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GEOSTATISTICAL CHARACTERIZATION OF SPACE-TIME VARIATION IN QUALITY PARAMETERS IN KLODZKO WATER SUPPLY SYSTEM (SW PART OF POLAND)

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INTRODUCTION

The quality of water in the urban water supply system is vitally important since it affects the health of the population. Generally, the farther below the permissible levels the water quality parameters are, the better our health (which is an invaluable asset).

The subject of this study is the area-time variation in the quality parameters of the water in the water supply system in the town of Klodzko (SW part of Poland) in the years 2007-2011. The subject of spatial estimations was the variation in the main three quality parameters, i.e. iron (Fe) content, manganese (Mn) content and ammonium ion (NH_4^+) content, of the water in the water supply network in the Klodzko town area. Data on network water determinations were made available to the author by the Klodzko Water Board in connection with her research carried out in the years 2011-2012.

The present paper is another work dealing with the quality of water in the Klodzko water supply system, focusing on the variation in the basic quality parameters. The spatial analyses are based on the results of chemical determinations of the network water for the years 2007-2011 and of the treated water for the years 2008-2011 [6].

The results of the estimation of treated water and raw (mixed) water determinations carried out in the years 2008 ÷ 2011 are reported. Also the results of assessments of the basic parameters of the quality of water in the water supply network carried out in the years 2007-2011 are presented.

Then spatial analyses, i.e. 3D geostatistical studies) of the quality parameters of the network water and the treated water, were carried out. The analyses were based on the directional variogram function and the ordinary kriging technique (in its block and point versions). The theoretical basis of the methods is presented in, e.g., [1, 3, 5, 11].

EVALUATION OF BASIC STATISTICS OF TREATED (first point of water consumption) WATER QUALITY PARAMETERS

According to the Regulations of the Minister of Health the amount of Fe iron and Mn manganese tin the water can't be greater, than respectively 0.2 g Fe/m^3 and 0.05 gMn /m^3.

Fe and Mn compounds are washed into deep water from the rocks and soil. Iron Fe may also come from sewage metallurgical and manganese Mn with wastewater from mining, metallurgical, ceramic, or with fertilizers. Iron Fe presents in the water in the form of Fe^{+2} compounds of di- and trivalent Fe^{+3}, respectively Fe (II) and Fe (III). Under aerobic conditions, eg. in surface waters prevail compounds of Fe (III). Hydrolyze - under the influence of the water precipitated as a solid. The concentration of the compounds of the Fe present in the dissolved form is thus usually small. In the deep-sea, which under anaerobic conditions dominate Fe in the form of ions dissolved in the water divalent Fe^{+2} (II). Their number can range from trace values to several gFe/m^3. Mn manganese is present in the deep-sea in the form of soluble compounds of divalent Mn^{+2} (II). Mn is very often accompanied compounds of Fe, but it is usually much less - up to 10 gMn/m^3. Fe iron removal is based on the oxidation of all the soluble forms of two-value + 2 Fe^{+2} (II) to water-insoluble trivalent form Fe^{+3} (III), followed by the removal of the water formed compounds of Fe (III). Removal takes place by means of filtration and adsorption on appropriately selected fields. Demanganization extends in a similar way, except that the compounds of the divalent Mn^{+2} (II) is oxidized to form tetravalent Mn^{+4} (IV). Created by Mn compounds, however, are more durable and harder to remove.

In the presented case, i.e. study for the region of Klodzko, sources of the increased contents of Fe and Mn are connected first of all with agriculture, i.e. farming, improper fertilization of agricultural land and also caused by the factors of geochemical origin (rock-base in Klodzko water intake area).

A modern water treatment plant with a capacity of about 9000 m^3/24 h was built in Klodzko in the years **1996-1999.** Water from the intakes is fed into the aeration tower from where it gravitationally flows through reaction tanks, filters and a clean water tank. The function of the tower is to aerate the water and separate carbon dioxide (CO_2), hydrogen sulphide (H_2S), other volatile substances and low-molecular-mass organic compounds from it. Atmospheric oxygen introduced into the water oxidizes iron (Fe) and manganese (Mn) compounds, which improves the taste and smell of the water. The forming Fe and Mn compounds are captured as sediment by sand filters. The filters, made of stainless steel, are characterized by high quality of workmanship, simple design, minimal service requirements, continuous operation, high filtration efficiency and low bed-washing water consumption. After filtration an aqueous solution of chlorine dioxide (ClO_2) is added to the water, acting bactericidally and protecting the water in the urban network distribution system. Chlorine dioxide is odourless, prevents deposit build-up in water installations, kills bacteria, leaves no harmful residue and does not require neutralization. Pure water is collected in a 1000 m^3 capacity tank and then pumped by a pumping station to the urban network. The quality of the treated water is controlled by the water company and independent water quality laboratories.

