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Changes in the flow and quality of water in the dam reservoir of the Mała Panew catchment (South Poland) characterized by multidimensional data analysis

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Abstract: Multidimensional exploratory techniques, such as the Principal Component Analysis (PCA), have been used to analyze long-term changes in the flow regime and quality of water of the lowland dam reservoir Turawa (south-west Poland) in the catchment of the Mała Panew river (a tributary of the Odra). The paper proves that during the period of 1998–2016 the Turawa reservoir was equalizing the river's water flow. Moreover, various physicochemical water quality indicators were analyzed at three measurement points (at the tributary's mouth into the reservoir, in the reservoir itself and at the outflow from the reservoir). The water quality assessment was performed by analyzing physicochemical indicators such as water temperature, TSS, pH, dissolved oxygen, BOD_5, NH_4^+, NO_3^-, NO_2^-, N, PO_4^{3-}, P, electrolytic conductivity, DS, SO_4^{2-} and Cl^-. Furthermore, the correlations between all these water quality indicators were analyzed statistically at each measurement point, at the statistical significance level of $p \leq 0.05$. PCA was used to determine the structures between these water quality variables at each measurement point. As a result, a theoretical model was obtained that describes the regularities in the relationships between the indicators. PCA has shown that biogenic indicators have the strongest influence on the water quality in the Mała Panew. Lastly, the differences between the averages of the water quality indicators of the inflowing and of the outflowing water were considered and their significance was analyzed. PCA unveiled structure and complexity of interconnections between river flow and water quality. The paper shows that such statistical methods can be valuable tools for developing suitable water management strategies for the catchment and the reservoir itself.

Introduction

In view of water shortage, both in Poland and worldwide, the retention of water becomes particularly important. Similar to other countries, dam reservoirs in Poland are built in order to control the flow of water, limit the flood risk, generate hydropower, enable navigation, fishing, aquaculture, recreation and supply water for public use and irrigation (Braatne et al. 2008, Castilla-Hernández et al. 2014, De Melo et al. 2017, Kröger et al. 2013, Ling et al. 2016, Mazur et al. 2017, Varol et al. 2012, Wei et al. 2009, Wiatkowski and Paul 2009, Zhao et al.2018). Despite numerous conflicts, a reservoir can be operated quite smoothly, provided that some basic conditions are met (Wiatkowski 2015). Extensive urbanization, development of industry and intensive agriculture are factors that contribute to the deterioration of the water quality in watercourses and reservoirs. This deterioration has become a global environmental problem (Cachada et al. 2012, Kanownik et al. 2013, Koszelnik et al. 2018, Kowalik et al. 2010, Munyao et al. 2017, Nthunya et al. 2018, Rosik-Dulewska and Karwaczyńska 2008, Siepak and Sojka 2017). Dam reservoirs are artificial structures introduced into the river environment. They result in very significant changes in both the river and its valley (Hejzlar et al. 2009, Jaguś and Rzętała 2011, McCartney et al. 2001). Different opinions exist on the impact of water retention in reservoirs on water quality (Hejzlar et al. 2009, Janus and Vollenweider 1982, Kasza 2017, Koszelnik et al. 2018, Kurunc et al. 2006, Mazur et al. 2017, McCartney et al. 2001, Wiatkowski 2011, Wiatkowski et al. 2015). Numerous research studies on flow conditions and water quality were carried out both for reservoirs located in Poland (Bartoszek and Koszelnik 2016, Jaguś and Rzętała

2011, Kijowska-Strugała et al. 2016, Kostecki and Suschka 2013, Koszelnik et al. 2018, Olds et al. 2011, Wiatkowski 2011, Wiatkowski et al. 2015) and abroad (Benndorf and Pütz 1987, Boyacioglu and Boyacioglu 2008, Boyacioglu 2014, Braatne et al. 2008, De Melo et al. 2017, Kurunc et al. 2006, Ling et al. 2016, Paul and Pütz 2008).

The concentrations of indicators are usually analyzed separately and their maximum values are set out in the implementing provisions such as e.g. the Water Framework Directive in the EU (Directive 2000) and the Regulation of the Minister of Environment in Poland (Regulation 2016). A water quality assessment based solely on the comparison of water samples with the maximum levels set out in the guidelines does not provide a full picture of the sources of such pollutions and the scale of their impact on water quality (Debels et al. 2016). Consequently, other methods are needed to assess the water quality and to estimate the water flow through reservoirs. Simultaneously, these methods are required to account for many interconnected physicochemical indicators and for classification of hydrological structures into homogeneous classes based on similar water quality attributes. The use of multidimensional statistical techniques such as the PCA of complex data matrices can help to identify the possible sources that influence water quality and can be a valuable tool for the management of water resources and for instant identification of problems related to water pollution (Siepak and Sojka 2017, Varol et al. 2012, Varol and Şen 2009). To this effect, this paper attempts to use the Exploratory Data Analysis (EDA), which allows one to better understand the structures formed by the indicators that determine water quality. These indicators often remain invisible and are hard to recognize when large sets of observations are analyzed (Boyacioglu 2006, 2014, Boyacioglu and Boyacioglu 2008). Because of the high space and time variability of natural and anthropogenic factors, identifying the pollutants and their type in the area under study is currently a priority task in the monitoring and safeguarding of water resources in general (Gu et al. 2015, Praus 2005) and water storage reservoirs in particular (Boyacioglu 2014, Siepak and Sojka 2017).

