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THE IMPACT OF TEMPERATURE ANOMALIES ON SUDDEN INCREASE IN WATER PRODUCTION AND CONSUMPTION

The paper presents the influence of weather conditions on water consumption in two selected water-pipe networks. The analyzed problem seems to be significant because even several days with extremely high temperatures cause exploitation difficulties in the distribution system due to water consumption exceeding the average. Water companies should be prepared for complications in exploitation when even whole water from reservoirs is supplied to the network. The obtained results show that a high correlation between anomalies in temperatures and water consumption exists, especially during weekends. The Pearson coefficient varied between 0.76 and 0.88 which means that the temperature has a significant influence on water demand. The aim of the work was also to note that reasonable usage of tap water by individual consumers can influence the security of water distribution. On days when extremely high external air temperatures are forecasted, water consumption for non-essential purposes, such as watering gardens or filling backyard pools, should be limited.

1. INTRODUCTION

Water production at treatment plants and its consumption have been regulated at almost constant levels for years. This results from the stabilized water economy in settlement units and a rational approach to the use of water for domestic, service, and production purposes [1–4]. However, unforeseen situations occurring independently of the operators of water supply systems impact the uncontrolled increase in water demand and consequently the increase in its production. In such situations, it is crucial to manage the distribution system in a way that increased water consumption does not threaten the continuity of water supply to all recipients, including not only individuals but also service and production facilities, as well as strategic locations like hospitals.

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Not all operational situations can be predicted, planned, and modeled, e.g., atmospheric conditions, characterized as a random variable, are one of the factors that affect the need to change the approach of managing water and sewerage systems. Climate changes, affecting human behavior, are noticeable in many sectors of the economy, including the municipal sector. The problem concerns not only warm climate regions [5], where the average annual temperature is around 10 °C higher [6] than in Wrocław [7], but also many other places worldwide. Already over 20 years ago [8], attention was paid to the fact that in the Mediterranean basin, as well as in other regions with low water resources, problems with water supply might arise shortly. Even a small and initially unnoticed increase in external temperature and a decrease in precipitation affect the disruption of the hydrological cycle and the decrease in available resources also due to variability in water consumption by recipients. Research conducted in both Poland and the Czech Republic indicates that these factors also influence the entire hemisphere [9–12].

The trend of cold domestic water consumption is correlated with the increase in air temperature, while the opposite trend can be observed in the case of hot domestic water consumption, which seems obvious from the perspective of the needs and functioning of water recipients [13]. Due to the dynamics of development, technological changes, and unforeseen events worldwide, short-term forecasting [14, 15] regarding water consumption variability is more reasonable than prognosis in the perspective of several decades [16], as evidenced by the example of the total decrease in water consumption for national economy and population needs in Poland by about 20% in 2020 compared to 2010 [17].

Due to the epidemic situation and the influx of population caused by the war, anomalies can be observed compared to years when water production was considered typical and stabilized. Not only in Poland we can observe a changed structure of water consumption in residential and hospital buildings [18] due to lockdown. However, the epidemic situation lasted a relatively short time compared to global climate changes affecting the sudden appearance of several-day weather anomalies (rapid increases in external temperature), which are significant for the safety of functioning of settlement units in the context of rapid depletion of water reserves accumulated by water companies. Especially in small municipalities, this is a problem because the adaptation of the infrastructure of the entire water supply system does not always keep up with relatively quick changes in external conditions. Currently, analysis and simulation of the amount of water accumulated in reservoirs in the case of failure are rather carried out [19], while adjusting water production and storage during the occurrence of extreme weather conditions is in its initial stage in Poland. In this aspect, a solution (beneficial from the financial point of view of municipal water companies) based on short-term contracts for water supply in the event of problems with locally depleted water reserves has been proposed [20]. At the country level, divided into provinces [7], a difference in water consumption per capita is noticeable but it is more related to the role played by a given region than slightly different climatic conditions in, e.g., the so-called cold and warm poles in Poland. For example, in Szczecin, the average unit water consumption can be estimated using the assumption that the average water intake is a random variable with a normal distribution [21]. Whereas in Bydgoszcz, an attempt was made to analyze the unevenness of water consumption by different types of recipients [22]. Therefore, since the proposed topic of changes in water consumption and production in the context of climate changes is extensive, and the research results are correlated with many factors (e.g., location, operation of the water supply system, spatial development structure, technical condition of the network, etc.), it was decided in this study to analyze water consumption in the situation of temperature anomaly and its impact on the volume of water production in two selected municipalities near Wrocław.

