

## **QUALITY AND QUANTITY ASSESSMENT OF GROUNDWATERS IN THE VICINITY OF KUTNO WITH RESPECT TO POTABILITY. PART I**

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### **ABSTRACT**

The study presents the characteristics of drinking water sources and subsequently performs an analysis of the deviations from the norm in terms of ions of iron, manganese, ammonia, sodium, chlorides as well as other factors affecting the quality of drinking water in the years 2015 - 2017 occurring in individual water intake points in the Kutno district.

**Keywords:** drinking water, properties, pollution, Kutno district.

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## INTRODUCTION

### DRINKING WATER

Drinking water as a foodstuff is available in bottled form, drawn from wells or supplied through the water supply system. Tap water is drawn from surface or underground waters, but regardless of the source of intake it must meet purity standards. Technologies used to treat substandard water should effectively improve its sensory and health qualities [1]

The quality of drinking water is standardised and controlled, hence the assessment of its suitability for consumption is the subject of numerous studies.[2]

Drinking water in small towns and villages is most often drawn from underground waters, which are very often characterised by elevated concentrations of mineral and organic substances.[3]

In Poland, the quality of drinking water is defined by annexes to the Regulation of the Minister of Health of 13 November 2015.[4] They take into account the recommendations of the World Health Organization, but above all they comply with the Directive of the Council of the European Union 98/83/EC, which defines parameters harmful to health, colour, turbidity, total bacterial count, total organic carbon content, taste and smell.[5,6]

Water quality analysis most often involves multiple indicators that are described and analysed separately[7].

The aim of this study was to assess the physico-chemical properties of drinking water in Kutno district.

### DRINKING WATER TREATMENT

The most frequently questioned raw water parameters include:

- turbidity,
- colour,
- ammonium ion,
- iron,
- manganese.

In order to eliminate these elements and improve the quality of water intended for consumption, it is necessary to subject it to a process of purification – treatment.

The following stages are distinguished in the water treatment process:

- purification;
- removal of superfluous substances by aeration;
- enrichment with desirable substances;
- disinfection.

### SANITARY REQUIREMENTS FOR DRINKING WATER

The quality of water intended for human consumption is regulated by the Regulation of the Minister of Health of 13 November 2015 on the quality of water intended for human consumption. [8]

On 27 November 2002, the Minister of the Environment issued a regulation on the requirements to be met by surface waters used for supplying the population with water intended for consumption [9].

Sanitary control of the water supply to the

public aims towards:

- the prevention of "waterborne" epidemics (infectious diseases transmitted by water),
- the prevention of poisoning and other adverse effects which may occur as a result of the pollution of water by chemicals.

The basis for the sanitary assessment of the conditions of water supply to the population is the sanitary and technical condition of the water supply facilities, established on the basis of field inspection, as well as the results of tests of the physical, chemical and microbiological properties of water. Inspection of equipment for supplying water to the public is aimed at checking the state of protection of water against the possibility of its contamination at the place of intake, treatment, collection and distribution systems.

The sanitary assessment of the water supply to the public includes:

- the sanitary-topographical conditions of the water intake;
- the establishment and development of protection zones;
- monitoring the surrounding area for sources of water and soil pollution that may threaten water quality at the intake site;
- components of water supply facilities in the order of the water flow direction, controlling their sanitary and technical condition to ensure their proper functionality and to protect against the possibility of water contamination;
- the method of control and dosage of the disinfectant;
- preventing the entry of rainwater and animals into clean water reservoirs;
- prevention of access to tanks by members of the public or animals.

The sanitary assessment of drinking water consists of:

- evaluation of selected water properties: organoleptic, physical, chemical and microbiological;
- comparison of the results obtained with the standards in force;
- the correct interpretation of these results (based on medical knowledge, mainly toxicology and human physiology);
- issuing a statement on the suitability of the water for drinking.

### ORGANOLEPTIC AND PHYSICO-CHEMICAL CHARACTERISTICS OF WATER

It is important to remember that substances present in water are not inert to health. For example:

- excess iron and manganese in water can promote tooth decay and cardiovascular disease,
- excess aluminium can cause skin pigment to disappear and accelerate the development of Alzheimer's disease,
- high levels of chlorine irritate the mucous membranes, cause headaches, and its prolonged action damages the kidneys and liver,
- elevated nitrate concentrations, the presence of detergents and phenols can cause skin irritation,

upper respiratory tract irritation and chronic poisoning,

- bacteriological contamination may result in infections and diseases of the digestive system.

If the water taste is a cause for concern, if it is turbid, has an unpleasant odour, leaves irritated skin after washing or if there are rust marks on the bathtub or the washbasin, water control tests should be carried out.

#### TEMPERATURE

The optimum temperature of water for drinking is between 7 ÷ 11°C. In this range of temperatures, gases (mainly CO<sub>2</sub>) which determine the taste and refreshing properties of water, dissolve in appropriate quantities for humans. Temperature of water in a well should be constant; "jumps" in temperature indicate possible contamination coming from other sources.

#### COLOUR

There are two types of water colour:

- apparent (caused by suspension, disappears after filtration);
- real (caused by a solution, does not disappear after filtration).

Drinking water should be colourless. Exceptionally, it may be yellow (according to the scale) if the water is disinfected with chlorine.

#### ODOUR

The odour should be acceptable to consumers. Depending on what it is caused by, the odour can be:

- of plants living in water;
- specific – chemicals mainly from industry,
- putrid – caused by the presence of organic substances in a state of decomposition. A putrid odour disqualifies water for drinking.

#### TURBIDITY

Turbidity is an optical property that depends on the presence of light-scattering fine suspended solids in the water. Drinking water should not contain substances that make it turbid.

#### TASTE

The taste of the water must be acceptable to consumers and without abnormal variations.

#### CHEMICAL PROPERTIES OF WATER

##### WATER REACTION

A neutral reaction is difficult to obtain due to the presence of salts. For physiological reasons, we limit the pH to the range of 6.5÷9.5.

##### CHEMICALS

Iron up to a limit of 0.200 mg/l, manganese up to a limit of 0.050 mg/l and, inter alia, sulphates, aluminium, sodium, lead and pesticides shall be determined.

#### CHEMICAL INDICATORS OF WATER POLLUTION

These are substances (Cl<sup>-</sup>, NO<sub>2</sub><sup>-</sup>, NO<sub>3</sub><sup>-</sup>, NH<sub>4</sub><sup>+</sup>, oxidisability) whose concentrations in water exceeding acceptable standards are indicative of faecal contamination of the water and therefore a risk of microorganisms of intestinal origin.

#### BIOLOGICAL PROPERTIES OF WATER

The microorganisms found in water are divided into three groups:

- appropriate aquatic bacteria, generally harmless to humans,
- soil bacteria - flushed into the water with rainfall, not harmful to humans,
- sewage micro-organisms, including those pathogenic to humans.

Enteric pathogenic waterborne bacteria are bacteria of the genera: *Salmonella*, *Shigella*, *Escherichia coli*, *Vibrio cholerae*, *Yersinia enterocolica*, *Campylobacter fetus (jejuni)*.

Of the viruses found in water, illnesses are most commonly caused by: *Hepatitis A*, enteroviruses (*Polio*, *Coxsackie*, *ECHO*), *Norwalk viruses*, *Rota viruses*.

Eggs of waterborne parasites include: human roundworm, *Trichinella*.

For sanitary-epidemiological purposes, methods indicating indirectly the presence of pathogenic microorganisms in water are used, detecting the so-called indicator microorganisms, which represent the normal and constant intestinal flora of humans and animals. The dominant species here is *Escherichia coli* of the faecal type, indicating fresh contamination, as opposed to other types of this group (*Citrobacter*, *Enterobacter*) indicating contamination more distant in time.

The microbiological requirements to be met by drinking water are:

- *Escherichia coli* with a maximum limit of 0 cfu in 100ml of water sample,
- enterococci with the highest value of 0 cfu in 100 ml of water sample,
- coliforms with a standard of 0 cfu in 100 ml volume of a water sample,
- total microorganisms count at 36±2°C after 48 hours – up to 50 cfu in 1ml of water sample,
- total micro-organism count at 22±2°C after 72 hours – up to 100 cfu/1ml of water sample,
- *Clostridium perfringens* (including spores) – 0 cfu/100ml water.

The drinking water standards in force in Poland do not solve the problem of protecting the population against drinking water of impaired quality. This is because it is assumed that there is no right for the standards to be exceeded, which unfortunately is not confirmed in practice.

The association of springs with top quality water is not always correct, as not all spring water is drinkable. As soon as water flowing from springs is allowed to come into contact with the earth's surface, it becomes surface water and is not drinkable, even in the case of an artesian spring.

## WATER TREATMENT

Water treatment methods vary depending on the quality of the water drawn and the quantity needed. The primary process for improving the physical characteristics of water is the sedimentation of contaminants in sedimentation tanks. These are basins through which water flows at a very slow rate. As a result, the gravity force acting on a pollutant particle is greater than the current force of the flowing water, allowing the pollutant to settle to the bottom of the tank.

In order to remove colloidal fines from the water, coagulants are added to the sedimentation tanks.

Coagulants are substances that cause destabilisation of colloids in water, as a result of which particles aggregate into larger aggregates, which accelerates sedimentation. For coagulation, chemical compounds are used which have the property of producing colloidal particles in water which have the opposite electrical charge to that of the particles we intend to remove from the water. The particles present in the water and those produced artificially attract each other and adhere together. The resulting "flocs" of gel have sorption properties, so they also "capture" electrically neutral particles from the water. Most colloid particles that pollute natural waters have a negative electrical charge. In order to neutralise them, coagulants producing colloidal particles with a positive charge are used. Such substances include mainly glycine sulphate and ferrous and ferric sulphates.

The coagulation process takes place in three phases:

- mixing coagulant with water,
- the actual "flocculation" process,
- removal of the resulting "flocs" in the sedimentation tank.

The next stages of water treatment are:

- aeration – the passage of air from the bottom of the water tank,
- filtering on post-filters.

The grain size of the filter material affects the size of the pores between them, i.e. the ability to retain contaminants of a certain size. In post-filters, which are used only for cleaning, the filtering material is gravel and coarse sand.

## WATER DISINFECTION

Drinking water should be free of pathogenic substances. Natural waters containing bacteria and viruses must therefore be disinfected. Water is also one of the basic ingredients of many food products. Ensuring the microbiological purity of water is essential to the quality of the final product. Examples include the brewing industry, beverage bottling plants, meat, fruit and vegetable industries, etc.

Water for swimming pools and refrigeration circuits also requires disinfection. Disinfecting water means destroying bacteria in the water or removing them to such an extent that consumed water or food products made with it cannot cause illness.

Disinfection can be carried out by:

- exposure of water to ultraviolet rays,
- chlorination,
- ozone treatment,
- ultrafiltration.

## WATER CHLORINATION

Chlorination is the most cost-effective and popular disinfection method. Bacteria are destroyed by treating water with chlorine compounds or pure chlorine gas. This produces hypochlorite – as an active compound in water disinfection. The most common agent used for disinfection is sodium hypochlorite solution – NaOCl. The dose of chlorine should be selected according to the water quality.

Post-treated water is disinfected with a very low dose of chlorine gas. As the quality of groundwater is very good from a bacteriological point of view, disinfection is only carried out to protect the water during its transport to the population, often over long distances..

Chlorinators are used to prepare and dose the solution.

The chlorinator consists of:

- motorised diaphragm suction and pressure pump,
- polyethylene tank for sodium hypochlorite solution,
- a suction line that draws in the disinfectant solution contained in the tank,
- the discharge line.

The chlorinator should be installed in a separate room equipped with ventilation and as close as possible to the consumer into which the sodium hypochlorite solution is to be injected.

A side effect of chlorine disinfection is deterioration of smell and taste, so it is important to choose the right equipment and constantly check the consumption of preparations.

## DE-IRONING AND DE-MANGANISING OF WATER

Groundwater is less vulnerable to pollution caused by human economic activity. However, it is characterised by elevated manganese and iron contents and the presence of hydrogen sulphide and ammonia. The iron content ranges from trace amounts to several dozen mg/l and the manganese content from trace amounts to several g/l.

High concentrations of iron and manganese in water cause an intensification of its colour and turbidity, which negatively affects its organoleptic properties. In addition, rusty deposits appear on the appliances, left by mixtures of hydrated iron and manganese oxides. De-ironing and de-manganising consists of converting dissolved iron and manganese compounds into insoluble forms that are retained by filtration in a filter bed. De-ironing involves the professional selection of the type of bed. This depends on the physico-chemical composition of the water, the form in which iron or manganese occurs, the dissolved oxygen content, and the content of carbon dioxide and organic compounds.

De-ironing – a technological process in terms of iron and manganese removal consists of:

- aeration of raw water by means of an injector or compressor and a water/air mixer,
- correction of the water reaction,
- bed filtration.

If iron and manganese are present in significant quantities, de-ironing should be carried out in two stages, with the iron removal filter used first.

Water de-ionisation and de-manganisation are also connected with the proper selection of filter flushing. Depending on the bed selected, a distinction is made between:

- water-air rinsing at high capacities,
- water rinsing,
- water rinsing with dosing of  $KMnO_4$ .

Desliming and demineralisation filters are always installed before water softening filters. Water de-ironing is implemented first.

#### REMOVAL OF AMMONIUM ION FROM WATER

The current regulations on the quality of water intended for human consumption specify a maximum ammonium ion concentration of 0.5 mg  $NH_4^+$ /l. This is a change from the 2002 Regulation, where the maximum ammonium ion concentration of 0.5 mg/l applied to chlorinated waters, while for non-chlorinated waters the standards were met by water containing up to 1.5 mg  $NH_4^+$ /l.

Three basic methods of ammoniacal nitrogen removal can be distinguished:

- degassing,
- biological nitrification,
- ion exchange.

In classical groundwater treatment systems, removal of ammonium nitrogen in quantities not exceeding 1.0 mg  $NH_4^+$ /l can be carried out with certain technological principles during de-ironing and de-manganising of water by filtration through a filter bed.

The nitrification process is additionally associated with the following changes in the chemically treated water:

- a decrease in the oxygen content consumed by biological processes,
- decrease in water alkalinity,
- reducing the reaction.