The main goals of the exploratory data analysis of the Turawa reservoir were as follows: (1) analysis of the water flow changes in the Mała Panew above and below the reservoir and analysis of the volume stored in the reservoir, (2) analysis of the probability and the possible differences between the content of concentrations of the physicochemical indicators between the individual water sampling points, (3) identification of structures formed by the analyzed physicochemical indicators of water inflowing to the reservoir, stored in it and outflowing from it and identification of sources of water pollution in the Mała Panew river that flows through the Turawa reservoir, (4) analysis of the influence of the large dam reservoir in Turawa on the improvement of water quality in the Mała Panew river.

Study area

The Turawa reservoir (50º43’25” N 18º07’13” E) is the tenth largest dam reservoir in Poland. It is located on the Mała Panew river (a tributary of the Odra) at 18+900 km of its course, approximately 20 km to the north-east of the city of Opole, south-west of Poland (Fig. 1). The reservoir has multiple tasks, but its primary role is to store water from the Mała Panew for navigation, power generation, fishing and recreation, to ensure the minimum flow and provide flood protection. The reservoir parameters are as follows: operational fill level (NPP) – 175.80 m ASL (80.04 MM m^3, 1829 ha), maximum fill level (Max PP) – 176.50 m ASL (92.61 MM m^3, 1941 ha). The Turawa reservoir was built in 1933–1939.

The catchment area of the Turawa reservoir at the reservoir cross section is 1423 km^2. The Mała Panew is a lowland river with low amplitude of flow. This is due to the high afforestation and permeable soil in the river basin as well as the relatively small longitudinal and crosswise slopes. The average gradient of the Mała Panew valley is 1.58‰. Approximately 60% of the catchment area is forested. The average annual temperature is 8.4°C and the average annual precipitation is 600 mm.

Materials and methods

Sample analysis

Results obtained during the research period include:

– an analysis of water flow rates on the Mała Panew above (In_res) and below (Out_res) the Turawa reservoir, as well as an analysis of volume stored in the reservoir

Fig. 1. The location of the Turawa reservoir on the river Mała Panew and the water sampling points for physicochemical analyses. This figure is drawn in ArcGIS 10.6, using the vector data from the OpenStreetMap server (http://download.geofabrik.de/europe/poland.html) (OpenStreetMap)

(W_res). The daily average values of these parameters were obtained from the State Water Management Authority "Polish Waters" – Regional Board of Water Management (PGW WP – RZGW) in Wrocław (Instruction 2015);

– an analysis of quality values for water in the Mała Panew river inflowing to the Turawa reservoir (In_res), outflowing from the reservoir (Out_res) and stored in the reservoir (W_res), (Fig. 1). The results of water quality measurements, carried out in line with the Polish Standards, were obtained from the Province Inspectorate of Environmental Protection (WIOŚ) in Opole (Inspectorate 2015). At the sampling point In_res a total of 185 water samples were taken, as compared to 40 samples taken at W_res and 109 samples at Out_res. The water quality assessment was performed by analyzing the physicochemical indicators such as: Water Temperature (T), Total Suspended Solids (TSS), pH, Dissolved Oxygen (DO), Biochemical Oxygen Demand (BOD_5), Ammonia (NH_4^+), Nitrates (NO_3^-), Nitrites (NO_2^-), Total Nitrogen (N), Phosphates (PO_4^{3-}), Total Phosphorus (P), Electrolytic Conductivity (Cond), Dissolved Substances (DS), Sulphates (SO_4^{2-}) and Chlorides (Cl^-).

Data analysis

For the analysis of water quantity, the following were assumed:

– the volume of water inflowing and outflowing to and from the reservoir: the period of 1998–2016 (because of the flood that took place in the Odra river basin in 2010, the results were split into two research periods: the years 1998–2009 and 2011–2016, and separately the year 2010.

For the purpose of water quality analysis, the following study periods were chosen:

– the quality of water in the inflow of the Turawa reservoir (In_res): the period of 1998–2009 and the years 2011, 2014 and 2016 (in 2010, 2012–2013 and 2015 the research was not carried out);
– the quality of water in the inflow of the Turawa reservoir (In_res*): the period 1998–2006, in order to compare the quality of the water inflowing to the reservoir (In_res) with that of the water outflowing from the reservoir (Out_res) (note: for the sampling location (Out_res) the research was carried out only for this period).
– the quality of water in the inflow of the Turawa reservoir (In_res*): the period of 1998–2006 for comparison with the quality of water in the outflow of the reservoir (since the quality of water in the outflow was only studied over the period, the data for the inflow (In_res) 1998–2009 and the years 2011, 2014 and 2016 were truncated to 1998–2006 to compare them with the corresponding outflow water quality data for the same period);
– the quality of water stored in the Turawa reservoir (W_res): the years 2011, 2014 and 2016;
– the quality of water flowing out of the Turawa reservoir (Out_res): the period of 1998–2006.