In June 2021 and July 2023, a sudden increase in external air temperature was observed in Lower Silesia (Poland). Considering the local conditions, it was even a kind of temperature anomaly, which immediately caused a very rapid increase in water consumption. Due to the needs of the recipients, it was necessary to maximize the use of water from current exploitation and stored in buffer-equalizing reservoirs. In some water supply systems, temporary problems arose in ensuring the continuity of its delivery in the required quantity and under appropriate pressure. If high temperatures had persisted for a longer time, emergencies regarding the process of abstraction, treatment, and distribution of water could have occurred, which would consequently result in a complete interruption of water supply to all recipients for a longer period.

2. CHARACTERISTICS OF WATER SUPPLY SYSTEMS

The impact of above-normal external air temperature on the sudden increase in water consumption was examined in two water supply systems. The first one (SW1) is a collective water supply system in a municipality adjacent to Wrocław. The system is supplied from two sources: its groundwater intake and an external network (MPWiK in Wrocław). The water supply network has a ring-branching structure. The total length of water pipes is approximately 238 km, built of PVC and PE with nominal diameters ranging from 90 to 225 mm. In 2021, the water supply served over 17 000 residents, while in 2023, around 19 000 residents in 13 locations. The overall water consumption pattern is mainly determined by single-family housing and to a lesser extent by multi-family housing, marginally by services and industrial production, while water is not drawn from the water supply for agricultural purposes. The average amount of water supplied into the water network in 2021 was approximately 2950 m^3/day, while in 2023, it increased to around 3255 m^3/day. The maximum daily production capacity of the own treatment plant is 3360 m^3/day, and the possible intake of treated water from an external source (Wrocław water supply network) is around 1500 m^3/day, which together gives around 4860 m^3/day. The total useful capacity of all buffer-equalizing tanks is around 1100 m^3.

The other water supply (SW2) is a small system serving approximately 1150 residents in 6 locations that are part of a municipality in Wrocław County. The number of residents practically did not change from 2021 to 2023. The dominant group of water customers is single-family housing. Services, industrial production, and agriculture constitute a small percentage of the total water demand. The water sources for this system are two groundwater wells. The water is treated in a classic system (aeration, rapid filtration, disinfection). The maximum daily capacity of the water treatment plant is 320 m^3/day. The treated water is directed to a buffer-equalizing tank with a useful capacity of 50 m^3, which is also a suction tank for a pumping station supplying water to the water network. The total length of water pipes is approximately 25 km with nominal diameters ranging from 90 to 160 mm made of PVC and PE. The average daily amounts of water supplied into the water network in 2021 and 2023 were approximately 190 m^3/day.

3. ANALYSIS OF WATER CONSUMPTION IN THE CONSIDERED WATER SUPPLY SYSTEMS

A detailed analysis of water consumption in the two considered water supply systems was conducted on June 17–21, 2021, and July 14–18, 2023 (Figs. 1–4). These periods were chosen for examination because they were characterized by the highest external air temperatures and also included weekends, which is significant in terms of the quantity and hourly distribution of water consumption by residents.

In system SW1, the highest water consumptions were observed on June 18, 2021 (Friday, 32.5 T = °C, Fig. 1), and on July 15, 2023 (Saturday, T = 34.4 °C, Fig. 2), at 5820 and 5560 m^3/day, respectively. Assuming that the maximum amount of water that could be obtained from exploited water sources is around 4860 m^3/day, the difference compared to water consumption had to be supplemented with water stored in buffer-equalizing tanks: on June 18, 2021 960 m^3/day and on July 15, 2023 700 m^3/day. The total useful capacity of these tanks is around 1100 m^3. If such large water withdrawals occurred only on one day, system SW1 would be able to supply all its consumers. However, increased water demand was also observed in the following days. As a consequence, there was insufficient replenishment of treated water from the buffer-equalizing tanks and a reduction in their available capacity for usage. Continuance of such an operational state for a longer period (over subsequent days) could lead to the total insufficiency of the considered water supply system. Therefore, long-term weather forecasts (even for over several years) could serve as a basis for short-term water consumption forecasting, as well as for the modernization and expansion of the water supply system, so that the operator can ensure the required amount of water to consumers during periods of weather anomalies.