## MATERIAL AND METHODS

#### CHARACTERISTICS OF THE STUDY AREA

Kutno is situated at latitude 52°14' north and longitude 9°22' east, in the north-western part of Łódź Province, on the western edge of the Kutno Plain which belongs to the Central Masovian Lowland macro-region.

There are two basic aquifers within the city of Kutno:

Jurassic level – connected with the Upper Jurassic limestones. The waters of this level have fracture character and their abundance is variable.

Quaternary level – its occurrence does not play a major role in water supply. It is discontinuous and as a near-surface level sensitive to pollution.

#### DOCUMENTED WATER RESOURCES WITHIN THE CITY

Kutno is located in the Kujawy massif. Within this massif the Upper Jurassic and Quaternary reservoirs are located.

In view of the lack of cover isolating the groundwater reservoirs from contamination, ONO and OWO protection zones have been established for these reservoirs (ONO – highest protection zone, OWO – high protection zone).

The ONO protection zone was delineated for the quaternary groundwater reservoirs situated in proglacial formations near Włocławek, in inter-marine formations north-west of Kutno and in valley formations near Łowicz. The Jurassic GZWP is partly protected by ONO zone north-west from Kutno and extends narrowly south-east along the Ochnia River, bypassing Kutno from the south. The OWO zone protects the Jurassic GZWP and extends in a small part west from Kutno and in a larger part south from Kutno along the Bzura river from Łęczycza to Łowicz.

#### SURFACE WATER

Kutno encompasses the Ochnia river floodplain, passing gradually into the upland of the Kutno moraine. The morphology of the area is reflected in the geological structure of the subsoil.

The floodplain areas are built of fluvial and lagoon sediments, represented mainly by sands and silts. The stagnation muds are interlayered with sandy Pleistocene sediments covered by a layer of embankments or soil, and locally by a layer of peats.

The sandy sediments are formed mainly as silty, fine and medium sands and silty clays.

The thickness of the interbedding ranges from 12 to 15 m. The upland area is made up mainly of boulder clays, the top of the clay was examined at the depth of 3.0÷12.5 m below the ground. The clay has lenses and thin sand intercalations.

During archival research drilling, two ground levels were found to be present within the town:

- the groundwater table associated with the sandy sediments of the floodplain,
- groundwater table occurring in sandy lenses and interbeds in glacial till.

Ground water occurring in the sandy sediments of the overbank areas is 2.0÷4.0 m below ground level, i.e. at 101÷102 m above sea level.

The groundwater of the aquifer in question is generally free groundwater table, locally only slightly pressurized. The inland groundwater connected with sand pockets lies at depths of 4.9÷8.7 m below the ground.

The groundwater table shows a downward slope towards the Ochnia River channel.

In the 1980s, the water table in the town's dug wells decreased and dry wells were liquidated. At present, about 15% of the town's inhabitants are supplied from their own dug wells in areas not covered by the water supply system.

The water supply plan under special conditions provides for supply of the aforementioned residents from emergency wells.[10]

#### GROUNDWATER

The wells and other boreholes drilled in the Kutno area indicate that there are three aquifers:

- Quaternary,
- Tertiary,
- Jurassic.

#### QUATERNARY AQUIFERS

The groundwater resources are quite significant. Formation and location of aquifers are variable which makes it difficult to find a well-formed aquifer. Thickness

of Quaternary sediments in the area of Kutno ranges from 35÷72,5 m and in the vicinity of Kutno from 11÷91 m. Unit capacities of Quaternary wells range from 1÷28,5 m<sup>3</sup>/h·m<sup>2</sup>.

### TERTIARY AQUIFERS

It is the least productive and rich in water. It is also characterised by poor water quality, which is mainly due to contamination of aquifers with lignite dust – bicarbonate miocene. The thickness of Tertiary sediments in the area of the town varies from 8 to over 15 m, and in the nearest vicinity from 1 to 77 m. The unit capacities of Tertiary wells range from 0.53÷26 m<sup>3</sup>/h·m<sup>2</sup>.

### JURASSIC AQUIFERS

Upper Jurassic formations were also encountered in well drilling covering the Kutno area. Waters extracted from these formations are fissured waters. The Upper Jurassic formations are mainly developed in the form of fissured limestones, hard limestones, sandy limestones and marls.

The surface of the Jurassic sediments lies 41÷72 m below the land surface. Its depth depends on the

intensity of cracks and fissures in the limestones and marls.

The depth of the Upper Jurassic intakes ranges from 49÷244 m and unit capacities of individual wells from 0.5÷80.4 m<sup>3</sup>/h·m<sup>2</sup> with pumping capacities from 0.5÷270 m<sup>3</sup>/h.

Hydrogeological and geological conditions in the Kutno area are fairly well recognised. The different aquifers are in contact with each other; Quaternary with Tertiary, Quaternary with Jurassic or Tertiary with Jurassic.

### RESEARCH METHODS

Test results on the quality of tap water in the Kutno district were obtained from the State District Sanitary Inspector in Kutno.

The data refer to studies from 2014 to 2017 that were carried out at 22 drinking water intakes (SUWs) for the assessment of water quality in terms of physicochemical parameters. The distribution of the stations is shown in Figure 1.

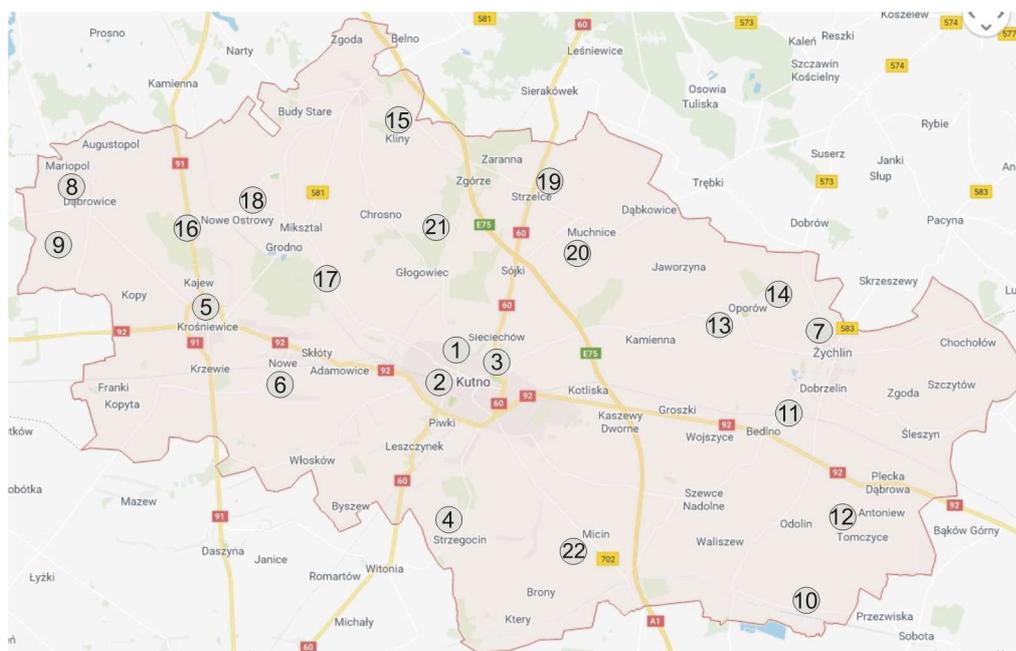


Fig. 1 Location of Water Treatment Stations in Kutno District. Source: own elaboration. 1. Kutno, 2. Kutno – PKP, 3. Kutno – Żurawieniec, 4. Kutno – Strzegocin, 5. Krośniewice, 6. Krośniewice – Nowe, 7. Żychlin, 8. Dąbrowice, 9. Dąbrowice – Baby, 10. Bedno – Orłów, 11. Bedno – Pniewo, 12. Bedno – Gluchów, 13. Opatów, 14. Opatów – Kurów, 15. Łanięta – Anielin, 16. Ostrowy, 17. Ostrowy – Grochów, 18. Ostrowy – Imielno, 19. Strzelce, 20. Strzelce – Muchnice, 21. Strzelce – Klonowiec, 22. Krzyżanów.

According to the Regulation of the Minister of Health of 13 November 2015 on the quality of water intended for human consumption, water samples for testing were taken twice a year.

Determinations of ammonia, nitrites, chlorides, manganese, iron and sodium in water from intakes were performed at the Laboratory Department of the District Sanitary and Epidemiological Station in Skierniewice.

The content of ammonia was determined by the spectrophotometric method according to PN-C-04576-4:1994, nitrites by the spectrophotometric method according to PN-EN-26777:1999, chlorides by the titrimetric method according to PN-ISO-9297:1994, manganese and iron by the FAAS method PB/L-04 issue 1, 15.05.2004 and sodium by the FAES method PN-ISO-9964-3:1994.

## RESULTS

### AMMONIUM ION CONCENTRATION

Tab. 1

Summary data on the concentration of ammonium ion in the analysed samples.

Number of samples analysed	73
Average concentration of ammonium ion in mg/l	0.140781
Standard deviation	0.140869
Coefficient of variation	100.062%
Minimum value of ions in test samples	0.06
Maximum ion value in test samples	0.767
Spanning	0.707
Standard skewness	12.7667
Standard kurtosis	22.5429

For the ammonium ion, the standardised skewness value is not within the range expected for data from a normal distribution. Also the standardised kurtosis value is outside the expected range for data from a normal distribution.

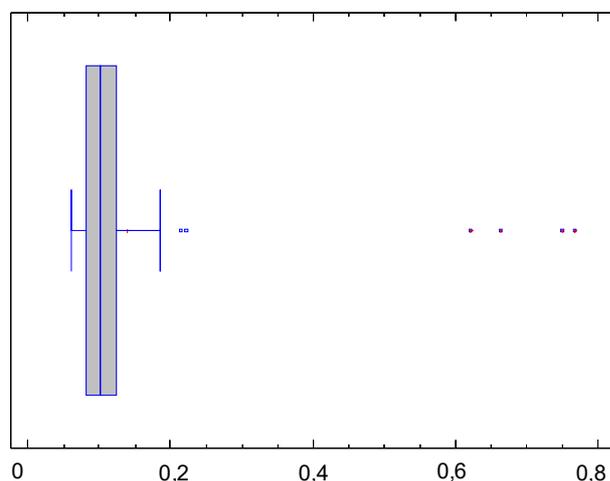


Fig. 2 John Tukey plot for the ammonium ion data series.

The graph shows a 5-number summary of the ammonium ion concentration data series under analysis. The central rectangle contains the middle half of the data extending from the lower quartile to the upper quartile. The lines extending left and right from the rectangle are called "whiskers" and show the location of the smallest and largest data values.

The data median data is illustrated by the vertical line inside the rectangle, while the "+" sign shows the position of the sample mean. From the fact that the right 'whisker' is slightly longer than the left, it follows that the arithmetic mean is slightly larger than the median, indicating a positive skewness of the data.

Frequency distribution of the analysed ammonium ion data series.

Group	Lower limit <i>less than or equal to</i>	Upper limit	Centre point	Frequency	Relative frequency	Total frequency	Relative total frequency
	0,0	0,0		0	0,0000	0	0,0000
1	0.0	0.125	0.0625	55	0.7534	55	0.7534
2	0.125	0.25	0.1875	14	0.1918	69	0.9452
3	0.25	0.375	0.3125	0	0.0000	69	0.9452
4	0.375	0.5	0.4375	0	0.0000	69	0.9452
5	0.5	0.625	0.5625	1	0.0137	70	0.9589
6	0.625	0.75	0.6875	2	0.0274	72	0.9863
7	0.75	0.875	0.8125	1	0.0137	73	1.0000
8	0.875	1.0	0.9375	0	0.0000	73	1.0000
	<i>higher</i>	1.0		0	0.0000	73	1.0000

Mean = 0.140781; Standard deviation = 0.140869

The table above divides the ammonium ion data series into intervals of equal width and an equal number of data values in each interval.

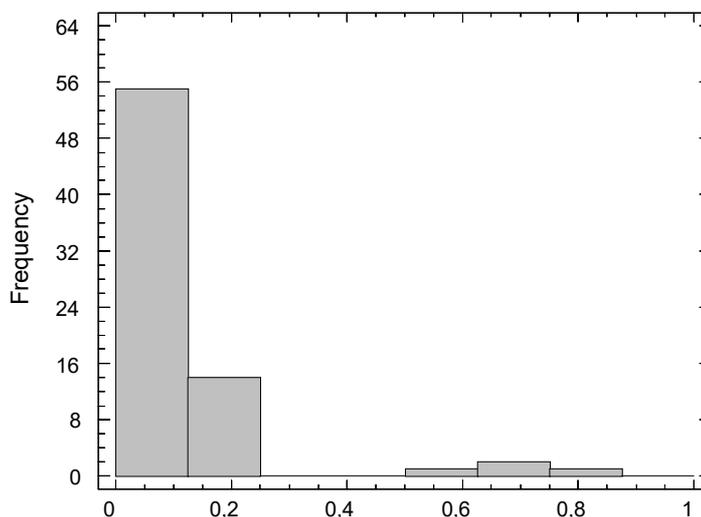


Fig. 3 Frequency histogram of the ammonium ion.

### NITRITE CONCENTRATION

Summary statistics of nitrite concentrations in analysed samples.

Number of samples analysed	73
Average concentration of nitrite ion in mg/l	0.0677808
Standard deviation	0.253099
Coefficient of variation	373.408%
Minimum value of ions in test samples	0.02
Maximum ion value in test samples	2.14
Spanning	2.12
Standard skewness	<b>27.4703</b>
Standard kurtosis	<b>112.943</b>

For nitrite concentration, the standardised skewness value is not within the range expected for data from a normal distribution. Also the standardised kurtosis value is outside the expected range for data from a normal distribution.