For the sampling locations In_res and Out_res (the Mała Panew) the type 19 of water category was assumed (sand--and-clay lowland river) and for the sampling location W_res – the type 0 (indefinite type of watercourse – channels and dam reservoirs) (Regulation 2011). The quality of water entering and leaving the reservoir as well as of water stored in the reservoir was assessed according to the Regulation of the Minister of Environment on the method of classification of water bodies (Regulation 2016), which is currently in force. All the statistical analyses of water quality and flow indicators were performed in *STATISTICA* following the tests of normality of distributions using the W test of Shapiro-Wilk and the Kolmogorov-Smirnov test with Lilliefors' significance (Razali and Wah 2011) and the assumed significance level $\alpha \leq 0.05$. The null hypothesis H_0: "the variable has a normal distribution" was rejected when at the assumed significance level of $\alpha = 0.05$ the test probability p fulfilled the inequality: $p \leq \alpha = 0.05$ (StatSoft 2011). The rejection of null hypothesis H_0: "the variable has a normal distribution" was equivalent with the acceptance of the alternative hypothesis H_1: "the variable does not have a normal distribution". For $p > \alpha = 0.05$ we had no grounds for rejecting the null hypothesis H_0 about the variable having a normal distribution.

The correlation was analyzed between the daily water outflow from the Turawa reservoir (Out_res) and the daily water inflow to the reservoir (In_res) over the analyzed period 1998–2016. The statistical description of the interdependence was given by means of the Pearson's correlation coefficient (Myronidis et al. 2018), using linear regression with assumed significance level $\alpha \leq 0.05$.

For all the water quality indicators the descriptive statistics and measures of distribution were calculated, including: arithmetic mean, range, standard deviation, coefficient of variation. Next, the correlations between all the water quality indicators were analyzed at each measurement point.

In order to find structures and regularities in the dependencies between the water quality indicators, the Principal Component Analysis (PCA) was used, a collection of multidimensional statistical procedures, which reduce the number of variables by transforming the initial variables into a set of mutually orthogonal variables (Stathis and Myronidis 2009); the new variables are independent and build a theoretical model which describes the structure of dependencies between the attributes under study (Shrestha and Kazama 2007). The number of components accounted for in the analysis was chosen based on the criterion of Kaiser, according to which the components to be analyzed correspond with eigenvalues greater than 1. The reduced share of the less important variables has maximized the difference between the indicators and facilitated the interpretation of the obtained principal components (Singh et al. 2005). The interpretation of components was carried out based on the analysis of factor loads, which expressed the share of a given water quality indicator in individual principal components.

In order to analyze the influence of the large dam reservoir in Turawa on the quality of water in the Mała Panew river, also the significance of the differences between the average concentrations of water quality indicators for the water that enters and exits the reservoir were verified; for this task the t test of Cochran-Cox for independent samples was used (Kumagai et al. 2009), at the significance level of $p \leq 0.05$. The hypothesis that there are no statistically significant differences between the analyzed mean values of water quality indicators for water flowing into the Turawa reservoir and leaving it was rejected.

Results and Discussion

Hydrology of the Mała Panew river and of the Turawa reservoir

From the point of view of water management of the Turawa reservoir, what matters are the amount of water stored in the reservoir and the amount of water inflowing and outflowing to and from the reservoir. As can be seen from the analysis of the amount of water entering the Turawa reservoir, the flow rate during the period under study was 7.87 $m^3 \cdot s^{-1}$ (0.68 MM m^3) (Table 1). The lowest inflow to the reservoir was recorded on 30.08.1998 – 0.41 $m^3 \cdot s^{-1}$ (0.035 MM m^3), the highest was recorded on 20.05.2010 – 188.72 $m^3 \cdot s^{-1}$ (16.305 MM m^3) (Table 2), during the flood in the basin of the Odra river and the Turawa reservoir. The year 2010 was classified as wet (Kosierb 2012). The outflow from the Turawa reservoir during the period of 1998–2016 was relatively stable, the average outflow rate was 8.30 $m^3 \cdot s^{-1}$ (0.717 MM m^3). The lowest outflow from the Turawa reservoir – 2.0 $m^3 \cdot s^{-1}$ (0.173 MM m^3) was recorded from March 1998 to April 1999 and from October to January 2000 (Table 1). As can be seen from the analysis of inflows at the cross section of the Turawa reservoir presented in the Reservoir Operation Manual (Instruction 2015), the average annual discharge (SSQ) for the period of 1966–2010 was 7.37 $m^3 \cdot s^{-1}$. Therefore, the results obtained for the period of 1998–2016 may suggest that the water resources in the catchment of the reservoir are slightly on the rise compared to the period of 1966–2010.

The average volume of water retained in the Turawa reservoir over the years 1998–2016 was 51.466 MM m^3, for the assumed NPP – 80.04 MM m^3 and Max PP – 92.61 MM m^3. As can be seen from the literature (Wiatkowski 2011), high fluctuations in water level are characteristic for dam reservoirs. These fluctuations result in significant exposing of the reservoir bed. Such phenomena are due to the variability of inflow, water discharge through the dam and water use for various purposes. It is also important to note that the changes in water level in reservoirs may occur in a very short time and several times a year (Wiatkowski et al. 2015). The biggest change in the volume of water stored in the Turawa reservoir was recorded between the 19th and 20th of May 2010; the difference was 10.430 MM m^3 (Fig. 2). The use of the reservoir during the flood in 2010 doubled the mean flow (tab. 2). The time of water retention in the reservoir during the flood also increased twofold from 65 days to 114 days (tab. 1–2). The volume of the reservoir during the flood increased by 20.96% (from 50.91 MM m^3 to 61.584 MM m^3). During the operation of the reservoir, discharges from the reservoir should, as a minimum, correspond to the minimum flow $Q_n = 0.78$ $m^3 \cdot s^{-1}$ (the value in force since 2015). The mean value of the volume of water stored in the reservoir during the investigated period was 1.041 MM m^3 and the amplitude of the changes of water level in the reservoir was about 2.53 m.