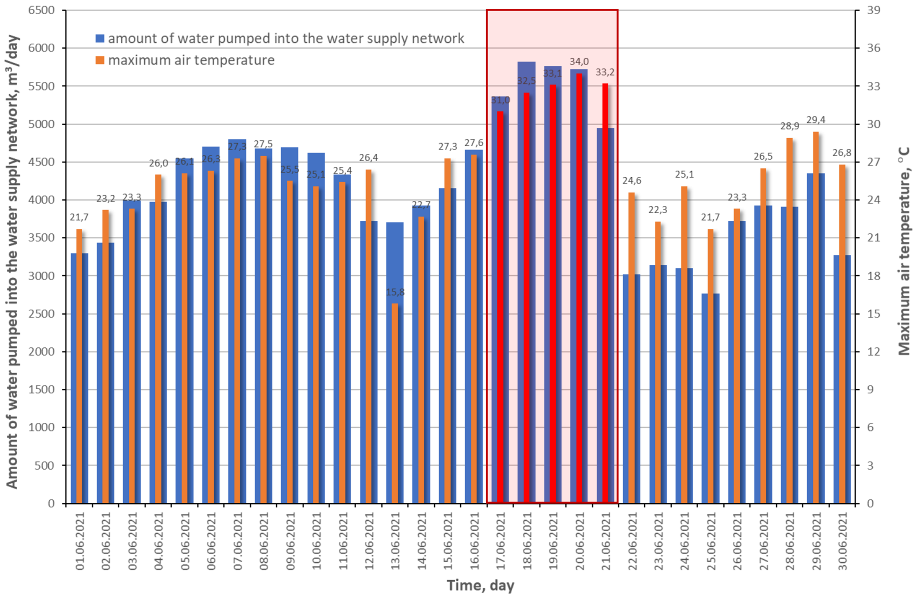

Fig. 1. Daily histogram of water pumped into the water supply network and maximum air temperature in the area of the SW1 water supply system in June 2021

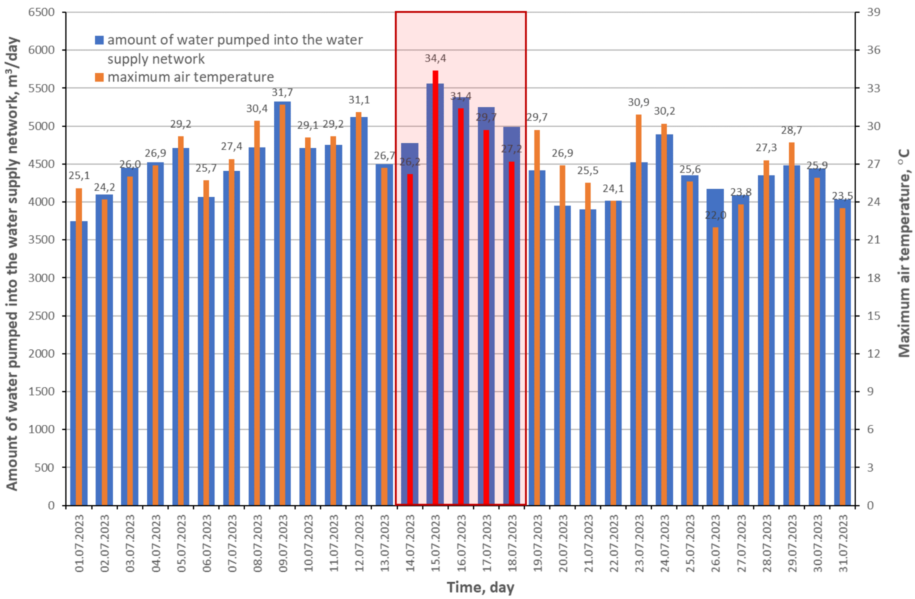

Fig. 2. Daily histogram of water pumped into the water supply network and maximum air temperature in the area of the SW1 water supply system in July 2023

