during the study are proprietary or confidential in nature and may only be provided with restrictions. Location data points – anonymised. Emerging Hot Spot and Local Outlier analysis results for both cases – available as a Figure, raw data not available.\\

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