Table 1. Descriptive statistical values of the hydrological variables from the Turawa reservoir area in 1998–2009 and 2011–2016

Parameters	Average	Min	Max	Range	Standard deviation	Coefficient of variation [%]
Reservoir capacity [MM m^3]	50.910	8.800	90.780	81.980	18.567	36.474
In_res [MM m^3]	0.680	0.035	6.913	6.878	0.562	82.482
Out_res [MM m^3]	0.680	0.173	5.184	5.011	0.571	83.273
Retention time [d]	113.98	6.502	1121.023	1114.521	103.684	90.966

Table 2. Descriptive statistical values of the hydrological variables from the Turawa reservoir area in 2010

Parameters	Average	Min	Max	Range	Standard deviation	Coefficient of variation [%]
Reservoir capacity [MM m^3]	61.584	40.290	95.100	54.810	9.048	14.692
In_res [MM m^3]	1.315	0.315	16.305	15.990	1.448	110.100
Out_res [MM m^3]	1.297	0.410	7.776	7.366	1.177	90.786
Retention time [d]	65.733	5.568	209.835	204.267	30.175	45.905

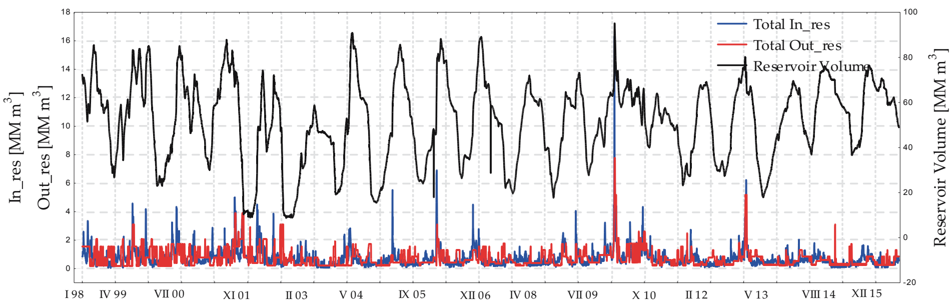

Fig. 2. Daily values of inflow and outflow to and from the Turawa reservoir and the reservoir capacity in 1998–2016

One of the important factors that shape the nature of reservoir environment is the time required for the replacement of all the water in the reservoir (time of water retention) (Straškraba & Hocking 2002, Uhlmann and Horn 2006). This parameter determines not only the hydrological regime of the reservoir, but also, together with the water mixing intensity, it is decisive in the circulation of matter in the reservoir; moreover, it influences the trophic condition and the quality of water in the reservoir (Kasza 2017, Kurunc et al. 2006). On the other hand, the retention of biogens in water ecosystems is often described as a function of morphometric and hydrological parameters of reservoirs (Hejzlar et al. 2009, Tomaszek and Koszelnik 2003, Wiatkowski et al. 2015).

The average water retention time in the Turawa reservoir was estimated based on the ratio between the reservoir capacity and the volume of water flowing into the reservoir (determined during the research period). In the analyzed period this parameter was 113.98 days, compared to 65.7 days in 2010 (Table 1, 2). As stated by Uhlmann and Horn (2006), large dam reservoirs have the retention time of approximately 1 year (Wiatkowski 2011). The retention time for small reservoirs ranges from a few to several dozen days (Wiatkowski and Paul 2009, Wiatkowski 2010, 2015). Figure 3 shows the amount of water entering and leaving the Turawa reservoir compared to the water retention time in the reservoir.

The hydrological regime of most river systems in the world is either strongly or moderately influenced by water reservoirs, which first of all applies to the flow of water (Wei et al. 2009). Several examples can be found in the literature which confirm the considerable influence of reservoirs on the hydrological conditions in the catchment area. The influence of a reservoir on the hydrological conditions in a river has been proved by Zuo and Liang (2015) for the Shaying river and by Wiatkowski (2011) for the Nysa Szalona river. The extent of this influence is determined above all by the ratio between the reservoir's useful capacity and its average annual discharge. The higher the ratio (which theoretically converges to 1), the greater the possibilities of control of the outflow (Wiatkowski 2011). It should be noted that the water management actions performed using the Turawa reservoir are decisive for the smoothing of flows in the watercourse down the dam. They lower the high flows by flattening the flood waves through retention in the reservoir and rise the low flows. Normal flows are controlled by increasing them in dry years and decreasing them in wet years (Fig. 2 and 3).

By analyzing the mutual influence of the volume of water flowing out of the Turawa reservoir (Out_res) and of that of water flowing into it (In_res), the Pearson's correlation coefficient and the equation of the regression line were calculated for the research periods of 1998–2009 and 2011–2016 ($r = 0.57$; $Out\_res = 0.43 + 0.37 \cdot In\_res$).