Table 1 shows the basic statistics for the treated (the first point of water consumption (FPWC) water quality parameters in the Klodzko town area. The estimates are based on the results of chemical analyses of the treated water carried out in the years 2007-2011. In that period chemical determinations of different quality parameters, i.e. iron (Fe) content, manganese (Mn) content, ammonium ion (NH_4^+) content, heavy metal (Cu, Cd, Pb, Ni, Cr, Hg) content, oxidation capacity and total organic carbon (TOC) content of treated (FPWC) water were carried out sixteen times.

From among the studied parameters, lead (Pb) content, ammonium ion (NH_4^+) content and copper (Cu) content show the strongest (extreme and very high) variation, reflected in the highest values of coefficients V (Table 1). Also total organic carbon (TOC), cadmium (Cd) content, manganese (Mn) content, oxidation capacity, chromium (Cr) content and iron (Fe) content were found to vary considerably.

Permissible values of the investigated quality parameters of a treated water:

- content of Mn manganese < 0.050 [gMn/m^3],
- content of Fe iron < 0.200 [g Fe/m^3],
- content of NH_4^+ ammonium ion < 0.500 [gNH_4^+/m^3],
- content of overall organic coal C (OWO) [5gC/m^3],
- oxidizability O_2 - [5gO2/m^3],
- content of Pb lead - 0.025 [gPb /m^3],
- content of Cd cadmium - 0.005 [gCd/m^3],
- content of Cu copper - 2.000 [g Cu/m^3],
- content of Hg mercury Hg - 0.001[gHg/m^3],
- content of Cr chromium Cr - 0.050 [gCr/m^3],
- content of Ni nickel - 0.020 [gNi/m^3],
- content of Ag silver - < 0.010 [gAg/m^3].

From among the eleven analyzed parameters, three basic quality parameters Fe content, Mn content and NH_4^+ content of the treated water in the Klodzko town area did not exceed the allowable values (Table 1). Only the maximum cadmium (Cd) content and the minimum, maximum and average mercury (Hg) content reach the level allowable for these elements (Table 1).
The coefficients of the correlation between the original values Z of the three analyzed quality parameter of treated water indicate no correlation or weak negative correlation between them:
Fe/Mn 0.1273, Mn/NH_4^+ 0.3133, Fe/NH_4^+ 0.0543.

Table 1. Basic statistics of quality parameters of treated (FPWC) water for years 2007-2011.

Analyzed parameter	Sample size n	Minimal value X_{min} [g/m^3]	Maximal value X_{max} [g/m^3]	Average value X [g/m^3]	Standard deviation S [g/m^3]	Variation coefficient V [%]
content of Fe iron	16	0.0005	0.1300	0.0566	0.0265	46.85
content of Mn manganese	16	0.0010	0.0440	0.0137	0.0093	67.86
content of NH_4^+ ammonium ion	16	0.0130	0.2900	0.0666	0.0682	102.40
content of Cu copper	8	0.0005	0.0030	0.0008	0.0008	101.76
content of Hg mercury	8	0.0030	0.0040	0.0039	0.0003	8.53
content of Cd cadmium	8	0.0005	0.0090	0.0031	0.0024	79.33
content of Ni nickel	2	0.0010	0.0020	0.0015	0.0005	33.33
content of Cr chromium	8	0.0010	0.0110	0.0051	0.0026	50.16
content of Pb lead	9	0.0003	0.0040	0.0011	0.0015	133.48
oxidizablity O_2	9	0.0005	0.0100	0.0042	0.0023	56.00
content of overall organic coal C (OWO)	9	0.0005	4.4000	1.7769	1.5888	89.41

EVALUATION OF BASIC STATISTICS OF WATER QUALITY PARAMETERS IN WATER SUPPLY SYSTEM

Estimates of the basic statistics of the water quality parameters in the Klodzko town water supply system in the years 2007-2011 are presented in Table 2. The results show that the maximum values of the two considered parameters, i.e. Fe content and Mn content, exceed the standard, the permissible values (Table 2). The mean value of Mn content reaches the allowable level of this element content in water. Whereas the averages of the other considered water quality parameters, i.e. Fe content and NH_4^+ content were much below the permissible values. The minimum values for the three parameters are close to zero.

High values of variation coefficient V were obtained for the water quality parameters in the water supply system, which were higher for Mn content and NH_4^+ content. This indicates stronger variation in the values of the two parameters in comparison with the Fe content variation (Table 2).

The coefficients of the correlation between the original values Z for the three network water quality parameters indicate (as expected) no correlation between them:
Fe/Mn 0.031,NH_4/Mn 0.099,NH_4^+/Fe 0.0968.

Table 2. Basic statistics of water quality parameters in water supply system in Klodzko town area (years 2007-2011).

