Anna KOCHANEK[1], **Aleksandra BODZIONY**[2]

[1] University of Applied Sciences in Nowy Sącz, Faculty of Engineering Sciences, Zamenhofa 1a, 33-300 Nowy Sącz, e-mail: akochanek@ans-ns.edu.pl
[2] University of Applied Sciences in Nowy Sącz, Faculty of Engineering Sciences, Zamenhofa 1a, 33-300 Nowy Sącz, e-mail: bodziola89@gmail.com

Quantitative and qualitative analysis of water demand for a water supply network

Abstract

The water supply network is an integrated system consisting of technological devices and pipes thanks to which it is possible to transport drinking water from the intake to the recipient. The water supply system under analysis underwent a number of modernisations over a long period of time, which increased the capacity of the water supply network and its water demand. The aim of the study was to make a forecast of water demand in the water supply network in the municipality of Limanowa in the locality of Kłodne, by means of computer research tools in the form of an Excel sheet, and on the basis of source materials obtained from the Water Supply Company.

Based on the findings, a proposal is presented for further modernisation of the water supply system in Kłodne. The research part consists of two stages. The first stage is preparation of a demographic prognosis and forecast of the number of people using the water supply system for the years 2022-2033. The second stage involves developing a forecast of water supply network demand for the years 2022-2033. This prognosis presents daily, monthly and annual demand for water for the above-mentioned localities. The last element of the study is to present a proposal for modernising the water supply system, which is developed on the basis of conclusions resulting from the analyses and forecasts.

Key words: water supply network, prognosis, demand for water.

Analiza ilościowo-jakościowa zapotrzebowania wody dla sieci wodociągowej

Streszczenie

Sieć wodociągowa to zintegrowany system, na który składają się urządzenia technologiczne i przewody dzięki, którym jest możliwy transport wody pitnej z ujęcia do odbiorcy. Analizowany system wodociągowy przez długi okres przechodził szereg modernizacji, które zwiększały wydajność sieci wodociągowej i jej zapotrzebowanie w wodę. Celem badań było przeprowadzenie prognozy zapotrzebowania wody w sieci wodociągowej w gminie Limanowa w miejscowości Kłodne za pomocą informatycznych narzędzi badawczych w postaci *Arkusza Excel*, a także na podstawie materiałów źródłowych pozyskanych w Spółce Wodociągowej.

Na podstawie ustalonych wniosków została przedstawiona także propozycja dalszych modernizacji sieci wodociągowej w miejscowości Kłodne. Część badawcza składa się z dwóch etapów. Pierwszym etapem jest opracowanie prognozy demograficznej i prognozy liczby osób korzystających z sieci wodociągowej na lata 2022-2033. Drugim etapem jest z kolei opracowanie prognozy zapotrzebowania wody pitnej na lata 2022-2033. Prognoza ta przedstawia dzienne, miesięczne i roczne zapotrzebowanie na wodę dla ww. miejscowości. Ostatnim elementem pracy jest przedstawienie propozycji modernizacji sieci wodociągowej, która opracowana jest na podstawie wniosków wynikających z opracowanych analiz oraz prognoz.

Słowa kluczowe: sieć wodociągowa, prognoza, zapotrzebowanie na wodę.

1. Introduction

According to Borkowski (2014), 71% of groundwater as well as 29% of surface water is used in the intake of drinking water depending on its use. Depending on the origin of the water, a range of equipment and machinery, adapted to the site or the amount of water to be captured, is used to extract the water. Drilled or dug wells are used for groundwater extraction. On the other hand, a damming weir or dams are used to capture surface water. In the next stage, according to Anielak (2015), the captured water is subjected to various purification and treatment processes depending on its parameters and subsequent use. The captured surface or groundwater is most often treated for elements such as manganese, lead, iron or arsenic. The final stage is the transport of the water. According to Grabarczyk (2017), water is transported by gravity or by pump. During the water supply, the pressure should be maintained at an appropriate level. All the stages described above are linked to the water supply system. This system consists of process equipment and buildings, which in effect is called a water supply system. This system serves to collectively and continuously supply drinking water to the user.

2. Purpose and scope

The aim of this study is to develop a drinking water demand forecast for the years 2022-2033 in the municipality of Limanowa for the village of Kłodne. The research tools used to carry out the study were the *Excel Calculation Sheet – Forecast Sheet*. The research part consists of two stages. The first stage is the development of a demographic forecast of the locality and a forecast of the number of people using the water supply network for the years 2022-2033. The second stage is the development of a drinking water demand forecast for the years 2022-2033. This forecast presents the daily, monthly and annual water demand for the analysed district. The final element of the work is the presentation of a proposal for the modernisation of the water supply network, which is developed on the basis of the conclusions resulting from the analyses and forecasts carried out. Forecasts were made based on source data obtained from the Water Supply Company in Kłodne.

3. Description of the research facility

The analysed water supply network belongs to the Water Supply Company of the village of Kłodne in the Limanowa Municipality. On the basis of the Directive of the European Parliament and of the Council, each intake in the Kłodne Water Supply Company is protected, through the Limanowa Municipality's ownership of the extensive plots of land on which the intakes are located. The water supply network consists of 5 water intakes: three shaft wells, one drilled well and one dug well. Figure 1 shows the water supply network in the village of Kłodne.