Calculations were also carried out for the year 2010, which was unique in its high flood waves ($r = 0.74$; $Out\_res = 0.52 + 0.60 \cdot In\_res$). The parameters were determined so as to minimize the sum of squares of observation deviations. For both research periods, the two variables, Out_res and In_res, are highly dependent on each other ($0.5 < (r) < 0.7$). This dependence is statistically significant at the assumed significance level of $p \leq 0.05$.

Water quality in the Mała Panew and in the Turawa reservoir

The results of water quality analysis for water flowing into (In_res, In_res*) and out of (Out_res) the Turawa reservoir as well as those for the water stored in the reservoir (W_res) are shown in Table 3.

In terms of the diagnostic properties being analyzed, the water quality indicators assumed for the analysis had various diversity (Table 3). The calculated range determined the maximum difference observed between the values of each

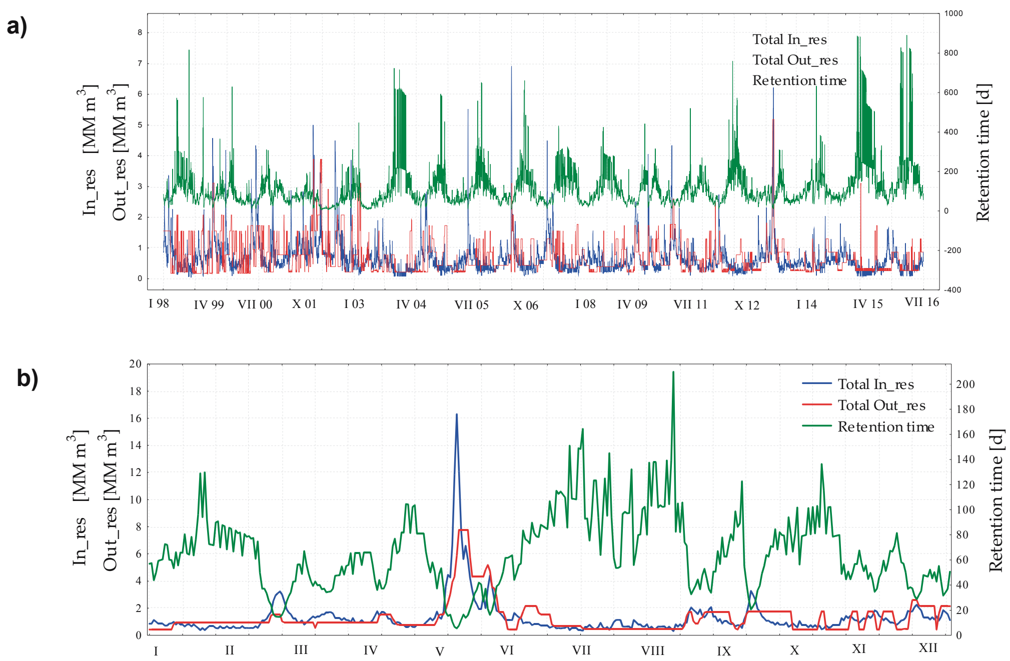

Fig. 3. The amount of water flowing into the Turawa reservoir (In_res) and the amount of water flowing out of it (Out_res) compared to the variability of retention time (monthly values): a) in 1998–2009 and 2011–2016, b) in 2010

Table 3. Characteristics of water flowing into the Turawa reservoir (In_res) 1998–2009, 2011, 2014, 2016; (In_res*) 1998–2006, reservoir water (W_res) 2011, 2014, 2016 and outflowing water (Out_res) 1998–2006 and the Polish classification of surface water bodies according to the Water Framework Directive*