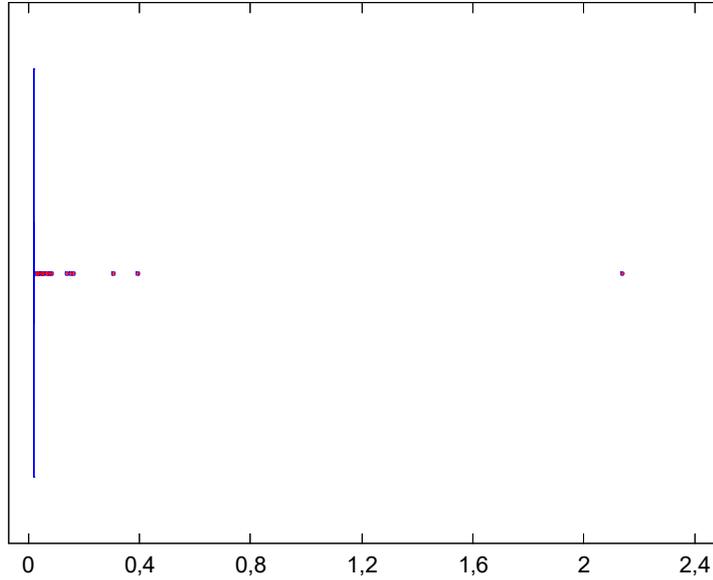


Fig. 1 John Tukey plot for the nitrite data series.

Tab. 4

Frequency distribution of the analysed nitrite data series.

Group	Lower limit	Upper limit	Centre point	Frequency	Relative frequency	Total frequency	Relative total frequency
	<i>less than or equal to</i>	-0,1		0	0,0000	0	0,0000
1	-0.1	0.2	0.05	70	0.9589	70	0.9589
2	0.2	0.5	0.35	2	0.0274	72	0.9863
3	0.5	0.8	0.65	0	0.0000	72	0.9863
4	0.8	1.1	0.95	0	0.0000	72	0.9863
5	1.1	1.4	1.25	0	0.0000	72	0.9863
6	1.4	1.7	1.55	0	0.0000	72	0.9863
7	1.7	2.0	1.85	0	0.0000	72	0.9863
8	2.0	2.3	2.15	1	0.0137	73	1.0000
	<i>higher</i>	2.3		0	0.0000	73	1.0000

Mean = 0.0677808; Standard deviation = 0.253099

The table above divides the data series for nitrite into intervals of equal width and shows the number of data values in each interval.

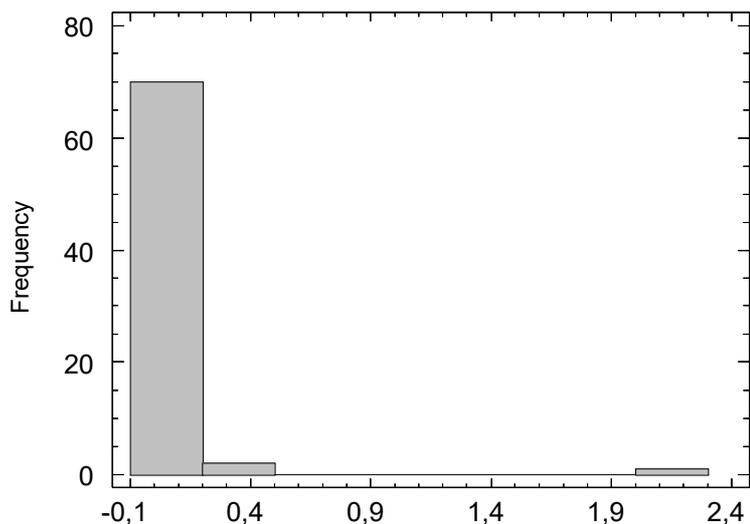


Fig. 2 Frequency histogram of nitrite.

**CHLORIDE CONCENTRATIONS**

Tab. 5

Summary statistics of chloride concentrations in analysed samples.

Number of samples analysed	73
Average chloride concentration in mg/l	41.2918
Standard deviation	61.3123
Coefficient of variation	148.486%
Minimum value of ions in test samples	7.0
Maximum ion value in test samples	370.0
Spanning	363.0
Standard skewness	<b>11.4755</b>
Standard kurtosis	<b>22.3746</b>

For chloride, the standardised skewness value is not within the range expected for data from a normal distribution. Also the standardised kurtosis value is outside the expected range for data from a normal distribution.

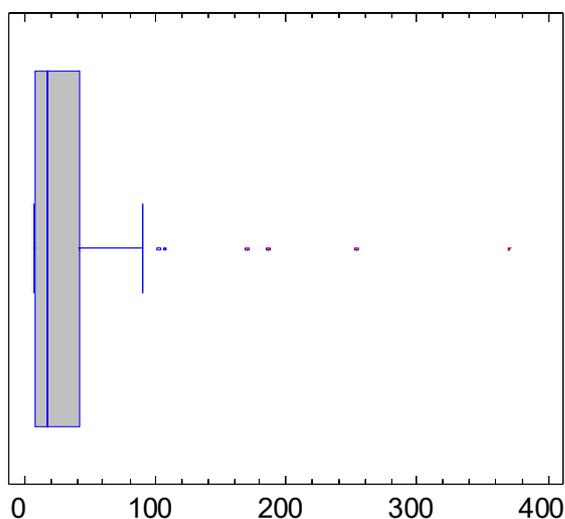


Fig. 6 John Tukey plot for the chloride data series.

The graph illustrates a 5-number summary of the chloride concentration data series under analysis. The central "rectangle" contains the middle half of the data extending from the lower quantile to the upper quantile. Your stretches to the left and right of the "rectangle" show the location of the smallest and largest data values.

The median of the data is depicted by a vertical line inside the "rectangle", while the "+" sign shows the position of the sample mean. The fact that the right "whisker" is longer than the left means that the arithmetic mean is greater than the median, which indicates a positive skewness of the data.

Tab. 6

Frequency distribution of the analysed chloride data series.

Group	Lower limit <i>less than or equal to</i>	Upper limit	Centre point	Frequency	Relative frequency	Total frequency	Relative total frequency
	-20,0			0	0,0000	0	0,0000
1	-20.0	42.5	11.25	55	0.7534	55	0.7534
2	42.5	105.0	73.75	11	0.1507	66	0.9041
3	105.0	167.5	136.25	2	0.0274	68	0.9315
4	167.5	230.0	198.75	3	0.0411	71	0.9726
5	230.0	292.5	261.25	1	0.0137	72	0.9863
6	292.5	355.0	323.75	0	0.0000	72	0.9863
7	355.0	417.5	386.25	1	0.0137	73	1.0000
8	417.5	480.0	448.75	0	0.0000	73	1.0000
	<i>higher</i>	480.0		0	0.0000	73	1.0000

Mean = 41.2918; Standard deviation = 61.3123

The table above divides the chloride data series into intervals of equal width and an equal number of data values in each interval.

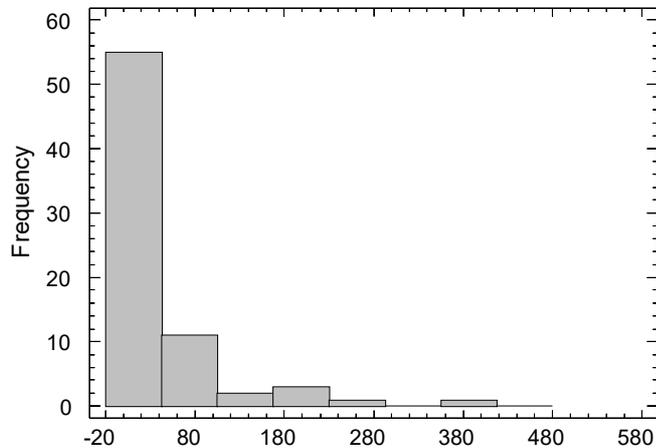


Fig. 7 Frequency histogram of chlorides.

## MANGANESE CONCENTRATION

Tab. 7

Summary statistics of manganese concentrations in the analysed samples.

Number of samples analysed	73
Average manganese concentration $\mu\text{m}/\text{l}$	38.8082
Standard deviation	37.8167
Coefficient of variation	97.445%
Minimum value of ions in test samples	18.0
Maximum ion value in test samples	199.0
Spanning	181.0
Standard skewness	<b>9.63707</b>
Standard kurtosis	<b>13.5415</b>

For manganese, the standardised skewness value is not within the range expected for data from a normal distribution. Also the standardised kurtosis value is outside the expected range for data from a normal distribution.

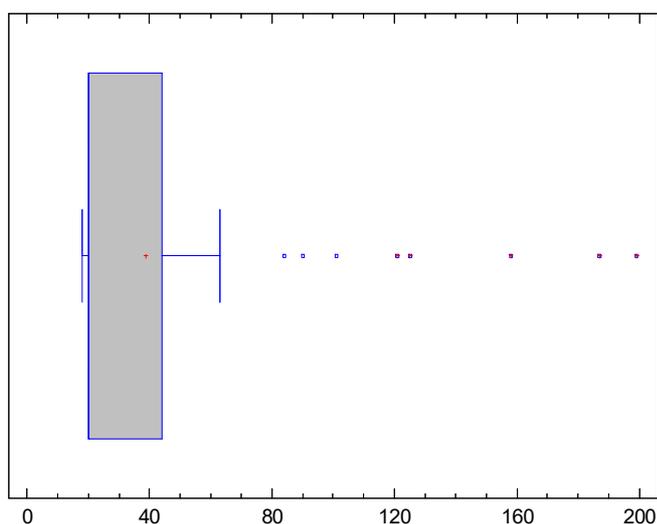


Fig. 8 John Tukey plot for the data series for manganese.

The graph shows a 5-number summary of the manganese concentration data series for the samples analysed. The central 'rectangle' contains the middle half of the data extending from the lower quartile to the upper quartile. The whiskers extending to the left and right of the 'rectangle' show the location of the smallest and largest data values.

The median, shown by the vertical line, coincides with the right side of the 'rectangle', with the '+' sign showing the position of the sample mean. From the fact that the right 'whisker' is longer than the left, it follows that the arithmetic mean is greater than the median, indicating a positive skewness of the data.

Frequency distribution of the analysed data series for manganese.

Group	Lower limit <i>less than or equal to</i>	Upper limit 0,0	Centre point	Frequency	Relative frequency	Total frequency	Relative total frequency
	0.0	30.0	15.0	48	0.6575	48	0.6575
1	30.0	60.0	45.0	15	0.2055	63	0.8630
2	60.0	90.0	75.0	4	0.0548	67	0.9178
3	90.0	120.0	105.0	1	0.0137	68	0.9315
4	120.0	150.0	135.0	2	0.0274	70	0.9589
5	150.0	180.0	165.0	1	0.0137	71	0.9726
6	180.0	210.0	195.0	2	0.0274	73	1.0000
7	210.0	240.0	225.0	0	0.0000	73	1.0000
8	<i>higher</i>			0	0.0000	73	1.0000

Mean = 38.8082; Standard deviation = 37.8167

In the table above, we obtained a division of the data series, concerning the manganese content of the samples, into intervals of equal width and an equal number of data values in each interval.

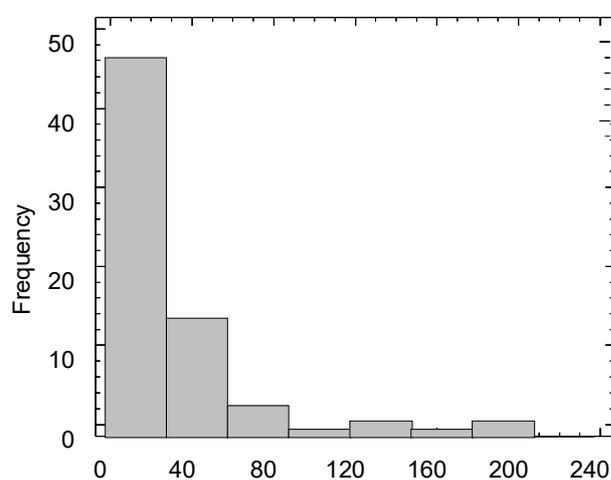


Fig. 9 Frequency histogram of manganese content in the sample.

## IRON CONCENTRATION

Summary statistics of iron concentration in analysed samples.

Number of samples analysed	73
Mean iron concentration $\mu\text{m/l}$	99.5342
Standard deviation	83.241
Coefficient of variation	83.6305%
Minimum value of ions in test samples	50.0
Maximum ion value in test samples	491.0
Spanning	441.0
Standard skewness	<b>8.40803</b>
Standard kurtosis	<b>11.9495</b>

For iron, the standardised skewness value is not within the range expected for data from a normal distribution. Also the standardised kurtosis value is not within the range expected for data from a normal distribution.

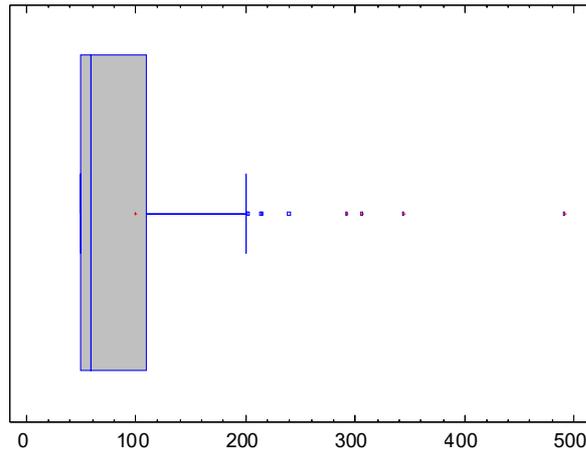


Fig. 10 John Tukey plot for the iron content data series.

The graph shows a 5-number summary of the data series for iron concentration in the samples analysed. The central "rectangle" contains the middle half of the data extending from the lower quartile to the upper quartile. The line extending to the right of the "rectangle" shows the location of the largest data values.

The median of the data is illustrated by a vertical line inside the "box", while the "+" sign shows the position of the sample mean. From the fact that the right 'whisker' is long, it follows that the arithmetic mean is greater than the median, indicating a positive skewness of the data.

Tab. 10

Frequency distribution of the analysed data series for iron.

Group	Lower limit <i>less than or equal to</i>	Upper limit	Centre point	Frequency	Relative frequency	Total frequency	Relative total frequency
		0.0		0	0.0000	0	0.0000
1	0.0	75.0	37.5	43	0.5890	43	0.5890
2	75.0	150.0	112.5	17	0.2329	60	0.8219
3	150.0	225.0	187.5	8	0.1096	68	0.9315
4	225.0	300.0	262.5	2	0.0274	70	0.9589
5	300.0	375.0	337.5	2	0.0274	72	0.9863
6	375.0	450.0	412.5	0	0.0000	72	0.9863
7	450.0	525.0	487.5	1	0.0137	73	1.0000
8	525.0	600.0	562.5	0	0.0000	73	1.0000
	<i>higher</i>	600.0		0	0.0000	73	1.0000

Mean = 99.5342; Standard deviation = 83.241

In the table above, we obtained a division of the iron content data series into intervals of equal width and an equal number of data values in each interval.