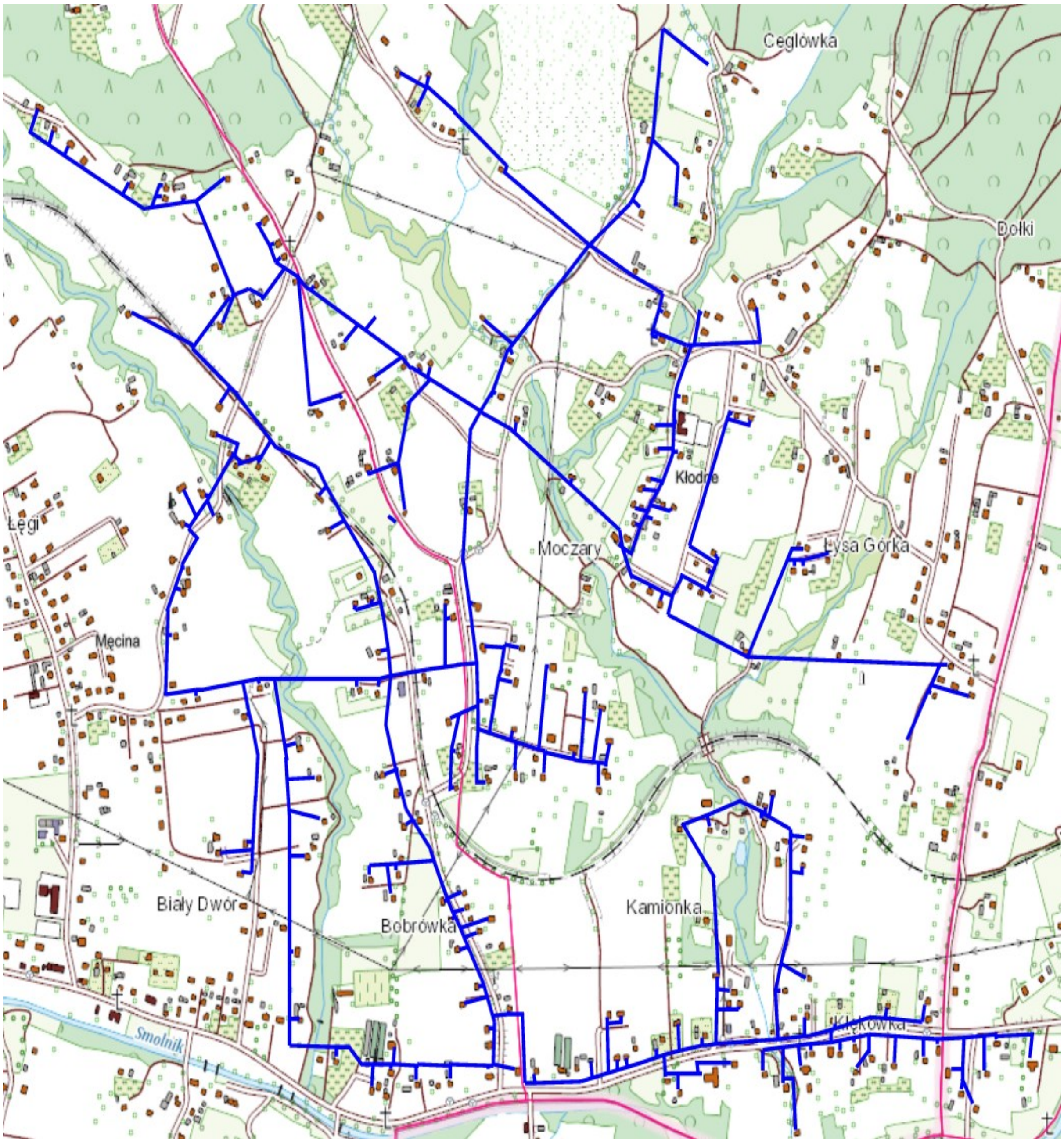

Figure 1. Map of the water supply network in Kłodne, Limanowa municipality
(source: authors' own compilation based on geodetic map from the Limanowa District Office)

The described water supply network counts 257 [pcs of] active water supply connections to buildings and other objects, including 245 [pcs of] water supply connections to residential and collective residence buildings. On the other hand, the length of the active main network measures 1,800 [m] and the length of the distribution network, without connections, measures 14,300 [m]. The water intake is carried out by means of four dug wells and one drilled well. The water abstracted is recorded through metering equipment. Table 1 shows the water intake values for the individual wells.

Table 1
Water intake values for individual wells

Type of well	Water intake $[m^3 \cdot h^{-1}]$	Water intake $[m^3 \cdot d^{-1}]$	Plot number
Three dug wells	6,10	73,78	207/2 i 207/4
One drilled well	3,00	72,00	457/1
One dug well	0,80	18,11	2017/1

(source: authors' own elaboration based on: source data from the Water Supply Company)

The main scheme of the water mains building consists of two rooms. The first room belongs to the water intake, via a bore well. In the second room, the water undergoes a purification process. Subsequently, the purified water is transported, by gravity, to an expansion tank. From the equalisation tank, the water is transferred to a collecting tank, from where it is properly supplied to the collection points via a pipe system. The equipment and apparatus that goes into the described borehole is shown in Figure 2.