Water quality indicators	Sampling site	Average	Min	Max	Range	Standard deviation	Coefficient of variation [%]	*Polish threshold values of water quality indicators for class I and II (Regulation 2016)	
								Class I	Class II
Water temperature T (°C)	In_res	10.55	0.20	23.00	22.80	6.37	60.42	≤ 22.0	≤ 24.0
	In_res*	10.31	0.20	23.00	22.80	6.48	62.82	≤ 22.0	≤ 24.0
	W_res	14.12	1.50	24.00	22.50	7.62	53.98	≤ 22.0	≤ 24.0
	Out_res	10.77	–0.10	22.00	22.10	7.08	65.77	≤ 22.0	≤ 24.0
Total Suspension Solids TSS (mg · dm^{-3})	In_res	11.99	2.50	72.00	69.50	8.53	71.09	≤ 11.0	≤ 18.5
	In_res*	12.50	3.00	47.00	44.00	6.89	55.15	≤ 11.0	≤ 18.5
	W_res	23.97	5.00	110.00	105.00	29.22	121.88	–	–
	Out_res	14.09	5.00	82.00	77.00	9.68	68.68	≤ 11.0	≤ 18.5
pH	In_res	7.42	0.00	9.20	9.20	0.69	9.37	7.4–8.0	6.7–8.1
	In_res*	7.31	6.10	8.20	2.10	0.36	4.97	7.4–8.0	6.7–8.1
	W_res	8.69	7.70	9.90	2.20	0.77	8.86	6.0–8.5	6.0–9.0
	Out_res	7.67	6.20	9.90	3.70	0.78	10.18	7.4–8.0	6.7–8.1
Dissolved Oxygen DO (mg O_2 · dm^{-3})	In_res	10.48	3.70	18.50	14.80	1.97	18.75	≥ 7.0	≥ 6.6
	In_res*	10.38	3.70	18.50	14.80	2.16	20.77	≥ 7.0	≥ 6.6
	W_res	11.14	8.10	17.20	9.10	2.32	20.82	≥ 7.0	≥ 5.0
	Out_res	9.95	2.90	18.10	15.20	2.69	27.06	≥ 7.0	≥ 6.6
BOD_5 (mg O_2 · dm^{-3})	In_res	2.96	0.00	12.00	12.00	1.64	55.19	≤ 2.6	≤ 3.7
	In_res*	3.03	1.00	12.00	11.00	1.62	53.43	≤ 2.6	≤ 3.7
	W_res	2.76	0.90	7.00	6.10	1.67	60.41	≤ 3.0	≤ 6.0
	Out_res	2.72	1.20	6.00	4.80	1.07	39.36	≤ 2.6	≤ 3.7
Ammonia (mg NH_4^+ · dm^{-3})	In_res	0.83	0.032	4.545	4.51	0.57	68.23	≤ 0.21	≤ 0.71
	In_res*	0.90	0.10	2.34	2.24	0.44	48.48	≤ 0.21	≤ 0.71
	W_res	–	–	–	–	–	–	–	–
	Out_res	0.71	0.13	1.95	1.82	0.32	44.77	≤ 0.21	≤ 0.71
Nitrates (mg NO_3^- · dm^{-3})	In_res	14.39	3.583	30.48	26.89	4.95	34.42	≤ 7.08	≤ 11.07
	In_res*	13.97	3.58	30.48	26.89	5.09	36.41	≤ 7.08	≤ 11.07
	W_res	4.42	0.222	12.198	11.976	3.36	75.94	≤ 9.74	≤ 22.14
	Out_res	8.04	0.44	30.53	30.08	5.43	67.55	≤ 7.08	≤ 11.07
Nitrites (mg NO_2^- · dm^{-3})	In_res	0.10	0.016	1.218	1.202	0.13	121.47	–	–
	In_res*	0.10	0.02	1.218	1.202	0.14	133.13	–	–
	W_res	0.06	0.02	0.115	0.095	0.04	55.04	–	–
	Out_res	0.08	0.02	0.22	0.20	0.05	58.27	–	–
Total Nitrogen N (mg N · dm^{-3})	In_res	4.66	0.00	10.00	10.00	1.61	34.58	≤ 2.6	≤ 3.8
	In_res*	4.56	1.79	8.660	6.87	1.40	30.61	≤ 2.6	≤ 3.8
	W_res	3.02	1.70	6.80	5.10	1.30	43.18	≤ 5.0	≤ 10.0
	Out_res	3.41	1.16	7.72	6.56	1.14	33.55	≤ 2.6	≤ 3.8
Phosphates (mg PO_4^{3-} · dm^{-3})	In_res	0.16	0.00	0.71	0.71	0.10	64.38	≤ 0.20	≤ 0.32
	In_res*	0.19	0.05	0.71	0.66	0.11	58.04	≤ 0.20	≤ 0.32
	W_res	0.18	0.05	0.56	0.51	0.15	79.76	≤ 0.20	≤ 0.41
	Out_res	0.16	0.05	1.32	1.27	0.16	100.05	≤ 0.20	≤ 0.32
Total Phosphorus P (mg P · dm^{-3})	In_res	0.68	0.215	3.372	3.157	0.45	65.31	≤ 0.20	≤ 0.30
	In_res*	0.67	0.22	3.372	3.157	0.44	65.13	≤ 0.20	≤ 0.30
	W_res	0.21	0.054	0.78	0.726	0.16	73.60	≤ 0.20	≤ 0.40
	Out_res	0.49	0.12	1.44	1.32	0.25	50.68	≤ 0.20	≤ 0.30
Electrolytic conductivity Cond (μs/cm)	In_res	372.20	243.00	467.00	224.00	39.78	10.69	≤ 411	≤ 553
	In_res*	373.56	243.00	467.00	224.00	39.86	10.67	≤ 411	≤ 553
	W_res	319.53	219.00	430.00	211.00	53.84	16.85	≤ 1000	≤ 1500
	Out_res	347.22	270.00	439.00	169.00	33.84	9.75	≤ 411	≤ 553
Dissolved Substances DS (mg · dm^{-3})	In_res	272.91	108.00	395.00	287.00	34.55	12.66	–	–
	In_res*	266.90	108.00	395.00	287.00	35.69	13.37	–	–
	W_res	249.50	187.00	438.00	251.00	62.94	25.23	–	–
	Out_res	240.76	142.00	310.00	168.00	26.02	10.81	–	–
Sulphates SO_4^- (mg SO_4^- · dm^{-3})	In_res	55.91	17.00	80.00	63.00	8.39	15.01	≤ 27.2	≤ 77.9
	In_res*	55.42	17.00	80.00	63.00	9.07	16.36	≤ 27.2	≤ 77.9
	W_res	–	–	–	–	–	–	–	–
	Out_res	52.21	13.00	80.00	67.00	9.30	17.82	≤ 27.2	≤ 77.9
Chlorides Cl^- (mg Cl^- · dm^{-3})	In_res	23.58	10.00	52.00	42.00	6.79	28.78	≤ 14.0	≤ 34.5
	In_res*	22.44	10.00	52.000	42.00	6.96	31.04	≤ 14.0	≤ 34.5
	W_res	–	–	–	–	–	–	–	–
	Out_res	19.46	12.00	27.30	15.30	3.16	16.26	≤ 14.0	≤ 34.5