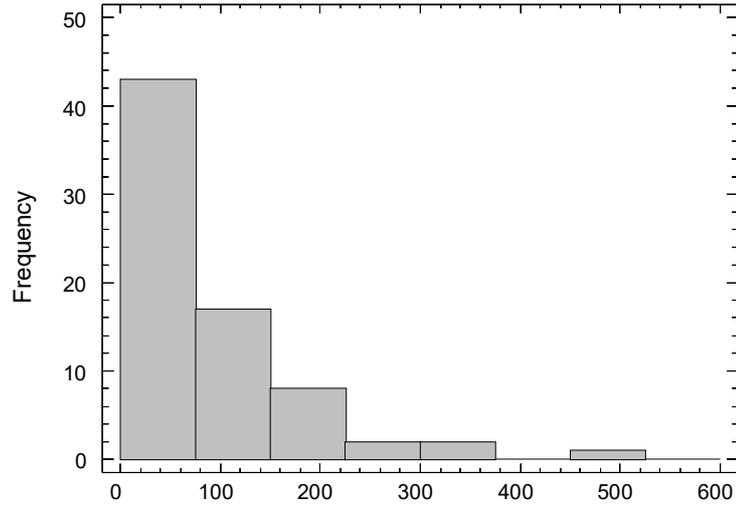


Fig. 11 Frequency histogram of the iron content of the samples.

**SODIUM CONCENTRATION**

Tab. 11

Summary statistics for sodium in the samples analysed.

Number of samples analysed	73
Average sodium concentration in mg/l	32.7562
Standard deviation	45.5847
Coefficient of variation	139.164%
Minimum value of ions in test samples	10.0
Maximum ion value in test samples	224.0
Spanning	214.0
Standard skewness	<b>9.67818</b>
Standard kurtosis	<b>13.2977</b>

For sodium, the standardised value of skewness is not within the range expected for data from a normal distribution. Also, the standardised kurtosis value is outside the expected range for data from a normal distribution.

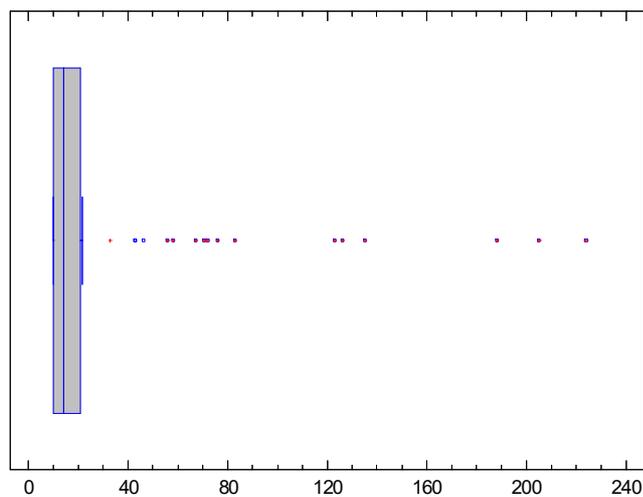


Fig. 12 John Tukey plot for the sodium data series.

The graph shows a 5-number summary of the sodium concentration data series under analysis. "Rectangle" contains the middle half of the data extending from the lower quartile to the upper quartile. The lines extending to the right of the moustache-shaped "rectangle" show the location of the largest values.

The median of the data is depicted by a vertical line inside the "rectangle", while the "+" sign shows the position of the sample mean. A slightly overhanging right 'whisker' means that the arithmetic mean is greater than the median, indicating a positive skewness of the data.

Tab. 12

Frequency distribution of the analysed sodium data series.

Group	Lower limit	Upper limit	Centre point	Frequency	Relative frequency	Total frequency	Relative total frequency
	<i>less than or equal to</i>	-10.0		0	0.0000	0	0.0000
1	-10.0	21.25	5.625	55	0.7534	55	0.7534
2	21.25	52.5	36.875	5	0.0685	60	0.8219
3	52.5	83.75	68.125	7	0.0959	67	0.9178
4	83.75	115.0	99.375	0	0.0000	67	0.9178
5	115.0	146.25	130.625	3	0.0411	70	0.9589
6	146.25	177.5	161.875	0	0.0000	70	0.9589
7	177.5	208.75	193.125	2	0.0274	72	0.9863
8	208.75	240.0	224.375	1	0.0137	73	1.0000
	<i>higher</i>	240.0		0	0.0000	73	1.0000

Mean = 32.7562; Standard deviation = 45.5847

The table above illustrates the division of the data series, for sodium, into intervals of equal width and an equal number of data values in each interval.

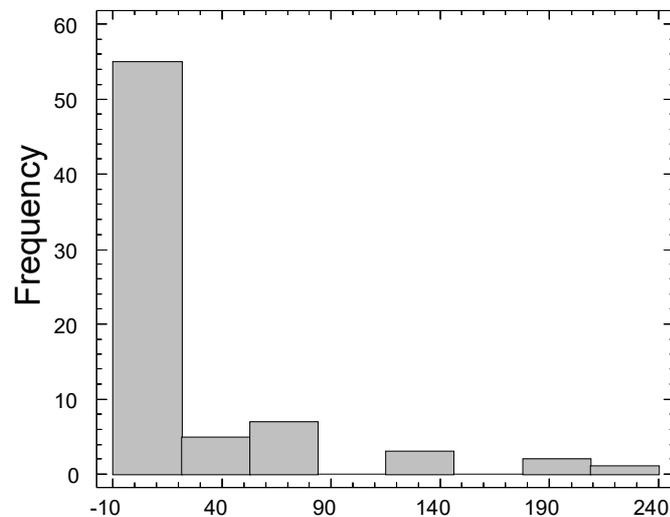


Fig. 13 Frequency histogram for sodium samples.

#### CORRELATION BETWEEN WATER pH, AMMONIUM ION, NITRITE, CHLORIDE, MANGANESE, IRON AND SODIUM

As all series of results for the contents of individual compounds and metals did not indicate normal distributions, Spearman correlations were used to determine the correlations between elements.

Correlation table.

	Water reaction (pH)	ammonium ion concentration	concentration nitrites	Concentration chlorides	Concentration manganese	Concentration iron	Concentration sodium
Water reaction (pH)		0.05	0.08	0.11	0.02	-0.11	-0.05
Ammonium ion concentration	0.05		0.00	0.24	0.15	0.19	0.24
Nitrite concentration	0.08	0.00		-0.06	0.12	-0.01	-0.06
Chloride concentration	0.11	0.24	-0.06		0.05	0.03	0.89
Manganese concentration	0.02	0.15	0.12	0.05		0.32	-0.02
Iron concentration	-0.11	0.19	-0.01	0.03	0.32		-0.02
Sodium concentration	-0.05	0.24	-0.06	0.89	-0.02	-0.02	

- full correlation
- low correlation
- weak correlation (no correlation)

The correlation between the pH of the water and the ammonium ion, nitrite, chloride, manganese, iron and sodium ranged from -0.1 to +0.1, indicating no correlation between the analysed components.

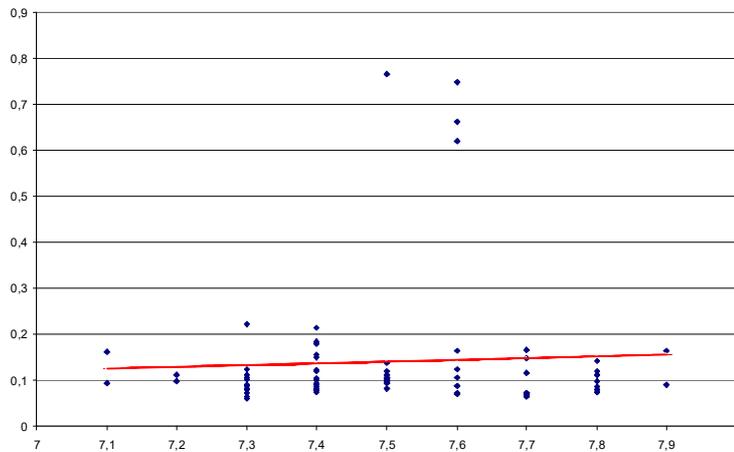


Fig. 14 Correlation scatter plot for water reaction and ammonium ion content.

The Spearman correlation coefficient between water reaction and ammonium ion content of the samples was  $r = 0.05$ .



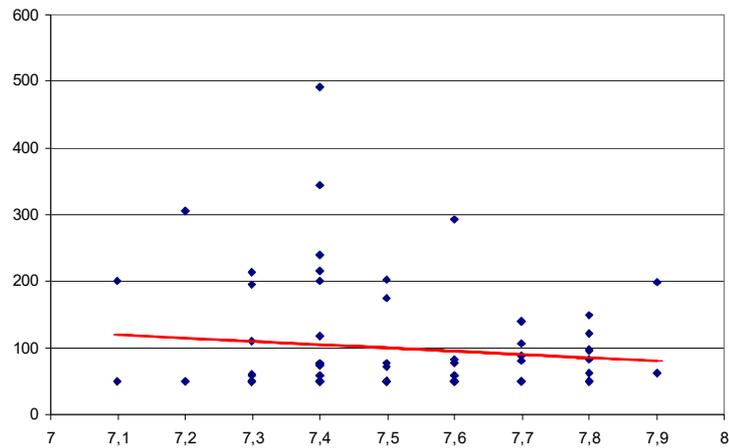


Fig. 15 Correlation scatter plot for water reaction and iron content.

The Spearman correlation coefficient between water reaction and iron content in the samples was  $r = -0.11$ .

The correlation between ammonium ions and chlorides and sodium was low at  $r = 0.24$ . The correlation between ammonium ions and iron in the water samples was slightly weaker at  $r = 0.19$ .

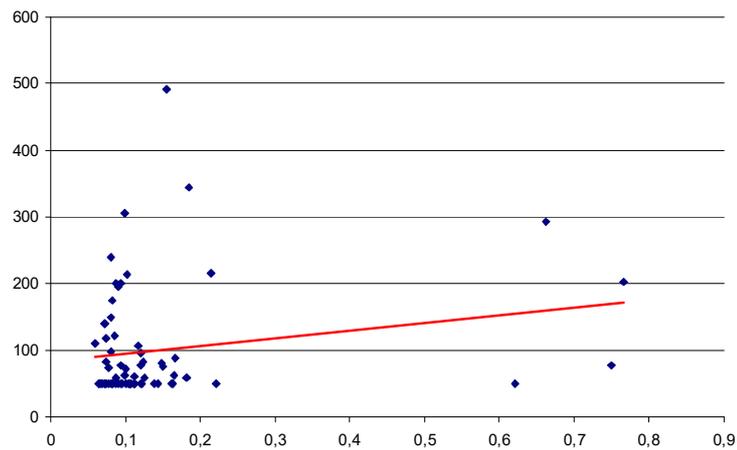


Fig. 16 Correlation scatter plot for ammonium ion and iron ( $r = 0.19$ ).

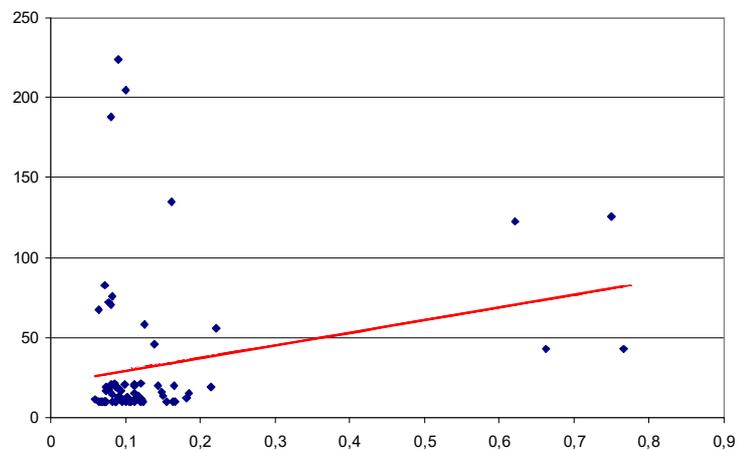


Fig. 17 Correlation scatter plot for ammonium ion and sodium ( $r = 0.24$ ).

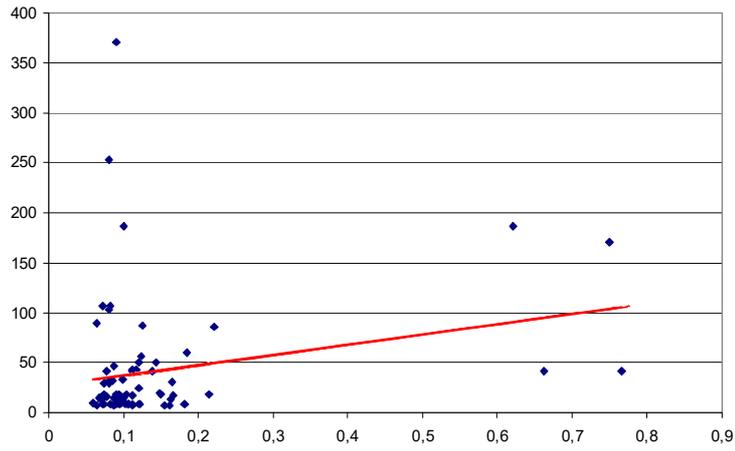


Fig. 18 Correlation scatter plot for ammonium ion and chloride ( $r = 0.24$ ).

There was a low correlation of  $r = 0.32$  between iron and manganese compounds in the samples.

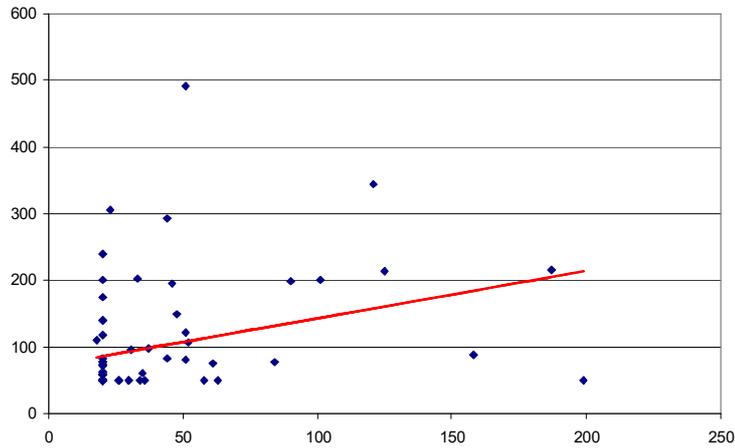


Fig. 19 Correlation scatter plot for iron and manganese ( $r = 0.32$ ).