Analyzed parameter	Sample size n	Minimal value X_{min} [g/m^3]	Maximal value X_{max} [g/m^3]	Average value X [g/m^3]	Standard deviation S [g/m^3]	Variation coefficient V [%]
content of iron Fe	65	0.01	0.34	0.07	0.05	70.00
content of manganese Mn	65	0.00	0.12	0.02	0.02	96.00
content of ammonium ion NH_4	65	0.01	0.36	0.05	0.05	97.00

Fig. 1. Histogram of distribution of iron (Fe) content [gFe/m^3] in water supply system in Klodzko town area.

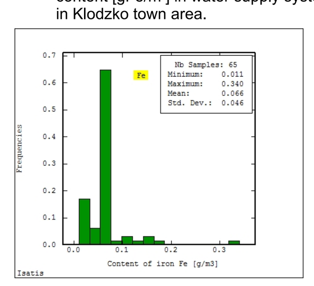


Fig. 2. Histogram of distribution of manganese (Mn) content [gMn/m^3] in water supply system in Klodzko town area.

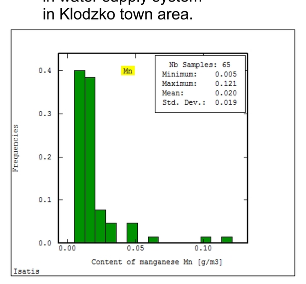
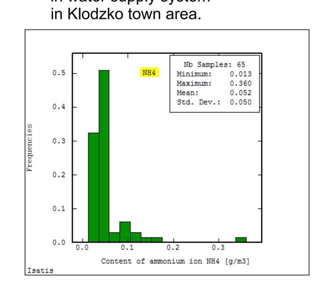


Fig. 3. Histogram of distribution of ammonium ion (NH_4^+) content [gNH_4^+/m^3] in water supply system in Klodzko town area.



ANALYSIS OF WATER QUALITY PARAMETERS IN WATER SUPPLY SYSTEM DISTRIBUTION HISTOGRAMS

Histograms of the distribution of the water quality parameters: Fe content, Mn content and ammonium ion (NH_4^+) content were calculated using water sampling data for the period 2007-2011 (Figs 1-3).

The histograms of the distribution of the considered parameters are distinctly positively skew and sharp (Figs 1-3) (Table 4). The histogram of the distribution of Mn content (Fig. 2) is single-wing while the histogram of Fe content distribution has a biomodal character. The histograms of Fe content and ammonium ion NH_4^+ distribution are characterized by the highest kurtosis (g_2) The positive skewness (g_1) of the histograms is in a range of 3.54-3.83 (Fig. 3).

ANALYSIS OF DIRECTIONAL SEMIVARIOGRAMS OF WATER QUALITY PARAMETERS IN KLODZKO TOWN AREA WATER SUPPLY SYSTEM

The directional semivariograms (D-90) of Fe content, Mn content and NH_4^+ content in the water in the Klodzko water supply system were analyzed. The directional semivariograms (D-90) of the water quality parameters were calculated along the time axis (the years 2007-2011) (Figs 4-6).

In the analyzed period of time the directional semivariogram (D-90) of Fe content showed a clear tendency towards periodic changes in the values of function ă(h) of this parameter, with a noticeable nugget effect (C_0) share in overall variation C (Fig. 4). The shape of this semivariogram could be more precisely represented by a sinusoidal model (e.g. Since Card) than by the adopted spherical model.

In the directional semivariogram (D-90) of Mn content one can observe a rather slow, but consistent, growing tendency in the values of function ă(h) of this parameter in the analyzed period (Fig. 5). The semivariogram reveals a very large share of the random component (nugget effect C_0) in overall variation C.

The directional semivariogram (D-90) of ammonium ion (NH_4^+) content also shows a clearly growing tendency in the values of function ă(h) of this parameter over the years 2007 2011 (Fig. 6). At the beginning of this period large fluctuations in function ă(h) values occur. Similarly as in the semivariogram of Fe content, also in the variogram of Nh_4^+ content one can notice a substantial share of nugget effect C_0 in overall variation C.

The analysis of the directional semivariograms (D-90) carried out for two basic quality parameters of underground water in the Klodzko water intake area showed a slow upward trend in Fe content which became apparent only over a long time period, i.e. over the years 1977-2012 [6, 9, 10]. In comparison with the semivariogram (D-90) of Mn content in the network water, the semivariogram of Mn content rose sharply in the initial part of the function ă(h) graph and stabilized only later (Fig. 5). In the former case, the increase in the values of ă(h) (Mn) was consistent, but proceeded slower and the changes in the value of ă(h) were more moderate.