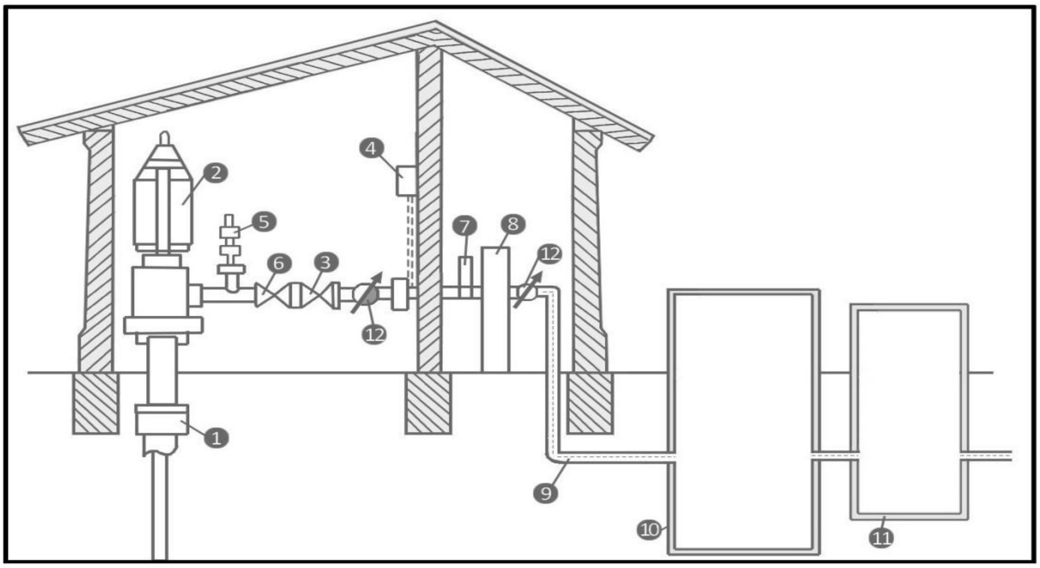

Figure 2. Diagram of the main building of the water supply system in Kłodne, Limanowa municipality
1 – wellhead, 2 – pump motor, 3 – pump valve, 4 – manometer, 5 – vent, 6 – valve flapper, 7 – pressure regulator, 8 – water treatment station, 9 – pipeline, 10 – equalising tank, 11 – tank, 12 – water meter
(source: authors' own elaboration based on: source data from the Water Supply Company)

Further components of the water supply network consist of four dug wells. The water intake runs through the side wall of the wells, where the bottom of the well is sealed and contains a filter made of a layer of gravel. The four wells described form an unstructured well assembly. The complex consists of four mounded wells, three equalisation tanks, and one collection tank (Knapik, 2010).

4. Forecast of changes in population demographics in Kłodne, Limanowa municipality

The projection of demographic data for the locality is based on the number of inhabitants obtained from the *Report on the State of Limanowa Municipality for the respective years 2018, 2019, 2020 and 2021*. The projection was developed using the *Excel* function – *Projection Sheet*. Table 2 shows the results of the forecast based on the *Excel – Forecast Sheet*.

Table 2
Projection of demographics, 2022-2033

Year	Population	Forecast (Population)	Lower confidence limit (Population)	Upper confidence limit (Population)
2018	1063	-	-	-
2019	1059	-	-	-
2020	1065	-	-	-
2021	1055	1055	1055	1055
2022		1055	1048	1062
2023		1053	1047	1060
2024		1051	1045	1058
2025		1049	1043	1056
2026		1047	1041	1054
2027		1045	1039	1052
2028		1043	1037	1050
2029		1041	1035	1048
2030		1039	1033	1046
2031		1037	1031	1044
2032		1035	1029	1042
2033		1033	1027	1040

(source: authors' own elaboration based on data from the Limanowa Municipality Report)

Based on the table above, the projected demographics in 2022 will be 1055, for which the upper confidence limit is 1062 people and the lower confidence limit is 1048 people. The difference between the lower and upper confidence limits will be 14 people. In contrast, in 2033, the projected demographics are 1033 inhabitants. Meanwhile, the upper confidence limit is 1,040 people and the lower confidence limit is 1,027 people. The difference between the lower and upper confidence limits will be 13 people. The projection of demographics between 2022 and 2033 is downward. The population from 2022 to 2033 will decrease by 22 inhabitants. To better illustrate the range of the upper and lower confidence limits of the demographic data projection, a graph has been produced and is shown in Figure 3.

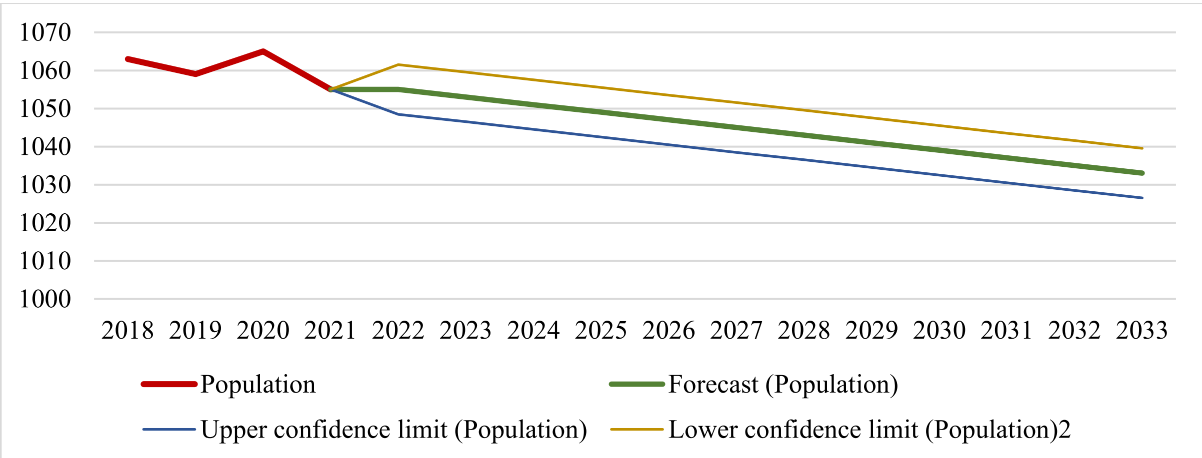

Figure 3. Forecast and lower and upper confidence limits of the demographics of the village of Kłodne, Limanowa municipality for the period 2022-2033