individual indicator. Higher standard deviation and higher scatter around the arithmetic mean value suggested higher diversification of individual indicators. The assessment of homogeneity of the indicators being analyzed was also carried out based on the coefficient of variation. For indicators such as: pH, conductivity, dissolved substances, sulphates and chlorides the coefficient was considerably lower than that for other indicators, which means that the values of these indicators were more concentrated around the mean value.

Table 3 shows that for most indicators, namely: ammonia, nitrates, nitrites, nitrogen, phosphates, phosphorus, conductivity, dissolved substances, sulphates and chlorides, the highest average concentrations were recorded in the water flowing into the reservoir (In_res, In_res*). During the research period, the highest average concentrations for water temperature, suspension, pH and oxygen were recorded in the water stored in the reservoir (W_res). This is consistent with the statement that water reservoirs disrupt the continuity of rivers and the transport of organic substances and metals in the fluvial system, thus they eventually influence the chemical and biological characteristics of the river ecosystem. As shown by Wei et al. (2009), because of the long retention time, trace elements accumulate easier in a reservoir than in flowing water. Dam reservoirs have long been seen as a way to improve the cleanness of surface waters. Depending on the water retention time, reservoir depth and the inflowing charge load, dam reservoirs may periodically withhold up to 90% of the overall inflowing mater (Wiatkowski 2011).

In terms of the water quality class of the water inflowing to the Turawa reservoir (the sampling point In_res), the values of water temperature, total suspended solids, reaction, BOD_5, ammonia, nitrates, total nitrogen, phosphates, total phosphorus and chlorides exceed the threshold values of water quality class II (the fact that the requirements for class II are not met means that the quality is less than good. The qualification below class II due to the indicators being studied should be a signal to take measures to improve them). However, in terms of the sulphates the water flowing into the reservoir has been classified as quality class II and in terms of the dissolved oxygen and electrolytic conductivity – as water quality class I. In terms of water temperature, reaction, BOD_5, phosphates and total phosphorus the water tested at the sampling point W_res was classified as water quality class below II. On the other hand, the levels of nitrates and total nitrogen have qualified the water in the reservoir as quality class II whereas the values of dissolved oxygen and electrolytic conductivity have qualified it as quality class I. The levels of the total suspended solids, reaction, BOD_5, ammonia, nitrates, total nitrogen, phosphates, total phosphorus and sulphates in the water at the sampling point Out_res have exceeded the threshold values for the water quality class II. In terms of chlorides, the water flowing out of the reservoir was classified as water quality class II, and in terms of water temperature, dissolved oxygen and electrolytic conductivity as water quality class I (Regulation 2016). The previous water quality analyses in the Turawa reservoir presented by Wiatkowski and Czerniawska-Kusza (2009) for the period of 2002–2005 show that the mean values of biogens qualify the water below the water quality class II.

The analysis of correlation between all the water quality indicators at each measurement point is shown in tables 4–7. This analysis shows that some water quality indicators are significantly correlated at the significance level of $p \leq 0.05$. Similar analysis can be found in the literature (De Melo 2017, Nyanti 2018, Wiatkowski 2010, 2011, Varol et al. 2012).

An analysis of correlation between the water quality indicators for the water flowing into the reservoir (In_res, In_res*), the water in the reservoir (W_res) and the water flowing out of the Turawa reservoir (Out_res) has shown that during the research periods the individual indicators were mutually dependent at the assumed significance level of $p \leq 0.05$ (Table 4–7).

Principal Component Analysis

Thanks to the Principal Component Analysis (PCA) it was possible to evaluate the strength with which the individual indicators determine the quality of water of the Mała Panew

Table 4. Correlation (Pearson's coefficient) between individual water quality indicators for water flowing into the Turawa Reservoir (In_res), 1998–2009 and 2011, 2014, 2016