The directional semivariogram of Fe content in the network water was characterized by the shortest extent of 1 year (Table 5). The directional semivariogram of Mn content showed a longer extent of 1.5-3.5 years. The longest extent, amounting to 6 years, characterized the directional semivariogram of ammonium ion (NH_4^+) content. In the studied time interval of 2007-2011 Fe content in the network showed a much lower correlation than that of Mn content or NH_4^+ content. In the case of the latter parameter, the correlation could be traced over a longer period of time.

The directional semivariograms of the basic water quality parameters in the water supply network were approximated using a combination of two spherical models and the nugget effect (Table 5). The results of the cross-validation of the adopted theoretical models of the directional semivariograms (D-90), performed using ordinary point kriging, show that the latter were approximated correctly.

The obtained coefficients (r) of the correlation between original values Z and estimated averages Z* were in a range of 0.61 (Fe content), 0.19 (Mn content) and 0.578 (NH_4^+ content).

The standardized errors, calculated using the test data reached: 1.00 (Fe content and Mn content) and 0.79 (NH_4 content).

For comparison, the extents of the directional semivariograms (D-90) determined on the basis of the underground water sampling data for the longer period of 1977-2012 amounted to about 3 years for Fe content and to 2 years for Mn content [6, 9, 10]. It was found that the correlation of the Fe content in the underground water extended over a longer time period than that of the Mn content.

ANALYSIS OF DIRECTIONAL SEMIVARIOGRAMS OF TREATED WATER QUALITY PARAMETERS

Analyzing the tendencies in the variation of the network water quality parameters determined from the directional semivariograms (D-90) and comparing them with the results of the structural analysis for the treated water one finds both a certain similarity and dissimilarities in the graphs of function ă(h). One should mention here the small size of the data sample (n = 16) available for the calculation of the directional semivariograms (D-90) of the treated water quality parameters (Table 1) in comparison with the size of the network water data sample (n = 66) (Table 2).

In the years 2008-2012 the directional semivariogram (D-90) of Fe content in the treated water shows some periodic variation in the value of ă(h), with nugget effect C_0 manifesting itself (Fig. 7). A certain analogy to the semivariogram (D-90) of Fe content in the network water is observed here (Fig. 4).

The directional semivariogram (D-90) of Mn content in the treated water, with a distinct small share of the random component (nugget effect C_0), shows a clear increase in the value of function ă(h) towards the years 2009-2010. In the further part of the graph a decrease in the value of ă(h) is observed (Fig. 8).

In the considered time period (the years 2008-2011) a very strong growing trend in the ă(h) value of the directional semivariogram of NH4+ content in the treated water is observed over the years (Fig. 9). This trend is visible in the entire course of the graph.

The directional variograms (D-90) were approximated with a single spherical model with the nugget effect or with a combination of two such models, with the nugget effect (Table 6). The longest extent of correlation characterized the semivariogram (D-90) of NH4+ content in the treated water (a = about 4 years) (Fig. 8), the intermediate correlation extent characterized the semivariogram of Mn content (a = about 2 years) and a shorter correlation extent characterized the semivariogram of Fe content (a = 1.55 year) (Fig. 7) (Table 6). A certain similarity to the shorter extent a of the semivariogram (D-90) of Fe content in the network water is visible here (Table 5).

The results of the cross-validation of the applied models of the treated water quality parameter semivariograms indicate relatively low values of the coefficients of the correlation between original values Z and estimated averages Z*. The correlation coefficients amounted to respectively: r = -0.23 (Fe content), r = -0.182 (Mn content) and r = 0.375 (NH_4^+ content).

The standardized errors would reach the standard value of 1 when the test data were used in the calculations and would amount to respectively 0.46 (Fe content), 0.48 (Mn content) and 0.33 (NH_4^+ content) when the robust data were used.

Fig. 4. Directional semivariogram (D-90) of Fe iron content [gFe/m^3]^2

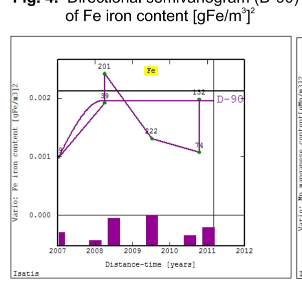


Fig. 5. Directional semivariogram (D-90) of Mn manganese content [gMn/m^3]^2

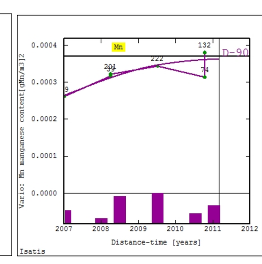


Fig. 6. Directional semivariogram (D-90) of NH_4^+ content [gNH_4/m^3]^2

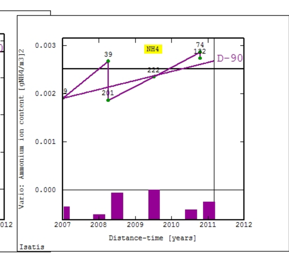


Fig. 7. Directional semivariogram (D-90) of Fe iron content [gFe/m^3]^2 in treated water