5. Drinking water demand forecast, for 2022-2033

The drinking water demand forecast was developed based on the conducted demographic data forecast of the village of Kłodne, Limanowa municipality and on the data acquired from 2018-2021. The first stage is to conduct a forecast of the number of people using the water supply network. The second stage, on the other hand, is to calculate the water demand for the individual years 2022-2033.

The forecast of the number of people using the water supply system is based on the data for the number of people using the water supply system for 2018-2021, acquired from the Water Company. This forecast was developed using the *Excel – Forecast Worksheet*. Table 3 shows the results of the forecast of the number of people using the water supply network for the period 2021-2030.

Table 3

Forecast and upper and lower confidence limits for the number of people using the water supply network in Kłodne, Limanowa municipality for the years 2022-2033

Year	Population	Number of people using the water supply network	Forecast (Number of people using the water supply network)	Lower confidence limit (Number of people using the water supply network)	Upper confidence limit (Number of people using the water supply network)
2018	1063	980	-	-	-
2019	1059	983	-	-	-
2020	1065	989	-	-	-
2021	1055	990	990	990	990
2022	1055		994	992	996
2023	1053		998	996	1000
2024	1051		1001	999	1003
2025	1049		1005	1003	1007
2026	1047		1008	1006	1010
2027	1045		1012	1010	1014
2028	1043		1015	1013	1017
2029	1041		1019	1017	1021
2030	1039		1022	1020	1024
2031	1037		1026	1024	1028
2032	1035		1030	1027	1032
2033	1033		1033	1031	1035

(source: authors' own elaboration based on data from the Limanowa Municipality Report)

Lower and upper confidence limits were also calculated for the forecast of people using the water supply network in Kłodne, Limanowa municipality, which is shown in the table above. The forecast of people using the water supply network in 2022 will be 994 people, for which the upper confidence limit is 996 people and the lower confidence limit is 992 people. This means that the difference between the lower and upper confidence limits is 4 people. By contrast, in 2033 the projection is 1,033 people, for which the upper confidence limit is 1,035 people and the lower confidence limit is 1,031 people. This means that the difference between the lower and upper confidence limits, in 2030, is 4 people. The lower confidence limit, as well as the upper confidence limit, are characterised by increasing values. To better illustrate the range of the upper and lower confidence limits of the projection of people using the water supply network, a graph has been drawn up and is shown in Figure 4.