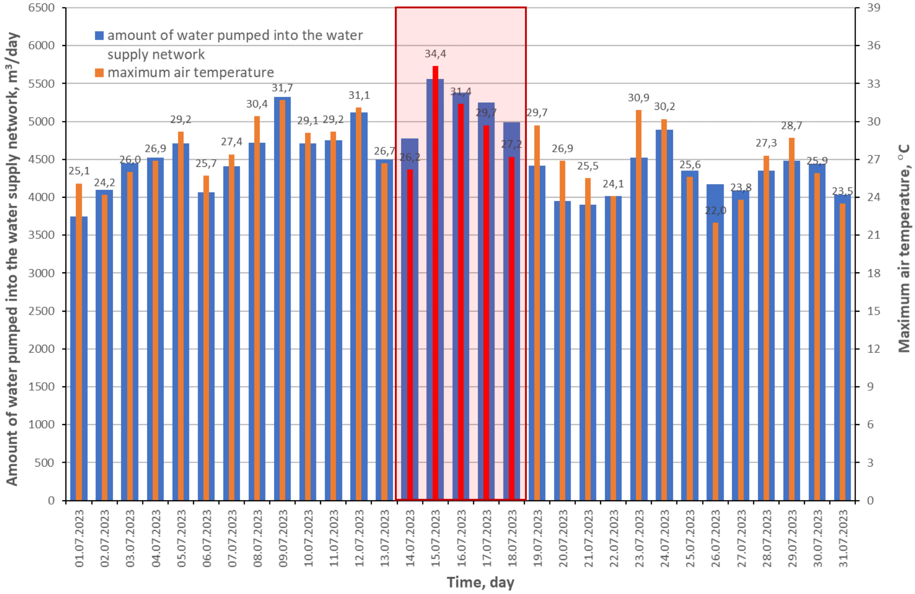

Fig. 3. Daily histogram of water pumped into the water supply network and maximum air temperature in the area of the SW2 water supply system in June 2021

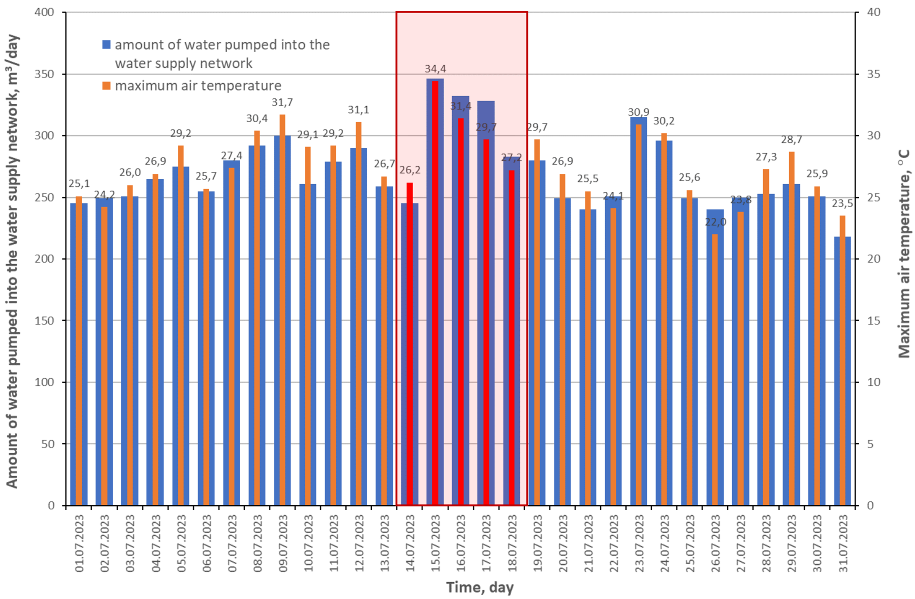

Fig. 4. Daily histogram of water pumped into the water supply network and maximum air temperature in the area of the SW2 water supply system in July 2023