A full correlation, at  $r = 0.9$ , occurred between chloride ions and sodium.

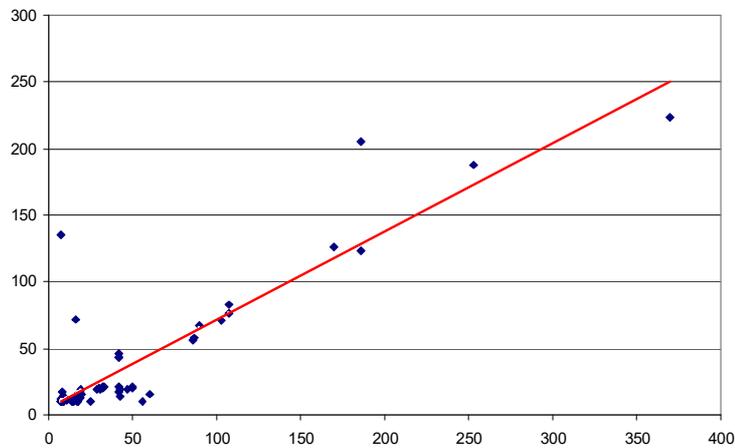


Fig. 20 Correlation scatter plot for chloride and sodium ions ( $r = 0.9$ ).

## ANALYSIS OF EXCEEDENCES OF AMMONIUM, NITRITE, CHLORIDE, MANGANESE, IRON AND SODIUM IONS

### THE CITY OF KUTNO

Since 2016, tests of water intakes in the city of Kutno, i.e. water points are treated as separate sources of water intake and the results are included in a collective tests protocol.

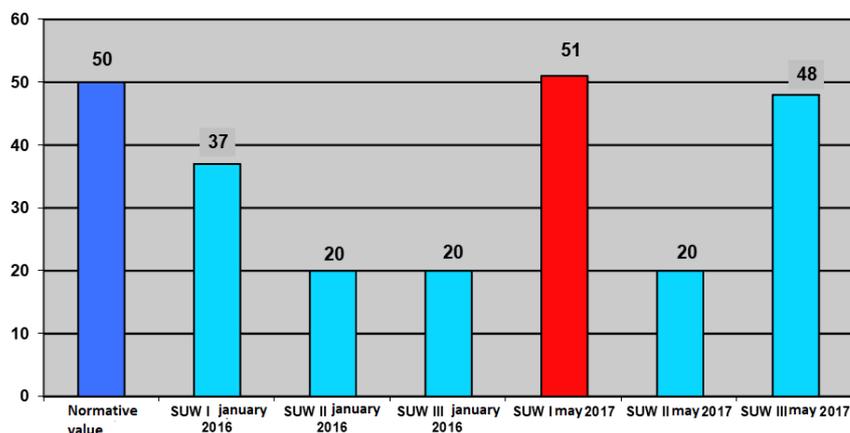


Fig. 21 Manganese concentration [mg/l] in the period 01.2016 - 05.2017. (Kutno city).

In May 2017, the concentration of manganese (51  $\mu\text{g/l}$ ) of the tested sample was slightly exceeded in relation to the normative value of 50  $\mu\text{g/l}$ . The other parameters, the concentration of ammonium ion and iron were within the norm.

### KUTNO - AZORY

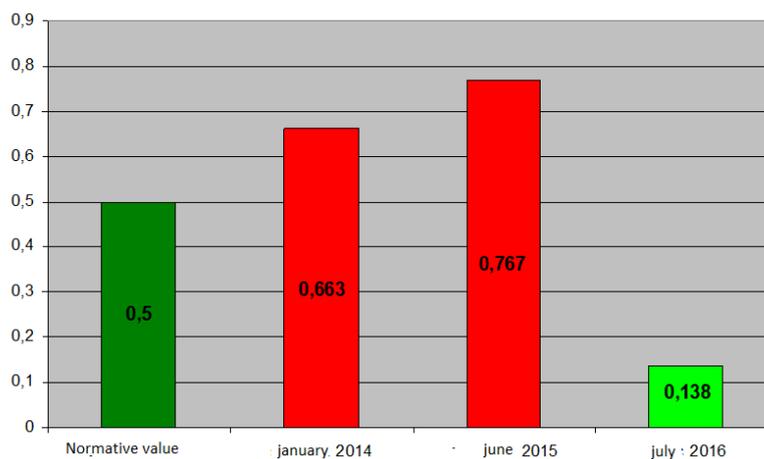


Fig. 22 Ammonium ion concentration [mg/l] in the period 01.2014 - 06.2016.

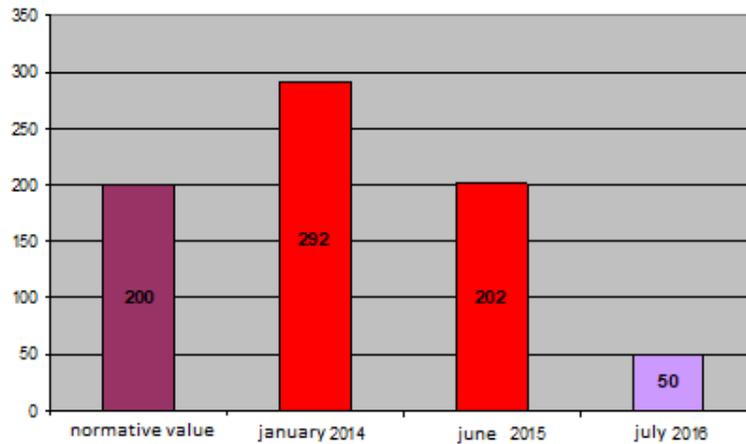


Fig. 23 Iron concentration [µg/l] in the period 01.2014. - 06.2016.

The parameters of concern in the intake were ammonium ion and iron content. Water testing from January 2014 to July 2016 showed exceedances of ammonium ion norms in January 2014 by 32.6%, and in June 2015 by 53.4%. During the same period the iron content was also exceeded by 92 units in 2014, but in 2015 the exceedance was only 2 units. In 2016, the water from the intake met all standards for water intended for consumption.

#### KUTNO — STRZEGOCIN

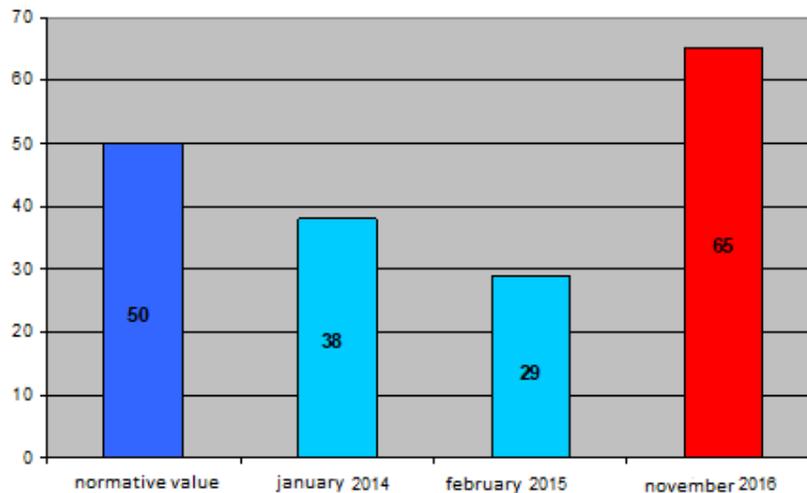


Fig. 24 Manganese concentration [µg/l] at the intake point in the period January 2014 – November 2016.

Testing of water parameters from January 2014 to November 2016 showed no exceedances in the normative values of ammonium ion concentration as well as iron content. The test from November 2016 showed that the norm of manganese content was exceeded by 30%. The iron content was not exceeded.

**WATER INTAKE POINT — KROŚNIEWICE**

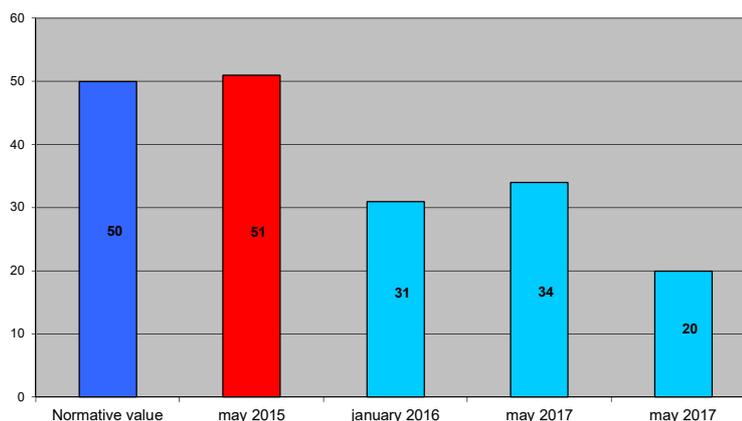


Fig. 25 Manganese concentration [µg/l] in the period 05.2015 – 05.2017.

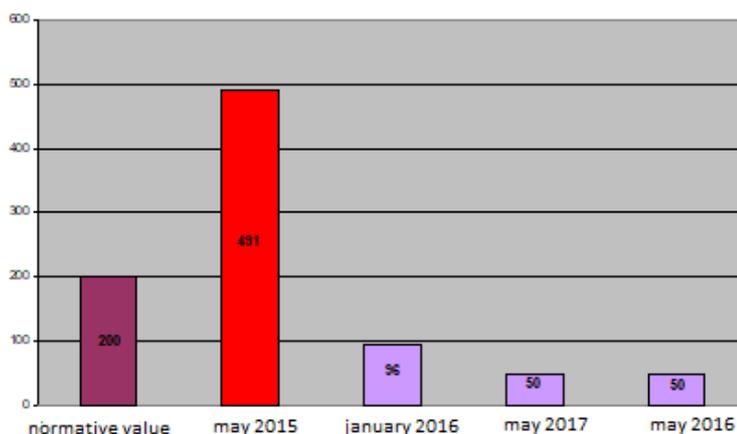


Fig. 26 Iron concentration [µg/l] for the period 05.2015 – 05.2017 r.

From May 2015 to May 2017, water colour and turbidity remained within normative values. Exceedances of manganese and iron parameters occurred in 2015. There was a slight exceedance of manganese concentration by 2% , while an exceedance of iron by 245.5%. Since 2016, all parameters are within the norms.

**WATER INTAKE POINT - MUNICIPALITY OF KROŚNIEWICE - NOWE**

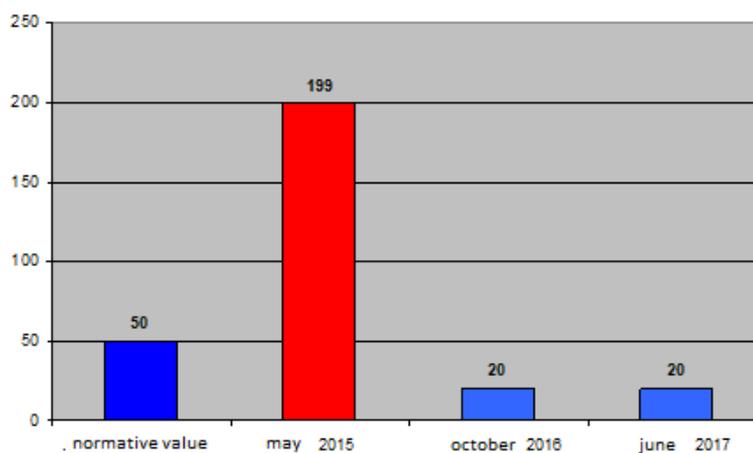


Fig. 27 Manganese concentration [µg/l] at the water intake from May 2015 to June 2017.

In the period from May 2015 to June 2017, no exceedances were recorded in the concentration of the questioned parameters included in the description of the water intake in Nowe, the municipality of Krośniewice, i.e. ammonium ions, iron. However, the study in May 2015 showed a four-fold exceedance of the permissible standard of manganese ions.

#### WATER INTAKE POINT - ŻYCHLIN

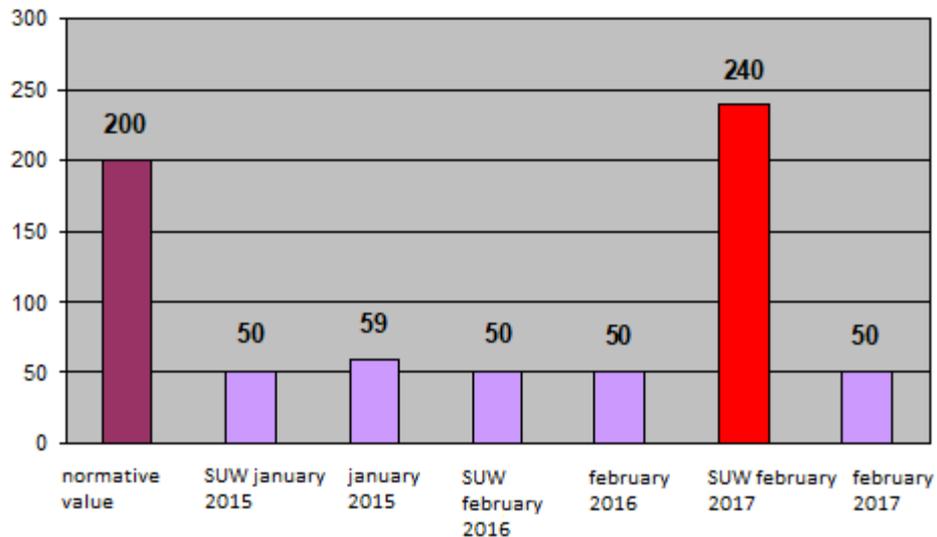


Fig. 28 Iron concentration [µg/l] at the water intake point during the period from April 2016 to July 2017.

The questioned parameters of the water intake were its colour, turbidity, content of ammonium and manganese ions. During the analysed period, from January 2015 to February 2017, no increase in the amount of the mentioned ions was observed. The ammonia level remained between 0.22 mg/l (2015) and 0.08 mg/l (2017) with a normative value of 0.5 µg/l. The iron content during the past period was at 20 µg/l with a limit value of 50 µg/l.