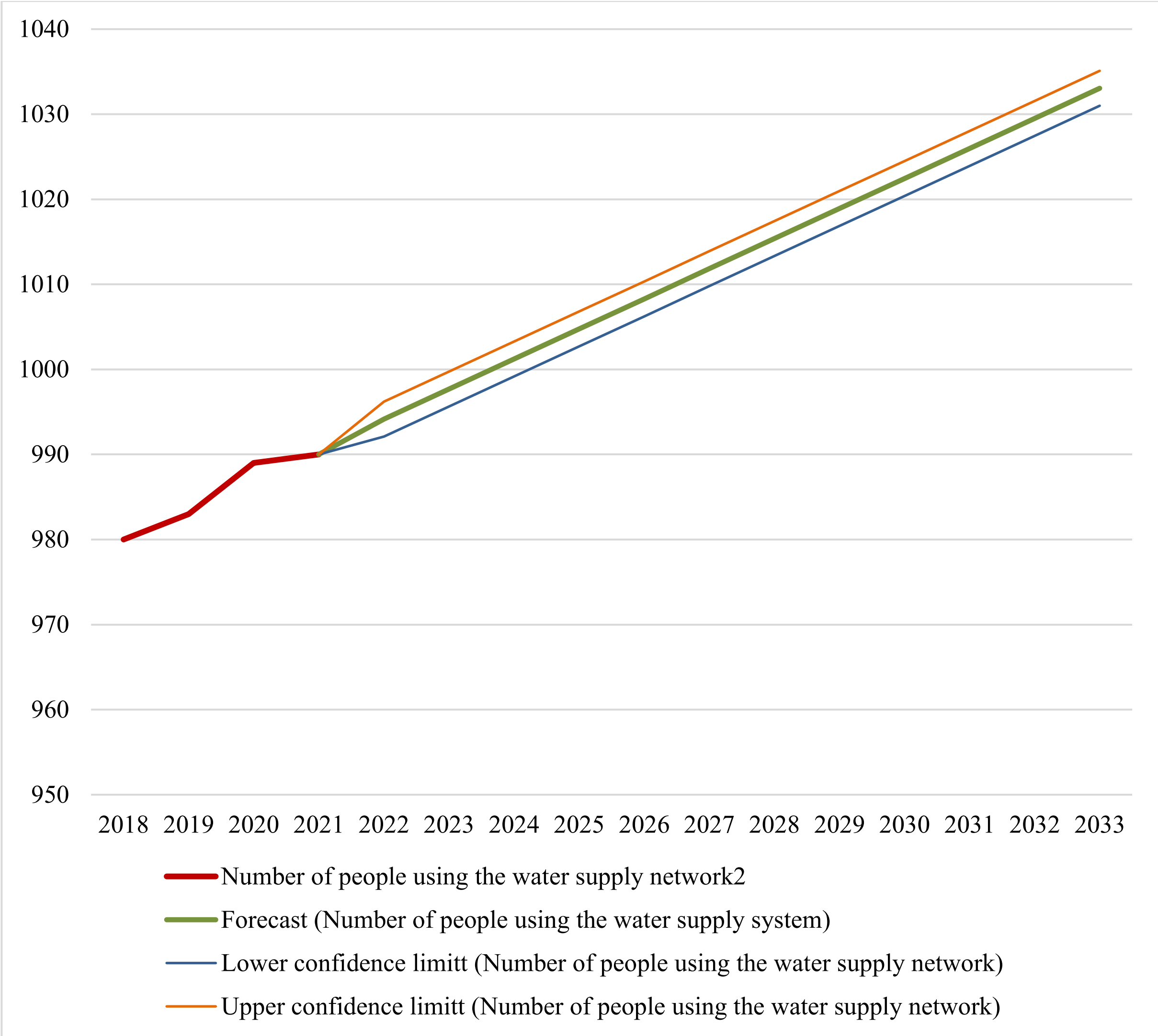

Figure 4. Forecast and upper and lower confidence limits of the number of people using water supply networks for 2022-2033

(source: authors' own elaboration based on: Table 3)

The second stage of developing the drinking water demand forecast involves calculating the average daily water demand, maximum daily water demand, maximum hourly water demand and annual water demand, for the individual years 2022-2033. Individual assumptions have been made to calculate the values listed:

- M – number of people using the water supply system – adopted according to the projected number of people using the water supply system for 2021-2030 (Table 2);
- q_j – unit water demand – 0,14 [m^3per inhabitant per day]. The value was selected on the basis of the Infrastructure Ordinance – average consumption standards and the Act on collective water supply and collective sewage disposal;
- N_d – daily irregularity coefficient – 1.5 [-]. The value was selected based on Table 4 below;
- N_h – hourly irregularity coefficient – 2.5 [-]. The value was selected based on Table 4 below (Kwietniewski, 2009).

Table 4
Coefficient of irregularity of water consumption in the water supply network

Water customers	**Water consumption irregularity factor**	
	daily $[N_d]$	**hourly** $[N_h]$
Multi-family housing	1,3 – 1,5	1,4 – 1,6
Single-family housing	1,5 – 2,0	2,5 – 3,0
Services	1,3	2,8 – 3,0
Public transport	1,2	4,0

(source: Kwietniewski, Olszewski, Osuch-Pajdzińska, 2009)

The following formulae were then used to calculate the average daily water demand, maximum daily water demand, maximum hourly water demand and annual water demand, for each of the years 2022-2033:

- average daily water demand

$$Q_{drs} = q_j \cdot M \tag{1}$$

where: Q_{drs} – average daily water demand $\left[m^3 \cdot day^{-1}\right]$;
q_j – unit demand per day $\left[m^3 \cdot \text{inhabitant per day}^{-1}\right]$;
M – number of inhabitants [-].

- maximum daily water demand

$$Q_{dmax} = Q_{dsr} \cdot N_d \tag{2}$$

where: Q_{dmax} – maximum daily water demand $\left[m^3 \cdot day^{-1}\right]$;
Q_{drs} – average daily water demand $\left[m^3 \cdot day^{-1}\right]$;
N_d – daily irregularity coefficient [-].

- maximum hourly water demand

$$Q_{hmax} = N_h \cdot \frac{Q_{dmax}}{24} \tag{3}$$

where: Q_{hmax} – maximum hourly water demand $\left[m^3 \cdot h^{-1}\right]$;
N_h – hourly irregularity coefficient [-];
Q_{dmax} – maximum daily water demand $\left[m^3 \cdot doba^{-1}\right]$.

- annual water demand

$$Q_r = Q_{dsr} \cdot 365 \tag{4}$$

where: Q_r – annual water demand $[m^3 \cdot year^{-1}]$;
Q_{drs} – average daily water demand $\left[m^3 \cdot day^{-1}\right]$;
365 – the number of days in a year (Kwietniewski, 2009).

Based on the formulae (1), (2), (3) and (4) described above, individual calculations were made for the water demand, for the years 2022-2033. The results were processed using *Excel*. The calculated values for the individual years are shown in Table 5.

Table 5
Calculated water demand values for 2022-2033 for the village of Kłodne

Assumptions						
q_j $[m^3 \cdot$ inhabitant per $day^{-1}]$			0,14			
N_d [-]			1,5			
N_h [-]			2,5			
Year	**Population**	**M [-]**	**Q_{drs} $[m^3 \cdot day^{-1}]$ (1)**	**Q_{dmax} $[m^3 \cdot day^{-1}]$ (2)**	**Q_{hmax} $[m^3 \cdot h^{-1}]$ (3)**	**Q_r $[m^3 \cdot year^{-1}]$ (4)**
2018	1063	980	137	206	21	50005
2019	1059	983	138	206	22	50370
2020	1065	989	138	208	22	50370
2021	1055	990	139	208	22	50735
2022	1055	994	139	209	22	50735
2023	1053	998	140	210	22	51100
2024	1051	1001	140	210	22	51100
2025	1049	1005	141	211	22	51465
2026	1047	1008	141	212	22	51465
2027	1045	1012	142	212	22	51830
2028	1043	1015	142	213	22	51830
2029	1041	1019	143	214	22	52195
2030	1039	1022	143	215	22	52195
2031	1037	1026	144	215	22	52560
2032	1035	1030	144	216	23	52560
2033	1033	1033	145	217	23	52925