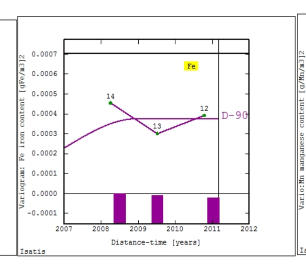


Fig. 8. Directional semivariogram (D-90) of Mn manganese content [gFe/m^3]^2 in treated water

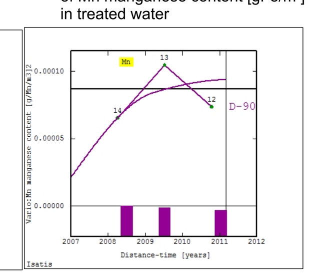


Fig. 9. Directional semivariogram (D-90) of NH_4^+content [gNH_4^+/m^3]^2 in treated water

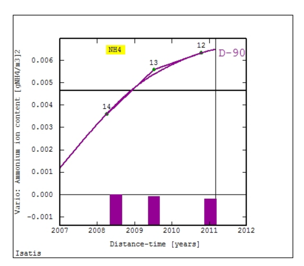


Table 5. Comparison of geostatistical model values of directional semivariograms (D-90) for water quality parameters in water supply system (years 2007-2011).

Analyzed parameter	Nugget efect variance C_0 [g/m^3]^2	Partial variance C' [g/m^3]^2	Total sill variance C [g/m^3]^2	Range of influence a [years]	Basic model structures
content of Fe iron [gFe/m^3]	0.000953865	0.0010002000	0.001954065	0.93	nugget efect, spherical,
content of Mn manganese [gMn/m^3]	0.0002632270	2.7636322632 7.1258452750	9.8897407653	2.08 3.43	nugget efect, spherical, spherical
content of NH_4^+ ammonium ion [gNH_4^+/m^3]	0.0018982408	0.001392832394	0.00342854	5.00 5.89	nugget efect, linear

Table 6. Comparison of geostatistical model values of directional semivariograms (D-90) for treated water quality parameters (years 2008-2011).

Analyzed parameter	Nugget efect variance C_0 [g/m^3]^2	Partial variance C' [g/m^3]^2	Total sill variance C [g/m^3]^2	Range of influence a [years]	Basic model structures
content of Fe iron [gFe/m^3]	0.00022673216	0.0001472044639	0.00037393662	1.55	nugget efect, spherical,
content of Mn manganese [gMn/m^3]	-	-	9.2880949610	1.94	nugget efect, spherical,
content of NH_4^+ ammonium ion [gNH_4^+/m^3]	0.001245021	0.00387296980 0.001513648347	0.006631639147	3.80 2.61	nugget efect, spherical, spherical.

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Raster map (in perspective view) showing distribution of estimated Fe iron content [gFe/m^3] averages Z* in Klodzko town area water supply system

Fig. 10. ... in 2007.

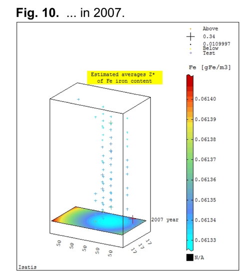


Fig. 11. ... in 2010.

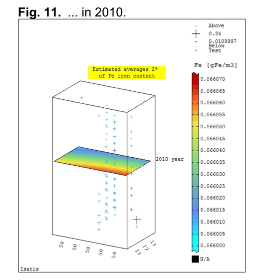
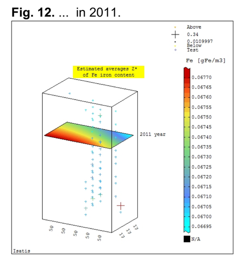


Fig. 12. ... in 2011.



Raster map (in perspective view) showing distribution of estimated averages Z* of Mn content [g/m^3] in Klodzko town water supply system

Fig. 13. ... in 2007.

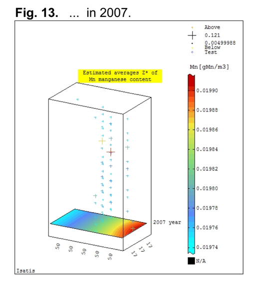


Fig. 14. ... in 2010.

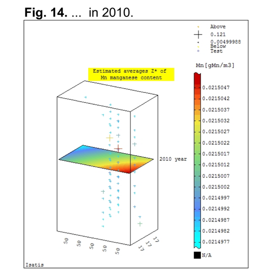
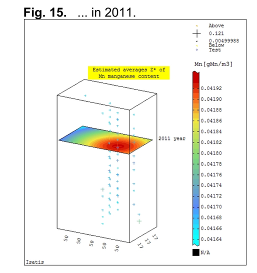


Fig. 15. ... in 2011.