The anomaly was a large increase in the concentration of iron ion in the February 2017 water sample taken at the Żychlin Water Treatment Station to a value of 240 µg/l with a limit value of 200 µg/l. Re-testing at a later date showed a return to 50 µg/l. Figure 28 shows the changes in the concentration of iron ion in the period 2015÷2017.

## WATER INTAKE POINT - DĄBROWICE

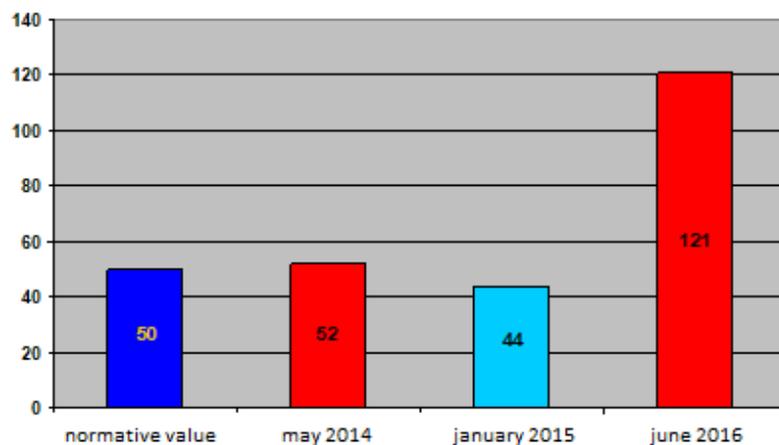


Fig. 29 Manganese content [µg/l] in samples taken between May 2014 and June 2016 at the water intake point.

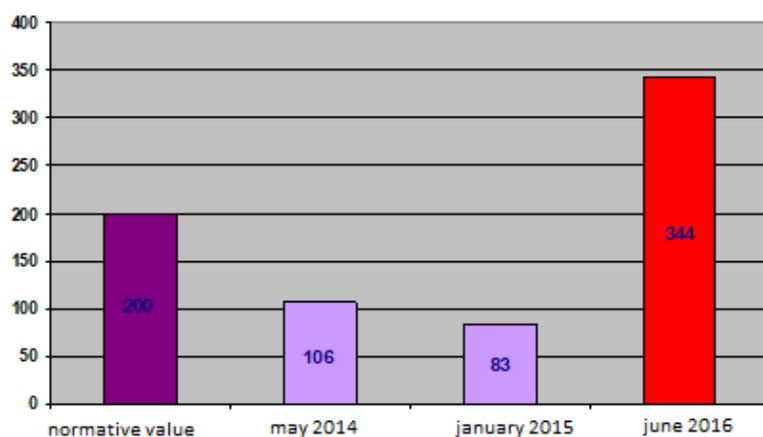


Fig. 30 Iron content [µg/l] in samples taken between May 2014 and June 2016 at the water intake point.

The questioned parameter of the water intake in Dąbrowice, was the high amount of manganese contained in the Jurassic spring. In May 2014 a slight exceedance of this standard of 52 µg/l was detected, but in June 2016 the manganese content increased to 121 µg/l. An exceedance of the allowable iron content was also detected in the 2016 sample. Other parameters were within the acceptable range.

## WATER INTAKE POINT - BEDLNO - ORLÓW

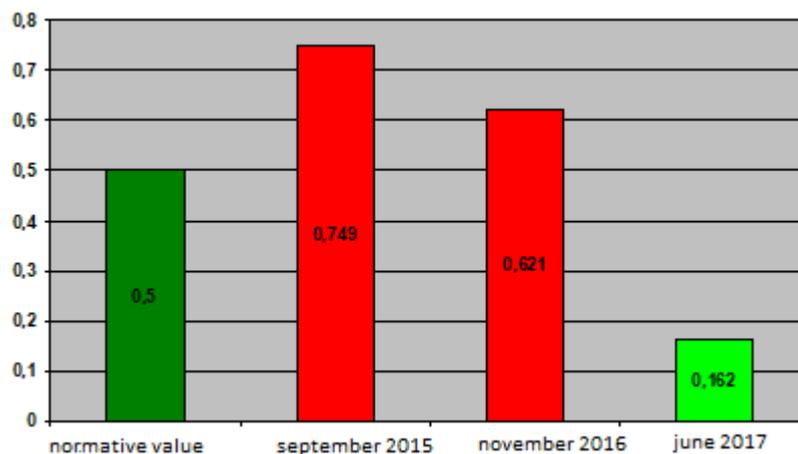


Fig. 31 Ammonium ion (ammonia) concentration [mg/l] at the water intake point, September 2015, June 2017.

In 2015 and 2016, the ammonium ion content exceeded the limit values, by 0.249 mg/l in September 2015 and by 121 mg/l in November 2016. The most recent test showed a reduction in the ammonia content to a value of 0.162 mg/l.

The manganese content in the sample increased sharply in the September 2015 sample and was 84 µg/l exceeding the permissible limit of 50 µg/l set by the drinking water standards.

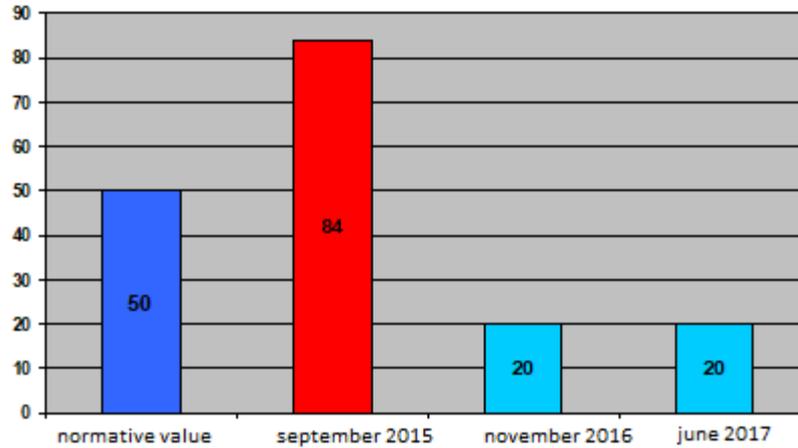


Fig. 32 Manganese content [µg/l] at the water intake point in September 2015, June 2017.

#### WATER INTAKE POINT - BEDLNO - PNIEWO

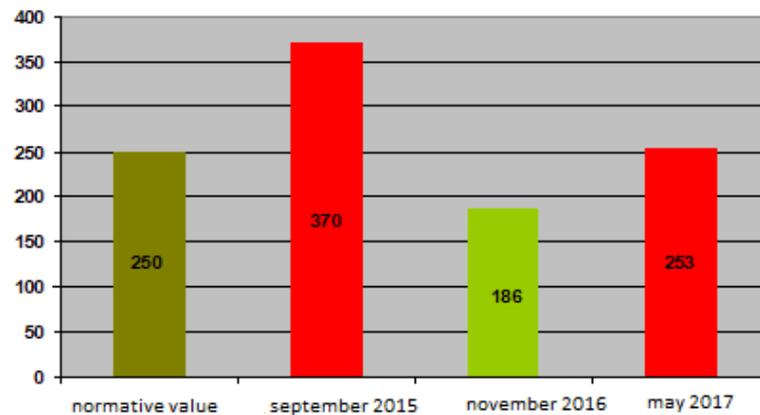


Fig. 33 Chloride concentration [mg/l] at the water intake point September 2015, May 2017.

In September 2015, a significant exceedance of chloride concentration was revealed at the water intake point Pniewo, Bedlno municipality, which was 48% higher than the permissible standard. In November 2016, the chloride content returned to normal, but was again slightly exceeded the following year. In May 2017 it was 253 mg/l compared to 250 mg/l allowed.

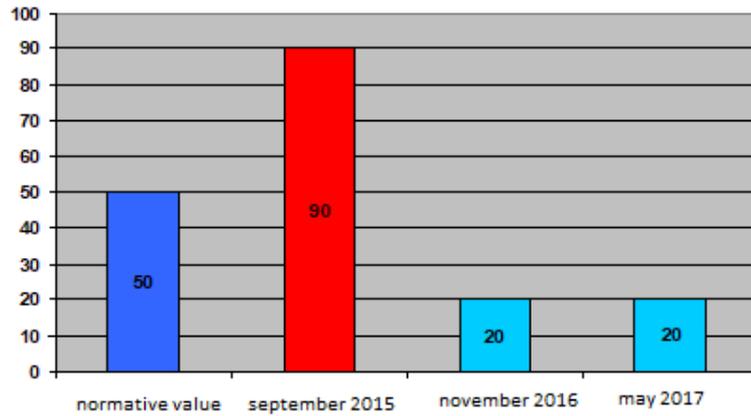


Fig. 34 Manganese concentration [µg/l] at the water intake point Pniewo - Bedlno commune, September 2015, May 2017.

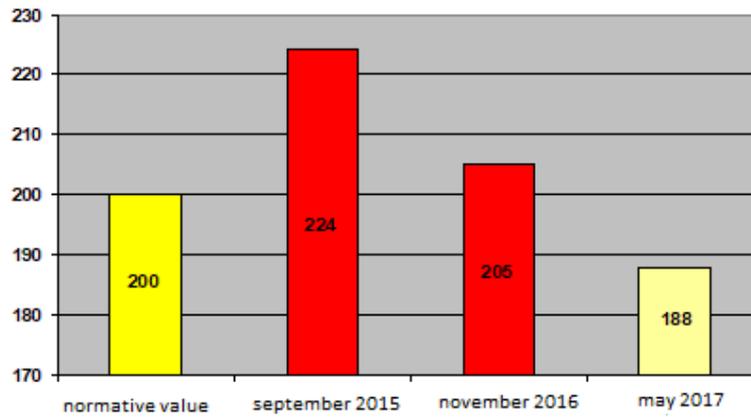


Fig. 35 Sodium concentration [mg/l] at the water intake point September 2015, May 2017.

An excess of manganese ions of 90 µg/l exceeding the permissible value of this element by 40 µg/l was also detected in the samples collected in 2015, this is shown in Figure 43. Sodium ions of 224 mg/l exceeding the prescribed standard by 12% appeared in the same samples. In 2016, the water sample did not show any exceedance of the permissible manganese standards and the concentration of sodium salts dropped to 2.5%.

Samples taken in May 2017 no longer contain any exceedances of the normative values.

**WATER INTAKE POINT - BEDLNO - GŁUCHÓW**

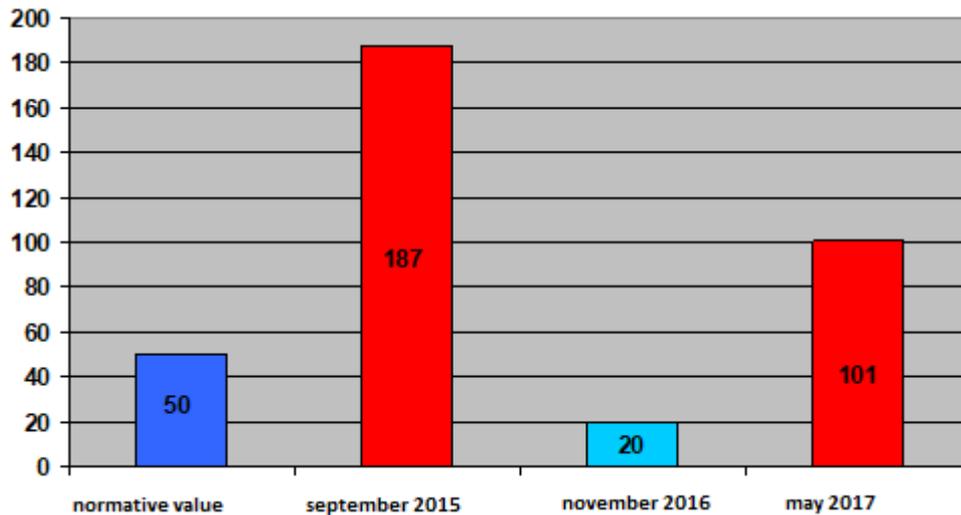


Fig. 36 Manganese concentration [µg/l] at the water intake point in the period September 2015 – May 2016.

The parameters of concern of the source located in Głuchów, Bedlno municipality, are the content of manganese and iron ions. Testing of water samples from September 2015 showed a very high content of manganese ions at 187  $\mu\text{g/l}$ , where the standard stipulates only 50  $\mu\text{g/l}$ . Also the iron ion standard was exceeded by 15  $\mu\text{g/l}$  against the standard of 200  $\mu\text{g/l}$ .

In 2016, manganese and iron ion contents were within the prescribed standard. Testing of the May 2017 samples again showed that the standards were exceeded. The amount of manganese ions was 101% higher than the standard, and iron increased slightly above the prescribed standard, only by 0.5%.

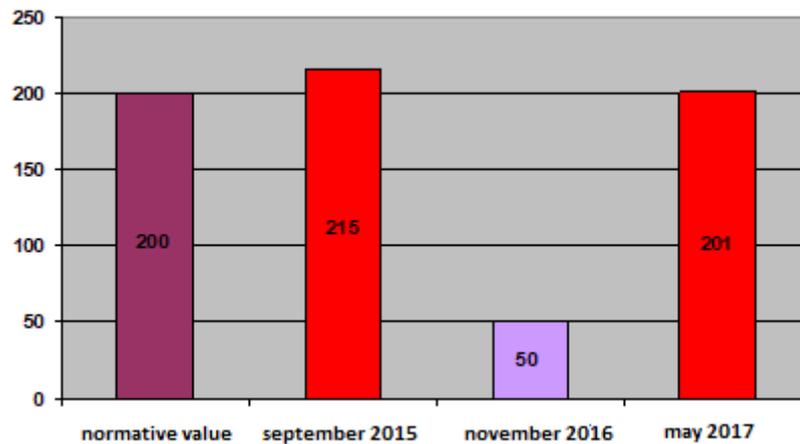


Fig. 37 Iron concentration [ $\mu\text{g/l}$ ] at the sampling point during the period September 2015 – May 2016.