(source: authors' own elaboration based on data from the Limanowa Municipality Report)

The developed projection of drinking water demand, for the period 2022-2033, in Table 5, is of an increasing nature. This means that in the following years 2022-2033 the number of people using the water supply network as well as the demand for water will increase. In 2022, the average daily demand was 139 $[m^3 \cdot day^{-1}]$. By contrast, the maximum daily water demand was 206 $[m^3 \cdot day^{-1}]$. This means that the capacity of the active facilities of the water supply network, which is 164 $[m^3 \cdot day^{-1}]$, is sufficient for the average daily demand until 2033. On the other hand, if the production capacity of the active facilities of the water supply network is compared with the maximum daily water demand, it can be seen that the production capacity of the active facilities is 53 $[m^3 \cdot day^{-1}]$ lower than the maximum daily water demand.

From Table 5, it is noted that the average daily water demand, over the 11 years, ranges from 139 $[m^3 \cdot day^{-1}]$ to 145 $[m^3 \cdot day^{-1}]$. Meanwhile, the maximum daily water demand, over the 11 years, ranges from 206 $[m^3 \cdot day^{-1}]$ to 217 $[m^3 \cdot day^{-1}]$. By contrast, the maximum hourly water demand, in 2021, will be 21 $[m^3 \cdot h^{-1}]$. Meanwhile, in 2033, the maximum hourly water demand will be 23 $[m^3 \cdot h^{-1}]$. The difference between the maximum hourly water demand in 2022 and 2033 will be 2 $[m^3 \cdot h^{-1}]$. By contrast, the annual water demand in 2022 will be 50,005 $[m^3 \cdot year^{-1}]$ and in 2033 the annual water demand will be 52,925 $[m^3 \cdot year^{-1}]$. The difference between the annual water demand in 2022 and 2033 will be 2,920 $[m^3 \cdot year^{-1}]$. Comparing these figures with the source data obtained for 2021, we note that the annual water demand for 2021, which was 50,740 $[m^3 \cdot year^{-1}]$ is close to the calculated annual water demand of 50,735 $[m^3 \cdot year^{-1}]$. The difference between the calculated annual demand and the value obtained from the Water Company is 5 $[m^3 \cdot year^{-1}]$. It should be taken into account from 50 740 $[m^3 \cdot year^{-1}]$ that 700 $[m^3 \cdot year^{-1}]$ are take-offs.

6. Proposal for modernisation of the water supply system in Kłodne, Limanowa municipality

Based on an analysis of the water supply network, a forecast of demographic data in the village of Kłodne, Limanowa municipality, and a forecast of people using the water supply network together with its demand, a proposal for the modernisation of the water supply network was developed. The water supply network requires renovation of the main water main and the distribution water supply network. This is due to its long service life. The main water main is 1800 [m] in length. On the other hand, the distribution water main network, without connections, amounts to 14300 [m] and was created as a branch of the main network, as a result of the extension of the water main network. The described network also needs to be upgraded, but only in individual sections, whose total length of reconstruction is about 5500 [m]. The main trunk mains and the distribution network are shown in Figure 5.