Raster map (in perspective view) showing distribution of estimated averages Z* of NH_4^+ ammonium ion content [gNH_4^+/m^3] in Klodzko town are water supply system

Fig. 16. ... in 2007.

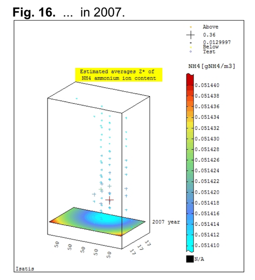


Fig. 17. ... in 2010.

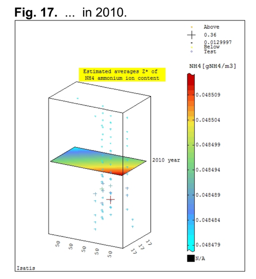
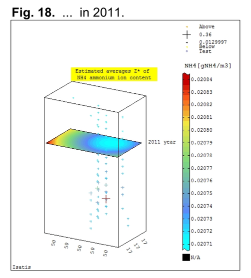


Fig. 18. ... in 2011.



Block diagram (3D Box) showing distribution of estimated averages Z* of Fe content [gFe/m^3] in water supply system

Fig. 19. ... in 2007.

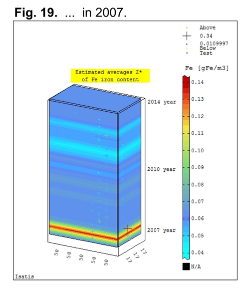


Fig. 20. ... in 2010.

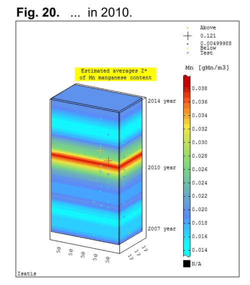
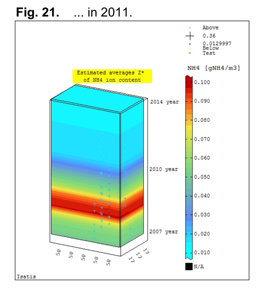


Fig. 21. ... in 2011.



Block diagram (3D Box) showing distribution of estimated averages Z* of NH_4^+ content [gNH_4^+/m^3] in treated water.

Fig. 22. ... in 2007.

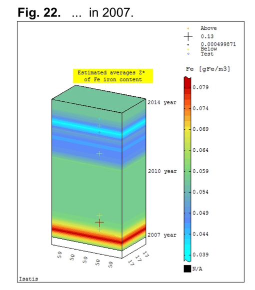


Fig. 23. ... in 2010.

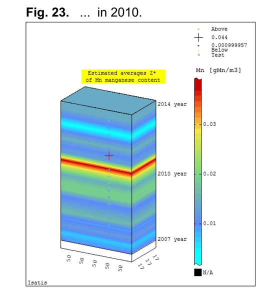
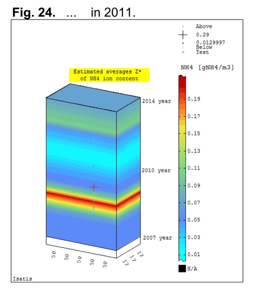


Fig. 24. ... in 2011.



RESULTS OF ESTIMATION

The results of the estimation of averages Z* and estimation standard deviation ó$_k$ of the water quality parameters calculated in 253825 nodes of the elementary grid covering the Klodzko town area water supply network are presented in Tables 7-8.

The variation coefficients (V) of averages Z* indicate merely moderate variation in Fe content and Mn content and high variation in ammonium ion (NH4+) content (Table 7). In the case of the latter parameter, the result of the calculations of coefficient V indicates considerable variation in NH4+ content over the years 2007-2011, which explains some difficulties in matching a suitable model to the directional semivariogram.

The coefficients of variation of estimation standard deviation ó$_k$ (Table 8) indicate small variation of this parameter for Fe content and NH_4^+ content and very small variation for Mn content.

Thus the results of the calculations of estimation deviation ó$_k$ (Table 8) validate the estimation of the Z* values of the network water quality parameters. Only the histograms showing the distribution of Fe content averages Z* and estimation deviations ó$_k$ of NH_4^+ content are clearly positively skew, and sharp (Table 9).

The averages Z* and estimation standard deviations ó$_k$ of the treated water quality parameters in 71500 nodes of the elementary grid covering the Klodzko town water supply network were estimated using the data for the years 2008-2011 (Tables 10-11).

The variation coefficients (V) for the averages Z* of the treated water quality parameters confirm the high variation in Mn content and the even higher variation in NH_4^+ content (Table 10). The variation coefficients (V) for estimation standard deviations ó$_k$ indicate high variation in Mn content and moderate variation in NH_4^+ content (Table 11). This can be due to the small size of the data sample (n=16) used to model and estimate averages Z*. The same applies to the size of the date sample (n=16) used to estimate the averages Z* of Fe content, but the variations in averages Z* and in ó$_k$ values are small (Tables 10-11).