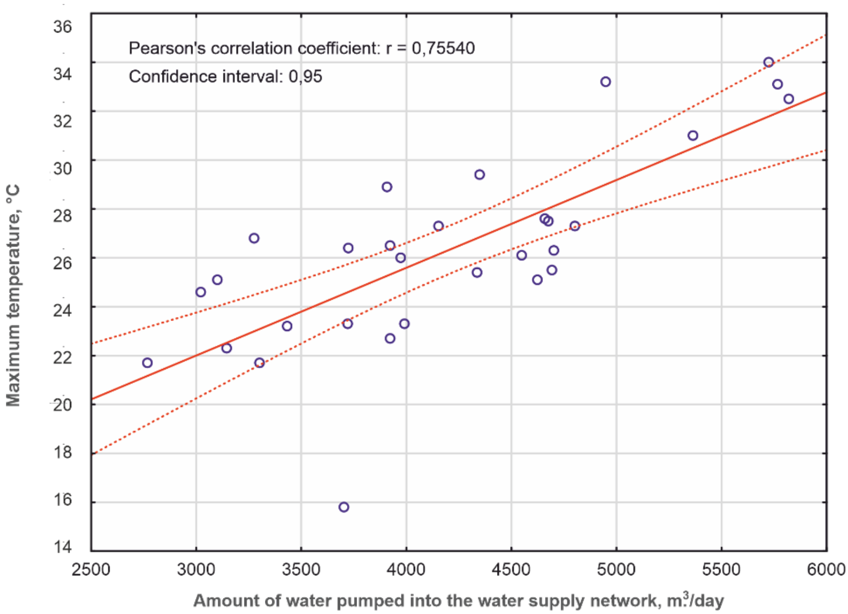

Fig. 5. Statistical analysis of the relationship between the amount of water pumped into the water supply network and the maximum air temperature in the area of the SW1 water supply system in June 2021

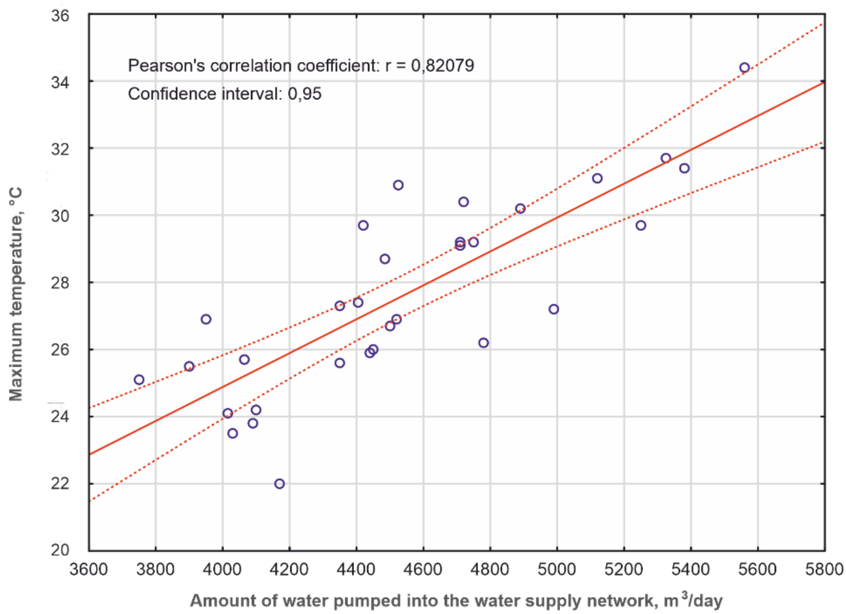

Fig. 6. Statistical analysis of the relationship between the amount of water pumped into the water supply network and the maximum air temperature in the area of the SW1 water supply system in July 2023