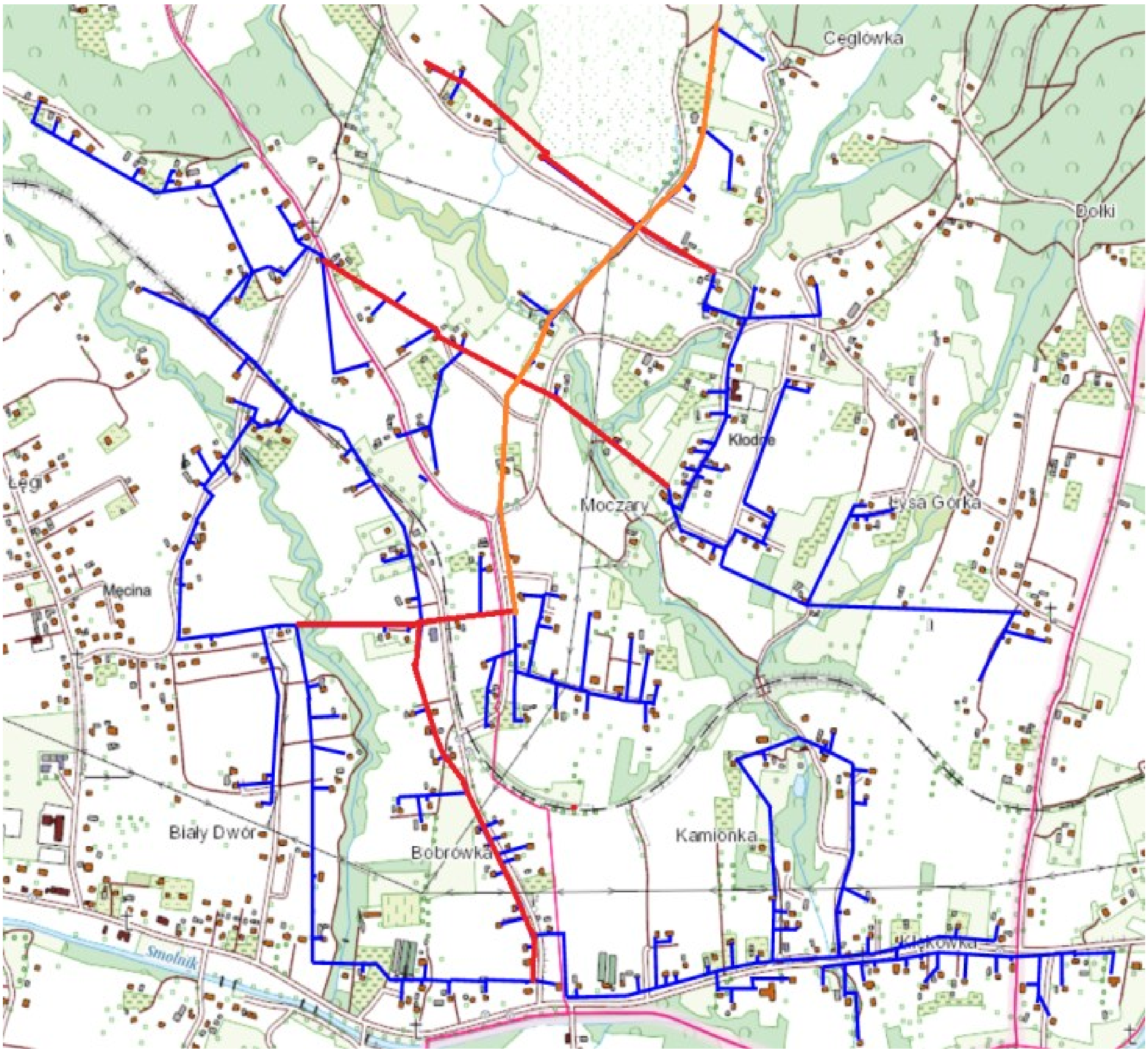

Figure 5. Main trunk line (orange) and distribution network (red) in need of upgrading (source: authors' own elaboration based on data from the Water Supply Company)

The main trunk and distribution network of the water mains consists of PVC pipes and has no protection, so these pipes will be replaced with PE 100 RC pipes. In addition, protection in the form of bipartite steel pipes will be used. The use of protective pipes in the water mains is intended to protect the PE 100 RC pipes from adverse environmental influences. The next stage in the modernisation of the water supply network is the construction of a zone pumping station, in other words, a second-stage pumping station. The water transport in the water supply network is carried out by gravity.

Although the main building of the water supply network and the water intakes are located at the highest point, the water pressure at the various sections of the water supply network is lower than the pressure required in the water supply network. The location of the second stage pumping station is given indicatively in Figure 6, based on the water mains pressures that were made available from the Water Company.