Table 7. Global statistics of estimated averages Z* of water quality parameters in water supply system (results of ordinary block kriging for years 2007-2011).

Analyzed parameter	Number of grid nodes n	Minimal value X_{min} [g/m^3]	Maximal value X_{max} [g/m^3]	Average value $\overline{X}$ [g/m^3]	Standard deviation S [g/m^3]	Variation coefficient V [%]
content of Fe iron	253825	0.0392	0.1682	0.0649	0.0191	29.36
content of Mn manganese	253825	0.0143	0.0419	0.0205	0.0063	30.51
content of NH4+ ammonium ion	253825	0.0153	0.1017	0.0456	0.0284	62.40

Table 10. Global statistics of estimated averages Z* of treated water quality parameters (results of ordinary block kriging for years 2008-2011).

Analyzed parameter	Number of grid nodes n	Minimal value X_{min} [g/m^3]	Maximal value X_{max} [g/m^3]	Average value $\overline{X}$ [g/m^3]	Standard deviation S [g/m^3]	Variation coefficient V [%]
content of Fe iron	71500	0.0399	0.0795	0.0564	0.0080	14.18
content of Mn manganese	71500	0.0035	0.0372	0.0141	0.0069	49.15
content of NH_4^+ ammonium ion	71500	0.0183	0.2064	0.0678	0.0441	65.07

SPATIAL VISUALIZATION OF ESTIMATION RESULTS

Raster maps (in perspective view) of water supply system quality parameters.

Iron (Fe) content

In 2007 the largest area with the lowest averages Z* of Fe content (Z*: 0.06133-0.06135 gFe/m^3) became apparent (Fig. 10). At the same time the maximum averages Z* of Fe content ranged from 0.06138 to 0.06140 gFe/m^3.

In 2010 in the S and SE part of the area a band of the maximum averages Z* of Fe content, ranging from 0.066060 to 0.066070 gFe/m^3, extended (Fig. 11). The lowest averages Z* ranged from 0.066000 to 0.066015 gFe/m^3 (the N part of the area).

In 2011 the maximum averages Z* of Fe content decreased (in comparison with 2010) to the range of 0.06760- 0.06770 gFe/m^3 while the lowest averages Z* ranged from 0.06695 to 0.06710 gFe/m^3 (Fig. 12). The maximum averages Z* of Fe content were found in the S and SW part of the area while the minimum averages Z* of Fe content occurred in the NE part.

Manganese (Mn) content

On the raster maps showing the distribution of Mn content averages Z* calculated for the particular years: 2007, 2010 and 2011 (Figs 13-15) one can see that the maximum averages Z* covered considerable areas of the water supply network. They occurred mostly in the west (W) and south-west (SW) parts, but also in the central part of the town of Klodzko.

On the map for 2007 the highest averages Z* of Mn content in water in the water supply network ranged from 0.01986 to 0.01990 gMn/m^3 while the lowest averages Z* ranged from 0.01974 to 0.01978 gMn/m^3 (Fig. 13).

On the map for 2010 two ranges stood out, i.e. the range of maximum averages Z*: 0.0215037-0.0215047 gMn/m^3 and the range of the lowest averages Z*: 0.0214977- 0.0214992 gMn/m^3 (Fig. 14).

On the map for 2011 the Mn concentration in the network water was found to vary. An extensive subarea of Mn content averages Z*, representing the highest averages Z* ranging from 0.04188 to 0.04192 gMn/m3, occurred in the SW part of the area (Fig. 15). The lowest Mn content averages Z* ranged from 0.04164 to 0.04170 gMn/m^3.

Ammonium ion (NH_4^+) content

Exemplary raster maps of estimated averages Z* of NH_4^+ content in the network water showed that this parameter tended to increase from 2007 to 2010 (Figs 16-17).

In the map for 2007 the maximum averages Z* ranged from 0.051436 to 0.051440 gNH_4^+/m^3 (Fig. 16). They occurred in the SW and SE parts of the Klodzko town area. The lowest averages Z* ranged from 0.051410 to 0.051416 gNH_4^+/m^3, covering a considerable area (2/3 of the Klodzko town area), occurred in the N, E and central part of Klodzko.

In the map for 2010 one could see an increase in averages Z*, i.e. the maximum averages Z* ranged from 0.048504 to 0.048509 gNH_4^+/m^3 and formed a small subarea in the SE part (Fig. 17). The minimum averages Z* ranged from 0.048479 to 0.048489 gNH_4^+/m^3, forming a large subarea (Fig. 17).

In the map for 2011 the maximum averages Z* were observed in the SW and W part of the Klodzko town area, ranging from 0.02082 to 0.02084 gNH_4^+/m^3 (Fig 18). The lowest averages Z*, forming a large centre (subarea), ranged from 0.02071 to 0.02074 gNH_4^+/m^3.