#### WATER INTAKE POINT — OPORÓW

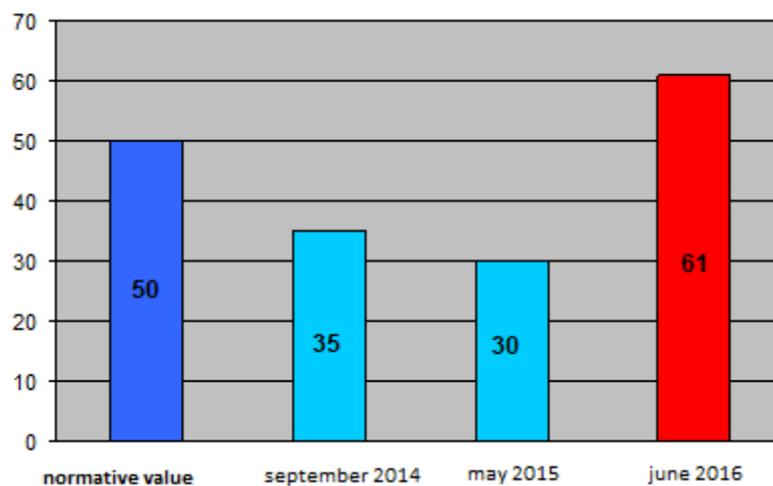


Fig. 38 Manganese content [ $\mu\text{g/l}$ ] in samples taken between September 2014, and June 2016, at the water intake point.

Between 2014 and 2015, no exceedances of water quality standards were detected at the water intake point in Oporów. In June 2016 a manganese exceedance of 22% was recorded. The sample tested contained 61  $\mu\text{g/l}$  of manganese.

**WATER INTAKE POINT — OSTROWY – GROCHÓW**

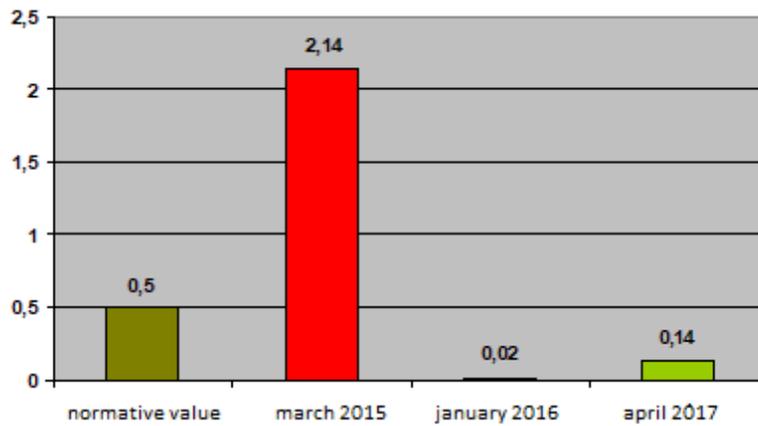


Fig. 39 Nitrite concentration[mg/l] at the water intake point, March 2015 - April 2017.

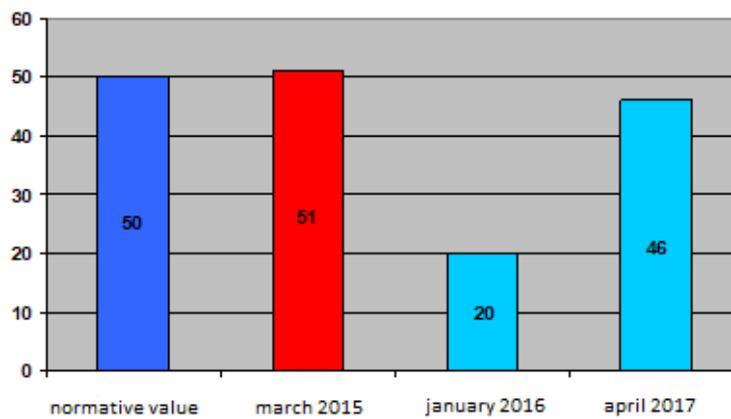


Fig. 40 Manganese concentration [µg/l] at the water intake point March 2015 – April 2017.

In March 2015, an elevated nitrite content was found in a water sample taken at the Grochów intake point, municipality of Nowe Ostrowy. The permissible value of 0.5 mg/l was exceeded by 328% and amounted to 2.14 mg/l. In the same sample the concentration of manganese was slightly exceeded - by 2% and amounted to 51 µg/l. The January 2016 survey of nitrite and manganese was within the normal range. The April 2017 survey also showed no anomalies.

**WATER INTAKE POINT – OSTROWY – IMIELNO**

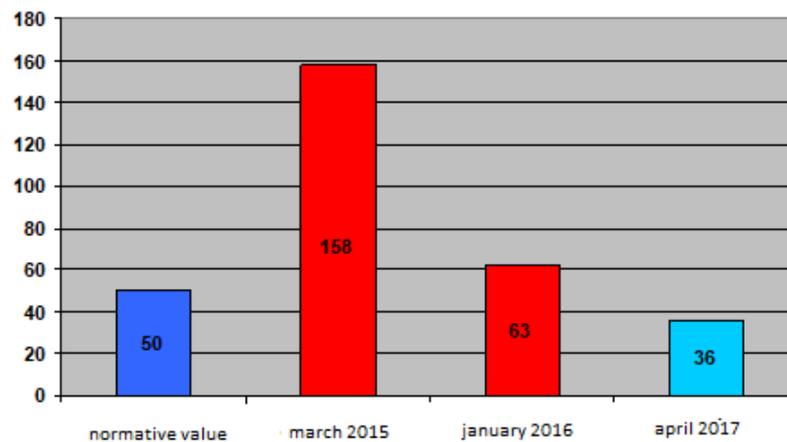


Fig. 41 Manganese concentration [µg/l] at the water intake point March 2015 – April 2017.

The testing of water in the village of Imielno, Nowe Ostrowy municipality in March 2015 and January 2016 showed that the permissible content of manganese in the intake was exceeded. In 2015 the manganese content was 216% higher and one year later it decreased and was only 26% of the permissible value. In April 2017 the manganese content was 36  $\mu\text{g}/\text{l}$  which is a value after the lower normative value.

#### WATER INTAKE POINT — STRZELCE – MUCHNICE

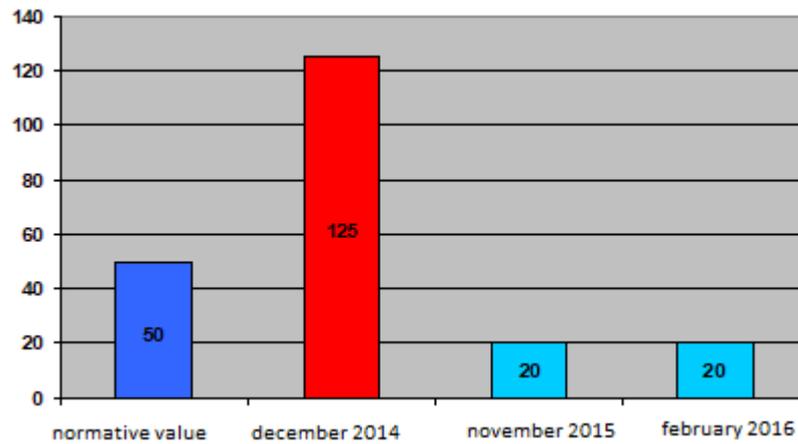


Fig. 42 Manganese concentration [ $\mu\text{g}/\text{l}$ ] at the water intake point, December 2014, February 2016.

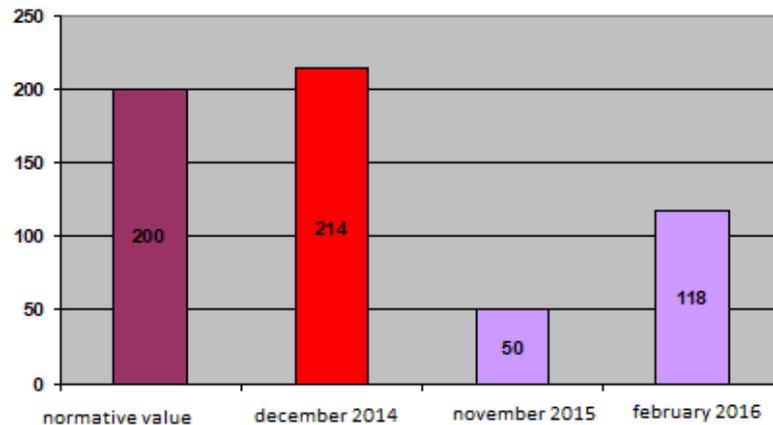


Fig. 43 Iron concentration [ $\mu\text{g}/\text{l}$ ] at the water intake point December 2014, February 2016.

The only exceedance of the standards was detected in samples collected for testing in December 2014. The amount of manganese was 75  $\mu\text{g}/\text{l}$  higher than the permitted value of 50  $\mu\text{g}/\text{l}$ . Iron ions exceeded the limit of 200  $\mu\text{g}/\text{l}$  that can be found in water permitted for consumption by 14  $\mu\text{g}/\text{l}$ .

## WATER INTAKE POINT — STRZELCE – KLONOWIEC

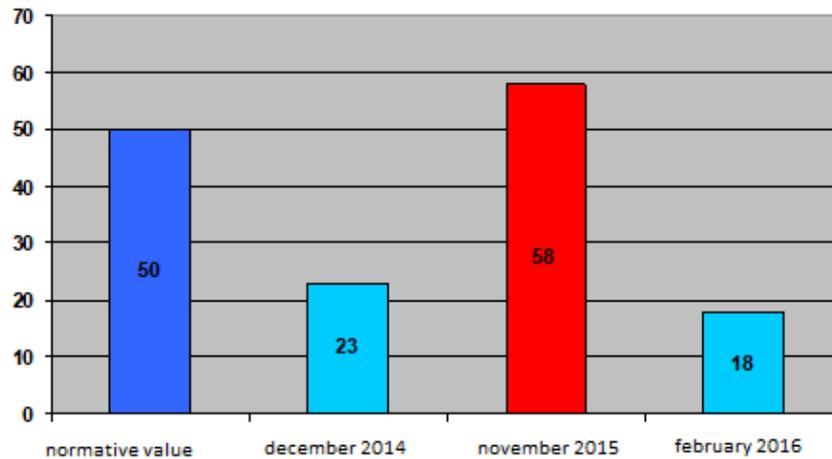


Fig. 44 Iron concentration [µg/l] at the water intake point, December 2014-February 2016.

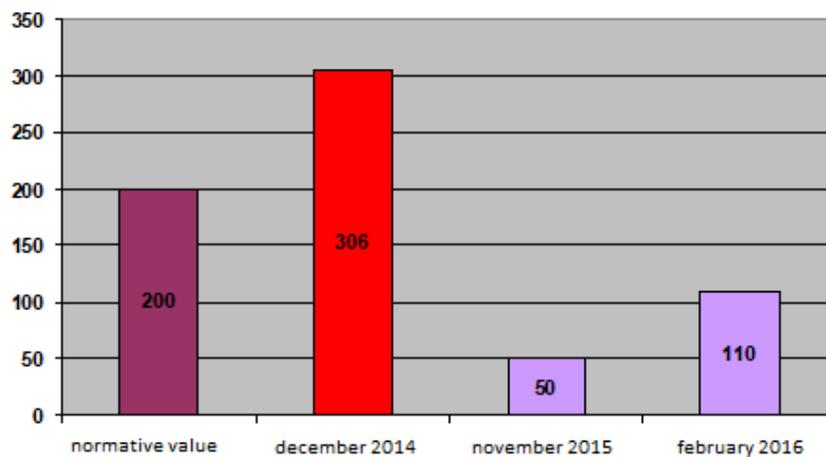


Fig. 45 Manganese concentration [µg/l] at the water intake point December 2014 – February 2016.

Among the questioned parameters at this intake point, which are colour, turbidity, ammonium ion, iron, manganese, the parameter of iron concentration was exceeded in 2014. The normative value of this parameter was exceeded by 53%. In November 2015, the iron concentration parameter was maintained within the norm. However, there was an exceedance of the manganese concentration parameter by 8 µg/l. In 2016, no exceedances of the parameters of water fit for consumption were found at the Klonowiec water intake point.

In the remaining water abstraction points during the study period, no exceedances of the reference values for the studied parameters were found.

## DISCUSSION

All analysed water intake points extracted water from groundwater, which constitutes about 70% of water supply sources for the population of Kutno District.

Deep water resources come from the following

strata:

- Jurassic,
- Miocene,
- Tertiary,
- Quaternary.



Exceedances of manganese in the area of Kutno district in 2014-2017.

Station number (according to the map)	Town	Aquifer	Number of exceedances in the reference period				
			2014	2015	2016	2017	Total
1	Kutno	jurassic	—	—	—	1	1
4	Kutno - Strzegocin	tertiary	—	—	1	—	1
5	Krosniewice	tertiary	—	1	—	—	1
6	Krosniewice - New	tertiary	—	1	—	—	1
8	Dąbrowice	jurassic	1	—	1	—	2
10	Bedno - Orłów	jurassic	—	1	—	—	1
11	Bedno - Pniewo	jurassic	—	1	—	—	1
12	Bedno - Głuchów	jurassic	—	1	—	1	2
13	Oporów	quaternary	—	—	1	—	1
17	Ostrowy - Grochów	quaternary	—	1	—	—	1
18	Ostrowy - Imielno	quaternary	—	1	1	—	2
20	Strzelce - Muchnice	quaternary	1	—	—	—	1
21	Strzelce - Maplewood	quaternary	—	1	—	—	1

Source: own elaboration.

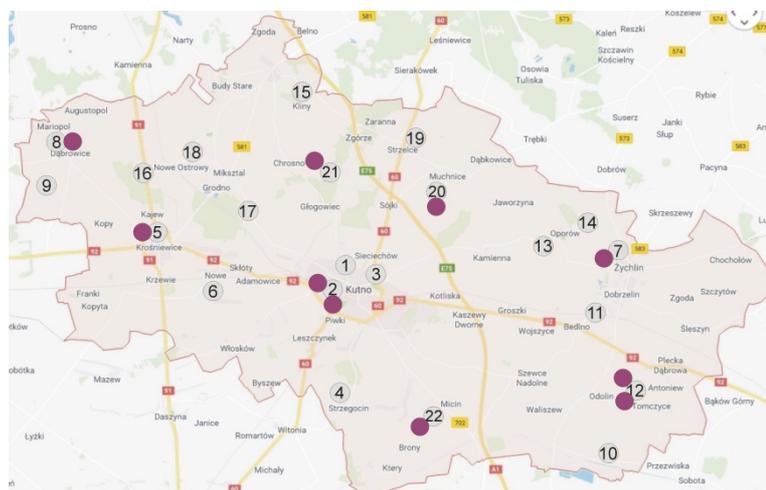


Fig. 47 Occurrence of iron exceedances in the area of Kutno district. Source: own elaboration.