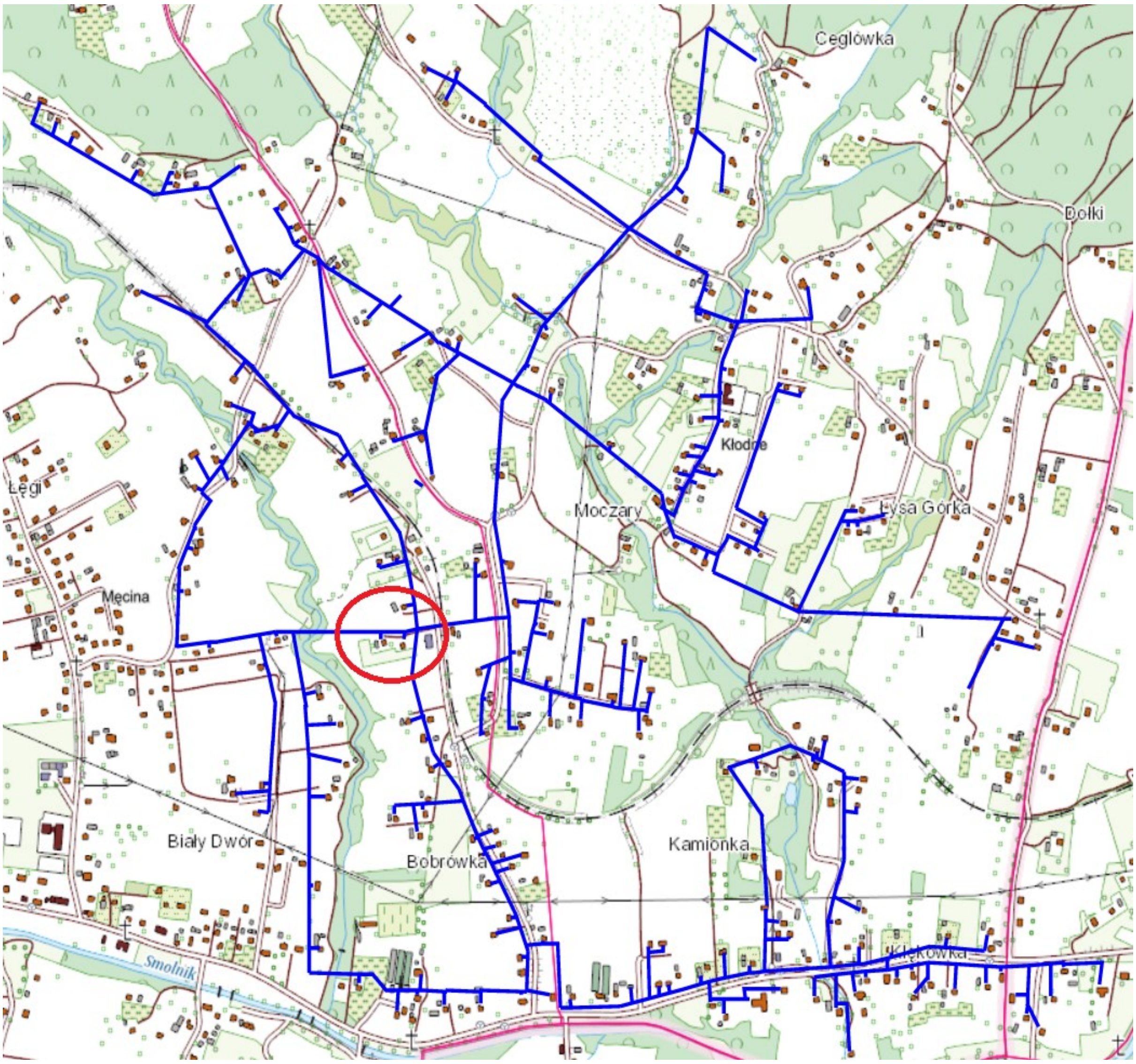

Figure 6. Map with indicative location of the second stage pumping station of the water supply network

(source: authors' own elaboration based on: data from the Water Supply Company)

With a secondary pumping station, it is possible to increase the pressure of the water while it is being transported through the water mains. A secondary pumping station consists of a pumping system and equipment for measuring, controlling, protecting or regulating the pressure and flow of water in the pipes. The pumping station must also have access to an electrical system, as the pumping system must be supplied with electricity. This makes the construction and maintenance of a pumping station expensive. To remedy the high electricity bills, it is recommended that the access to electricity comes from renewable energy sources. Such energy sources can include the construction of a photovoltaic farm to cover electricity requirements.

Another source of energy can be obtained from wind power, through a small vertical wind turbine. Another form of obtaining electricity that will cover the demand of the pumping system is the combination of a photovoltaic farm together with a small vertical wind turbine. The choice of energy source to obtain electricity will depend on the value of the electricity demand and the location of the secondary pumping station.

7. Conclusions

The first method for determining the projected demographics of the village of Kłodne was based on the population numbers from 2018-2022 and the *Forecasting Worksheet – Excel*. This projection is downward in nature, i.e., the number of people living in the village during the 11-year period significantly decreases by 22 people.

In contrast, the second stage involved a forecast of the number of people using the water supply network, which was based on data obtained from the Water Supply Network for the period 2018-2022. The forecast of people using the water supply network is of an increasing nature. This is in contrast to the demographic forecast for the locality. In 2033, the difference between the number of people living in Kłodne and the forecast of people using the water supply network will be 3 people. As a final step, a drinking water demand forecast was carried out based on four formulas for: average daily water demand, maximum daily water demand, maximum hourly water demand and annual water demand. The water demand forecast also has a growth pattern like the forecast of people using the water supply network.

In the final stage of the analysis of the efficiency of use of the water supply network in Kłodne, an example of a water supply network upgrade was developed. The proposed modernisation will be based on the reconstruction of the entire main network with a length of 1800 [m] and a partial reconstruction of the distribution network with a length of 5500 [m]. The reconstruction will consist of replacing unprotected PVC pipes with PE 100 RC pipes with protection in the form of steel bipartite pipes. In addition, another stage in the modernisation of the water mains will be the construction of a second-stage pumping station in the form of a hydrophore pumping station. The construction of the pumping station is intended to increase the pressure in the water supply network and thus improve the efficiency of the water supply system in the entire village of Kłodne.

References

Anielak, A.M. (2015). *Highly effective methods of water purification*. Warszawa: Wydawnictwo Naukowe PWN.

Borkowski, J., Sutowska, M., Borkowski, P. (2014). *Influence of Water Treatment Methods on pH Reaction*. Koszalin: University of Technology.

DIRECTIVE OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL. Downloaded from: https://eur-lex.europa.eu/resource.html?uri=cellar:8c5065b2-074f-11e8-b8f5-01aa75ed71a1.0016.02/DOC_1&format=PDF.

Grabarczyk, C. (2017). *Hydraulics of water treatment equipment*. Warszawa: Wydawnictwo Naukowe PWN.

Infrastructure Regulation of 14 January 2002 on the definition of average water consumption standards. Downloaded from: http://isap.sejm.gov.pl/.

Knapik, K., Bajer, R. (2010). *Waterworks. Podręcznik dla studentów wyższych szkół technicznych*. Kraków: Tadeusz Kościuszki Cracow University of Technology.

Kwietniewski, M., Olszewski, W., Osuch-Pajdzińska, E., Miszta-Kruk, K. (2009). *Designing elements of a water supply system*. Warszawa: OWPW.

Team for the development of the Limanowa Municipality Report 2018. (2018). *Limanowa Municipality Report 2018*. Limanowa: Limanowa Municipality Office. Downloaded from: https://bip.malopolska.pl/.

Team for the development of the Limanowa Municipality Report for 2020. (2020). *Limanowa Municipality Report for 2020. Limanowa*: Limanowa Municipality Office. Downloaded from: https://bip.malopolska.pl/.

Team for the development of the Limanowa Municipality Report for 2021. (2021). Limanowa Municipality Report for 2020. Limanowa: Limanowa Municipality Office. Downloaded from: https://bip.malopolska.pl/.

Team to develop the 2019. (2019). Limanowa Municipality Status Report *Limanowa Municipality Status Report 2019 Limanowa*: Limanowa Municipality Office. Downloaded from: https://bip.malopolska.pl/.