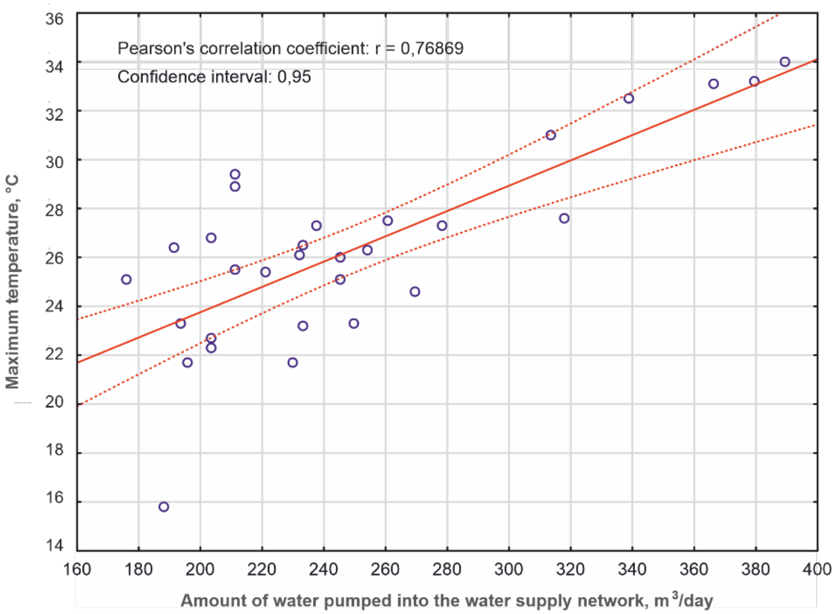

Fig. 7. Statistical analysis of the relationship between the amount of water pumped into the water supply network and the maximum air temperature in the area of the SW2 water supply system in June 2021

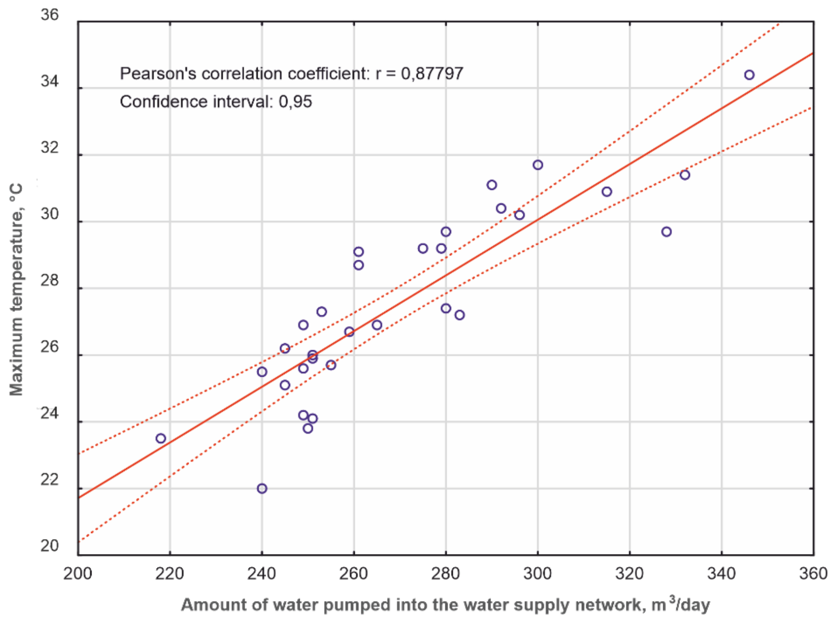

Fig. 8. Statistical analysis of the relationship between the amount of water pumped into the water supply network and the maximum air temperature in the area of the SW2 water supply system in July 2023

In system SW2, the highest water intake occurred on June 20, 2021 (Sunday, $T = 34.0$ °C, Fig. 3), and on July 15, 2023 (Saturday, $T = 34.4$ °C, Fig. 4), at 389 and 346 m^3/day, respectively. The maximum production capacity of the exploited water treatment plant is 320 m^3/day, therefore, on the first considered day, additional water supply had to be extracted from the buffer-equalizing tank (useful capacity 50 m^3) at 69 m^3/day, and on the second day at 26 m^3/day. Similarly to the SW1 system, in the analyzed SW2 system, due to the large water withdrawals sustained during the considered period, the total replenishment of the useful capacity in the buffer-equalizing tank was impossible. On June 20, 2021, the water intake exceeded the operational capabilities of the system considered. The maximum amount of water that could be supplied into the water network was 370 m^3/day. Therefore, a certain amount of water stored in the buffer-equalizing tank for fire-fighting purposes was depleted, which should not occur over a longer period of time due to the need to maintain adequate fire safety conditions.