1. Kutno, 2. Kutno – PKP, 3. Kutno – Żurawieniec, 4. Kutno – Strzegocin, 5. Krośniewice, 6. Krośniewice – Nowe, 7. Żychlin, 8. Dąbrowice, 9. Dąbrowice – Baby, 10. Bedno – Orłów, 11. Bedno – Pniewo, 12. Bedno – Głuchów, 13. Oporów, 14. Oporów – Kurów, 15. Łanięta – Anielin, 16. Ostrowy, 17. Ostrowy – Grochów, 18. Ostrowy – Imielno, 19. Strzelce, 20. Strzelce – Muchnice, 21. Strzelce – Klonowiec, 22. Krzyżanów.

iron (Fe)

Out of 73 inspections carried out at 22 water abstraction points, 10 exceedances of iron standards were found at 8 water abstraction stations.

Exceedances of iron on the territory of Kutno district in 2014-2017.

Station number (according to the map)	Town	Aquifer	Number of exceedances in the reference period				
			2014	2015	2016	2017	Total
2	Kutno - PKP	jurassic	1	1	—	—	2
5	Krosniewice	tertiary	—	1	—	—	1
7	Żychlin	tertiary	—	—	—	1	1
8	Dąbrowice	jurassic	—	—	1	—	1
12	Bedlno - Głuchów	jurassic	—	1	—	1	2
20	Strzelce - Muchnice	quaternary	1	—	—	—	1
21	Strzelce - Maplewood	quaternary	1	—	—	—	1
22	Krzyżanów	quaternary	—	—	—	1	1

Source: own elaboration.

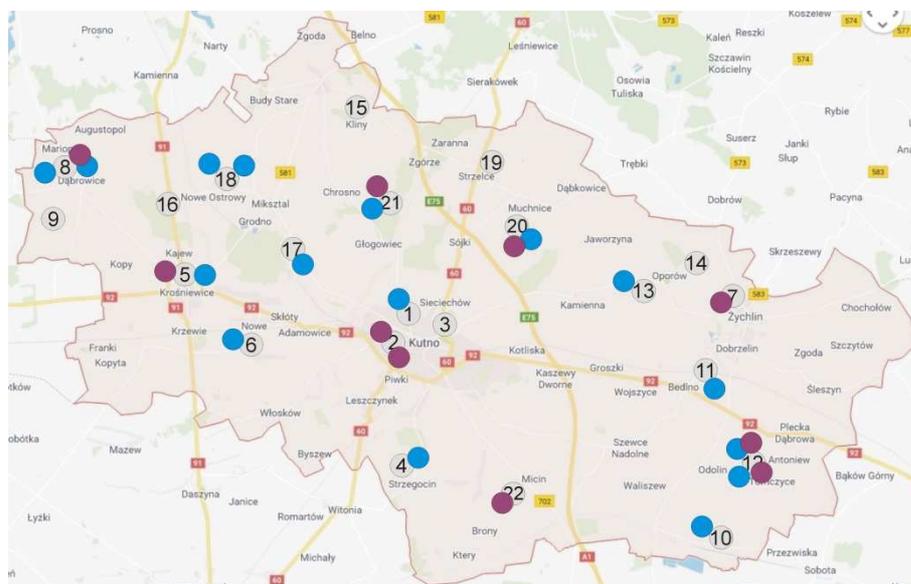


Fig. 48 Exceedances of manganese and iron norms. Source: own elaboration.

1. Kutno, 2. Kutno – PKP, 3. Kutno – Żurawieniec, 4. Kutno – Strzegocin, 5. Krośniewice, 6. Krośniewice – Nowe, 7. Żychlin, 8. Dąbrowice, 9. Dąbrowice – Baby, 10. Bedlno – Orłów, 11. Bedlno – Pniewo, 12. Bedlno – Głuchów, 13. Oporów, 14. Oporów – Kurów, 15. Łanięta – Anielin, 16. Ostrowy, 17. Ostrowy – Grochów, 18. Ostrowy – Imielno, 19. Strzelce, 20. Strzelce – Muchnice, 21. Strzelce – Klonowiec, 22. Krzyżanów.

■ manganese (Mn)  
 ■ iron (Fe)

Iron and manganese are present in groundwater in small amounts, with slightly higher contents in Quaternary formations in the form of ferrous bicarbonate  $\text{Fe}(\text{HCO}_3)_2$  or manganese  $\text{Mn}(\text{HCO}_3)_2$  and in the form of easily soluble sulphates  $\text{FeSO}_4$  and  $\text{FeSO}_4$ . [11]

In the Kutno district the occurrence of manganese and iron in deep waters is related to Quaternary formations. All abstraction sites are Quaternary formations, or earlier Tertiary and Jurassic formations on sandy substrate with high permeability.

Small quantities, of the order of tenths of  $\text{mg}/\text{dm}^3$ , cause a change in the taste of water (ink taste). The presence of ferrous ions  $\text{Fe}^{2+}$  in water creates favourable conditions for the growth of ferric bacteria. A sludgy deposit forms in water pipes, which hardens over time, reducing the active flow area until the pipes are completely clogged [11].

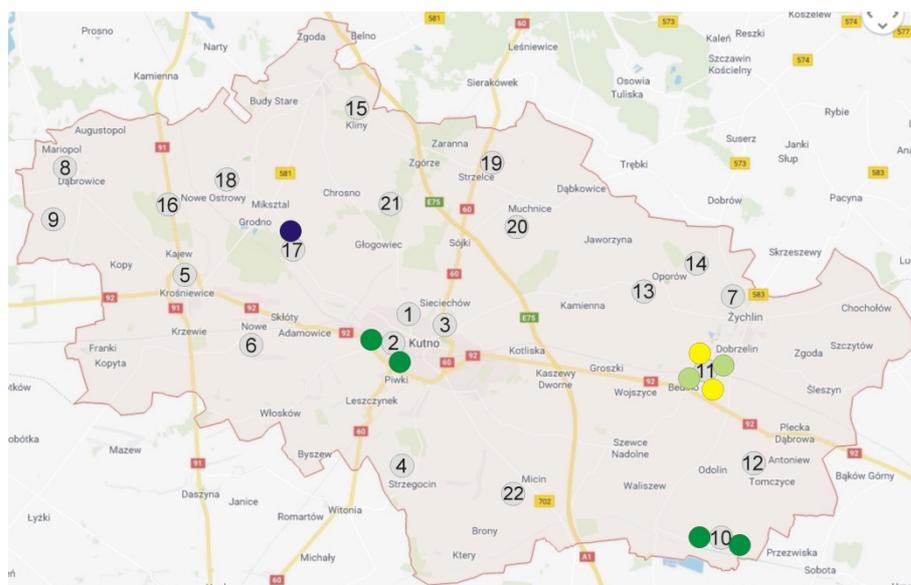


Fig. 48 Occurrence of exceedences of ammonium ion, chlorides, sodium and nitrites in the Kutno district. Source: own elaboration.

1. Kutno, 2. Kutno – PKP, 3. Kutno – Żurawieniec, 4. Kutno – Strzegocin, 5. Krośniewice, 6. Krośniewice – Nowe, 7. Żychlin, 8. Dąbrowice – Baby, 10. Bedlno – Orłów, 11. Bedlno – Pniewo, 12. Bedlno – Głuchów, 13. Oporów, 14. Oporów – Kurów, 15. Łanięta – Anielin, 16. Ostrowy, 17. Ostrowy – Grochów, 18. Ostrowy – Imielno, 19. Strzelce, 20. Strzelce – Muchnice, 21. Strzelce – Klonowiec, 22. Krzyżanów.

- ammonium ion (NH<sub>4</sub><sup>+</sup>)
- chlorides (Cl<sup>-</sup>)
- sodium (Na<sup>+</sup>)
- nitrites (NO<sub>2</sub><sup>-</sup>)

Tab. 17

Exceedences of ammonium ion, chlorides, sodium and nitrites in Kutno district in 2014-2017.

Station number (according to the map)	Town	Aquifer	Number of exceedances in the reference period				
			2014	2015	2016	2017	Total
2	Kutno - PKP	jurassic	1	1	—	—	2
10	Bedlno - Orłów	jurassic	—	1	1	—	2
11	Bedlno - Pniewo	jurassic	—	2	1	1	4
17	Ostrowy - Grochów	quaternary	—	1	—	—	1

Source: own elaboration.

Nitrogen compounds occur mostly in the form of ammonium ions NH<sub>4</sub><sup>+</sup>, nitrite ions NO<sub>2</sub><sup>-</sup> and nitrate ions NO<sub>3</sub><sup>-</sup>. Larger quantities, of the order of a few or several mg/dm<sup>3</sup>, are found in some shallow waters which can be reached from surface pollution sources. The decomposition of proteinaceous substances results in the formation of ammonia (in faecal and industrial effluents, gasworks, coking plants, chemical factories) in cooperation with putrefactive bacteria. The ammonia is oxidised by nitrifying bacteria to nitrite, which is then converted to nitrate. The mutual ratio of ammonia, nitrite and nitrate is therefore an important indicator of its pollution. Ammonia or the ammonium ion NH<sub>4</sub><sup>+</sup> of deep waters accompanies natural gas and oil deposits and can therefore be a valuable hydrogeochemical indicator in oil exploration. [12] The presence of ammonia in shallow water indicates a fresh source of pollution, while the

simultaneous presence of ammonia, nitrite and nitrate indicates that the water has been polluted for a long time. Under anaerobic conditions, nitrates and nitrites are reduced to the gaseous form N<sub>2</sub> with the participation of denitrifying bacteria.[12]

The occurrence of ammonium ion in the water intakes of Kutno-PKP and Bedlno-Orłów in 2014÷2016 may have been caused by an environmental disaster. At the beginning of 2014, there was a failure of the sewage treatment plant in Kutno, which resulted in the ingress of large quantities of untreated organic waste. This waste water was the reason for the disappearance of biological life in the rivers Ochnia and Bzura. The Kutno-PKP water intake point is located near the Ochnia riverbed. Exceeding of ammonium ion standards occurred in this intake shortly after contamination. The examination of the state of water in the Bedlno-Orłów point in the

following year also showed exceedence of the ammonium ion indicator. The return of the ecosystem of the Ochnia and Bzura rivers to normal in 2016 resulted in the disappearance of the occurrence of exceedances of the ammonium ion in the drinking water intakes Kutno-PKP and Bedno-Orłów.

The occurrence of a significant increase in nitrites in the Ostrowy-Grochów water intake in March 2015 was also most likely a consequence of the failure of the treatment plant in Kutno. The Głogowianka River, which has its sources near Grochów and is a tributary of the Ochnia River, which was a source of organic waste contamination during this period.

The chloride ion is one of the most common, accompanying the sodium and potassium ions and

causing the salinity of water. It negatively influences the taste and smell of water. In drinking water, the content of chloride ion must not exceed 250 mg Cl-/dm<sup>3</sup>, the presence of free chlorine is allowed only if the water is chlorinated at 0.3-0.5 mg Cl<sub>2</sub>/dm<sup>3</sup>. [13]

The occurrence of increased amounts of sodium and chloride ion in the Bedno-Pniewo water intake in 2015÷2017 may have been caused by the storage in this area of large amounts of road salt improperly protected against weather conditions. Currently, work is being carried out on a new borehole for the Water Intake Station in Bedno-Pniewo.

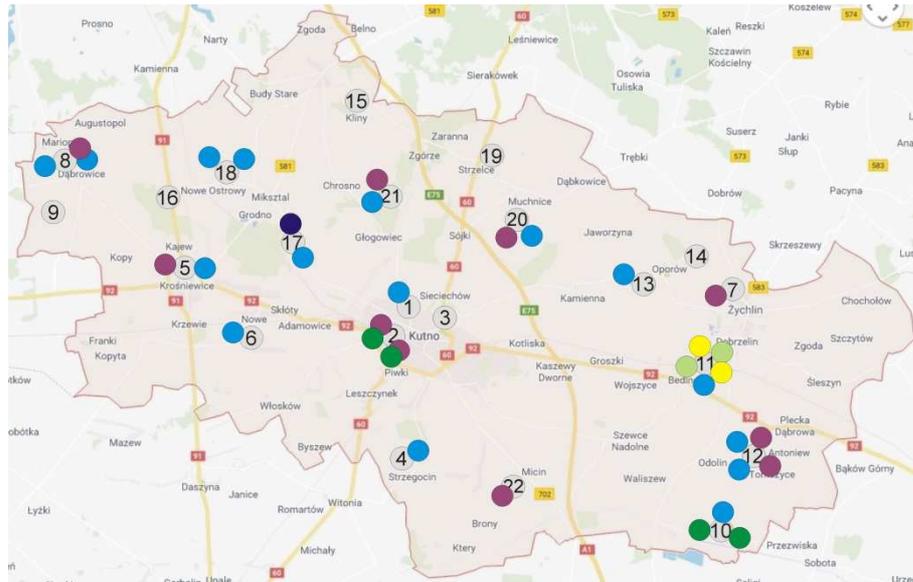


Fig. 49 Location of all exceedances in the Kutno district. Source: own elaboration.

1. Kutno, 2. Kutno – PKP, 3. Kutno – Żurawieniec, 4. Kutno – Strzegocin, 5. Krośniewice, 6. Krośniewice – Nowe, 7. Żychlin, 8. Dąbrowice, 9. Dąbrowice – Baby, 10. Bedno – Orłów, 11. Bedno – Pniewo, 12. Bedno – Głuchów, 13. Oporów, 14. Oporów – Kurów, 15. Łanięta – Anielin, 16. Ostrowy, 17. Ostrowy – Grochów, 18. Ostrowy – Imielno, 19. Strzelce, 20. Strzelce – Muchnice, 21. Strzelce – Klonowiec, 22. Krzyżanów.

- manganese (Mn)
- iron (Fe)
- ammonium ion (NH<sub>4</sub><sup>+</sup>)
- chlorides (Cl<sup>-</sup>)
- sodium (Na<sup>+</sup>)
- nitrites (NO<sub>2</sub><sup>-</sup>)

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