Block diagrams of water supply system quality parameters

The resultant (total) block diagrams (3D Box) showing the distribution of averages Z* of Fe, Mn and NH_4^+ content in the water supply network, reveal certain tendencies in the variation of the parameters characterizing the quality of the water in the years 2007-2011 (Figs 19-21). In the spatial block diagrams one can see levels of increased and decreased averages Z* of the parameters, corresponding to some of the years.

The year 2007 stood out because of the highest Fe content averages Z* (in a range of 0.13-0.14 gFe/m^3, with an aureola of values: 0.12-0.13 and 0.11-0.12 gFe/m^3) (Fig. 19). A downward trend in averages Z* started in the following years. Beginning with 2007 the changes in averages Z* were distinctly periodic (Fig. 19).

The Mn content parameter showed an opposite behaviour over the years. A variation trend was observed in the years 2007-2011, with a growth towards 2011. The maximum Mn content averages Z* (in range: 0.034-0.038 gMn/m^3, with an aureola of values: 0.032 ÷ 0.034 gMn/m^3) occurred in 2011 (Fig. 20).

The highest NH_4^+ content averages (in a range of: 0.080-0.100 gNH_4^+/m^3, with an aureola of values: 0.070-0.080 g NH_4^+/m^3) occurred in the years 2009-2010 (Fig. 21). A certain periodicity in the variation of NH_4^+ content was observed in the years 2007-2011.

Block diagrams of treated water quality parameters

Block diagrams of the distribution of treated water quality parameters, plotted in the basis of data from the years 2008-2011 show distinct elevations in the levels of average Fe, Mn and NH_4^+ content (Figs 22-24) in similar years in which they appeared in the block diagrams of the network water quality parameters (Figs 19-21).

In the block diagram of the averages Z* of Fe content in treated water for 2007 one could see a level representing a range of averages Z*: 0.074-0.079 gFe/m^3, with an aureola of values reaching 0.069 gFe/m^3 (Fig. 22).

An elevated level of averages Z* of Mn content in treated water, representing a range of values > 0.030 gMn/m^3, with an aureola of values: 0.025-0.030 gMn/m^3 appeared in the block diagram for 2011 (Fig. 23).

An elevated level of averages Z*, ranging from 0.17 to 0.19 and > 0.19 [gNH_4^+/m^3], with an aureola of values: 0.15-0.17 [gNH_4^+/m^3] appeared in the block diagram showing the distribution of the averages Z* of NH_4^+ content in treated water for 2009 (Fig 24).

DISCUSSION OF RESULTS

The modelling and estimation of the selected water quality parameters of the network water and the treated water for the Klodzko town area were based on a relatively small statistical sample of data. This particularly applies to the size of the treated water data sample. Nevertheless, even the small size of the data sample is sufficient to get a picture of the water quality, i.e. of the changes in Fe content and Mn content in the treated water over time. Generally, it is supposed that the quality of both the network water and the treated water can be the resultant of the quality of underground water in the Klodzko water intake area, i.e. of the changes in Fe and Mn content taking place in the years 1977-2012.

The technique of ordinary kriging was used to estimate Fe and Mn content averages Z*. However, the shapes of the histograms showing the distribution of the quality parameters, and their skewness coefficients g, seem to indicate that lognormal kriging could have been more useful in this case. The overestimation or underestimation of averages Z*, which is typical of the latter technique, was the reason for using ordinary kriging.

CONCLUSIONS

The results of the geostatistical studies show that, besides heavy metal (cadmium and mercury) content the basic water quality parameters first Mn content, then Fe content (in both network water and raw (mixed) water) and to a lesser degree NH_4^+ content should be regarded with special interest. Most often Mn content and Fe content (minimum, maximum or mean values) would exceed the levels permissible for these elements.Elevated levels of averages Z* of the investigated water quality parameters in both network water and treated water occurred in certain years (Fe content in 2007, NH_4^+ content in 2009-2010, Mn content in 2011). For both kinds of water (the network water and the treated water) the elevated levels were observed in the same years.

In the analyzed relatively short period (2007-2011) towards 2011 a clearly downward trend in Fe content in the network water, accompanied by a tendency towards periodic variation, became clearly apparent. The Mn content in the network water was characterized by an opposite behaviour, showing an upward trend in its variation towards 2011. A similar tendency was observed in the case of ammonium ion (NH_4^+) content, with a clear growth from 2007 to 2010.In the years 2007-2011 the maximum values of Mn content, Fe content and NH_4^+ content in the network water would occur in different parts of the Klodzko town water supply system area, but mostly they would appear in the SW, S and W parts. The results of the spatial analyses presented in this paper should be enriched with calculations based on the database content extended with the chemical determinations of network water and treated water for the years 2012-2015.