The impact of external air temperature on the water consumption in the water supply is a widely known relationship. For example, Dimkić [23] demonstrated a strong correlation between the amount of water consumed and air temperature (especially in the spring-summer period) in Serbia (Belgrade, Niš). Similarly, Rasifaghihi et al. [16] showed that in Montreal, Canada, seasonal water consumption depended on the minimum and maximum recorded air temperature as well as on daily total precipitation. Praskievicz and Chang [24] found that average daily and maximum daily air temperatures in Seoul were highly correlated with the amount of water taken by consumers.

The statistical analysis of the relationship between the amount of water supplied into the water network and the maximum external air temperature around the considered water supply systems near Wrocław indicated a high correlation between the parameters under study (Figs. 5–8), thus confirming the hypothesis put forward by other researchers. The calculated Pearson linear correlation coefficients ranged from 0.76 to 0.88 for the accepted confidence intervals at the 0.95 level. In further statistical research, an analysis of precipitation could be conducted, which, if properly collected, may constitute an alternative, for example, for watering gardens, thereby affecting lower water consumption from the water network. Additionally, further in-depth statistical analysis, using advanced mathematical tools, would allow identifying boundary conditions and trends in changes in both random variables, namely weather conditions and water production, which are influenced not only by the intake by users of the water supply network but also by the overall hydrological state of a given watershed.

The quality of water and its possible stagnation or sudden intake during periods of extreme temperatures should be considered, affecting the flushing of accumulated sediments inside pipes, and being related to the material from which they were made [25]. Therefore, the research conducted, and statistical analyses introduce further considerations regarding the dynamics of the situation, as it appears (based on the simple examples presented) that we are dealing with a stabilized water economy in Poland.

4. SUMMARY

Water supply systems are part of critical infrastructure, having a measurable impact on all sectors of the economy. The functions that a water supply system must fulfill, as well as its complexity, necessitate operation in such a way that all components of the system work as reliable as possible with the lowest financial outlay. However, cost minimization cannot lead to increased risk of water supply disruption because the task of a well-functioning water supply system is to provide consumers with sufficient quantity, at adequate pressure, and of appropriate quality. Sufficient quantity and required pressure are parameters allowing water to be drawn in the amount needed by the consumer without special conservation efforts and within an acceptable time frame.

The analyses of the water supply systems considered confirm the dependence of water consumption on external air temperature, as evidenced by high Pearson linear correlation coefficients ranging from 0.76 to 0.88. It has been observed that a sudden increase in external air temperature can lead to significant operational problems in water utility companies, especially when they occur on days off (weekends). At that time, water consumption by consumers may exceed the maximum capacities of water sources. Additionally, the operation of water treatment plants at maximum capacity over an extended period can lead to an overload of the technological system and, for example, degradation of water intake wells, resulting in deterioration of the quality of water supplied to consumers or even the inability to deliver it.

It should also be noted that in today's increasing environmental awareness of society, not only the operator of the water supply network is responsible for the proper functioning of the water distribution system. Especially individual consumers on days forecasted for extremely high external air temperatures should limit water consumption for purposes that are not currently essential, such as watering gardens or filling backyard pools. Of course, normal functioning requires water intake from the external network in such quantity as to ensure sanitary and health safety. However, in hot periods, it is possible to refrain from excessive use of water for purposes that are not the primary needs of the consumer. Additionally, a sense of solidarity should be instilled in society. Some individual consumers may not even realize that their increased water consumption (not always for essential needs) may result in decreased pressure or even the cessation of supply in other less favorably (from a hydraulic point of view) located areas of the given water supply system. This fact should be publicized because even minor changes in the way society manages the common good of clean tap water can prevent the occurrence of supply disruption situations and other operational problems.

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