	T	TSS	pH	DO	BOD_5	NH_4^+	NO_3^-	NO_2^-	N	PO_4^{3-}	P	Cond	DS	SO_4^-	Cl^-
T	1.00														
TSS	-0.06	1.00													
pH	**0.36**	-0.12	1.00												
DO	**-0.84**	0.03	-0.17	1.00											
BOD_5	**-0.31**	**0.61**	**-0.24**	**0.25**	1.00										
NH_4^+	**-0.45**	0.10	**-0.19**	**0.36**	**0.33**	1.00									
NO_3^-	**-0.44**	0.05	0.00	**0.39**	-0.02	0.08	1.00								
NO_2^-	**0.19**	-0.01	0.02	-0.17	0.05	-0.07	-0.17	1.00							
N	**-0.49**	0.19	-0.12	**0.39**	**0.22**	**0.28**	**0.91**	-0.12	1.00						
PO_4^{3-}	-0.06	0.01	**-0.34**	0.02	**0.24**	0.03	-0.07	0.01	-0.01	1.00					
P	-0.08	**0.46**	-0.09	-0.02	**0.47**	0.06	0.08	-0.04	0.18	**0.23**	1.00				
Cond	-0.13	**-0.42**	**0.26**	**0.20**	-0.18	0.14	**0.35**	0.10	**0.27**	-0.12	-0.09	1.00			
DS	0.11	-0.16	**0.40**	-0.03	**-0.20**	-0.02	**0.30**	0.04	**0.19**	**-0.20**	**0.23**	**0.63**	1.00		
SO_4^-	-0.11	-0.09	0.08	0.17	-0.00	0.14	**0.26**	0.06	**0.27**	-0.08	-0.03	**0.47**	**0.40**	1.00	
Cl^-	-0.05	-0.12	**0.34**	**0.27**	-0.05	0.04	**0.19**	-0.05	0.13	-0.17	-0.02	**0.35**	**0.32**	0.13	1.00

The significance level $p \leq 0.05$ is marked in bold

Table 5. Correlation (Pearson's coefficient) between individual water quality indicators for water flowing into the Turawa Reservoir (In_res*), 1998–2006

	T	TSS	pH	DO	BOD_5	NH_4^+	NO_3^-	NO_2^-	N	PO_4^{3-}	P	Cond	DS	SO_4^-	Cl^-
T	1.00														
TSS	0.12	1.00													
pH	**0.40**	-0.16	1.00												
DO	**-0.83**	-0.10	-0.21	1.00											
BOD_5	**-0.29**	**0.34**	**-0.32**	**0.24**	1.00										
NH_4^+	**-0.50**	0.06	**-0.27**	**0.40**	**0.38**	1.00									
NO_3^-	**-0.50**	-0.08	-0.09	**0.41**	-0.10	**0.27**	1.00								
NO_2^-	**0.22**	-0.01	0.05	-0.18	0.07	-0.08	-0.21	1.00							
N	**-0.52**	0.03	-0.19	**0.40**	0.14	**0.46**	**0.91**	-0.15	1.00						
PO_4^{3-}	-0.16	0.10	**-0.35**	0.11	**0.36**	0.10	0.03	-0.01	0.11	1.00					
P	-0.02	0.16	-0.16	-0.10	**0.28**	0.04	0.00	-0.04	0.09	**0.28**	1.00				
Cond	-0.17	**-0.43**	**0.29**	**0.24**	-0.10	0.18	**0.40**	0.09	**0.32**	-0.16	0.01	1.00			
DS	0.11	**-0.26**	**0.36**	-0.04	**-0.26**	-0.02	**0.27**	0.04	0.17	-0.17	**0.26**	**0.69**	1.00		
SO_4^-	-0.17	-0.00	-0.01	0.21	0.09	**0.21**	**0.26**	0.06	**0.31**	-0.07	0.00	**0.47**	**0.39**	1.00	
Cl^-	-0.09	-0.12	**0.24**	**0.30**	-0.05	0.10	0.11	-0.05	0.07	-0.12	-0.03	**0.36**	**0.26**	0.07	1.00

The significance level p≤0.05 is marked in bold

Table 6. Correlation (Pearson's coefficient) between individual water quality indicators for water in the Turawa Reservoir (W_res), 2011, 2014, 2016

	T	TSS	pH	DO	BOD_5	NO_3^-	NO_2^-	N	PO_4^{3-}	P	Cond	DS
T	1.00											
TSS	0.38	1.00										
pH	0.38	0.68	1.00									
DO	-0.44	0.32	0.42	1.00								
BOD_5	0.29	**0.77**	0.62	0.68	1.00							
NO_3^-	**-0.82**	-0.54	**-0.75**	0.21	-0.33	1.00						
NO_2^-	0.03	-0.49	**-0.77**	-0.53	-0.45	0.32	1.00					
N	-0.00	**0.86**	0.36	0.52	**0.74**	-0.05	-0.34	1.00				
PO_4^{3-}	0.38	**0.78**	0.62	-0.09	0.25	-0.65	-0.35	0.53	1.00			
P	0.42	**0.96**	0.62	0.14	0.61	-0.54	-0.43	**0.82**	**0.87**	1.00		
Cond	**0.88**	0.09	-0.04	**-0.75**	-0.06	-0.57	0.30	-0.21	0.16	0.17	1.00	
DS	**0.93**	0.36	0.36	-0.39	0.31	**-0.82**	0.11	-0.05	0.30	0.33	**0.83**	1.00

The significance level p≤0.05 is marked in bold

Table 7. Correlation (Pearson's coefficient) between individual water quality indicators for water flowing out of the Turawa Reservoir (Out_res), 1998–2006

	T	TSS	pH	DO	BOD_5	NH_4^+	NO_3^-	NO_2^-	N	PO_4^{3-}	P	Cond	DS	SO_4^-	Cl-
T	1.00														
TSS	-0.01	1.00													
pH	**0.39**	0.09	1.00												
DO	**-0.83**	0.01	-0.15	1.00											
BOD_5	0.22	**0.27**	**0.30**	-0.09	1.00										
NH_4^+	-0.08	0.06	**-0.38**	-0.19	-0.04	1.00									
NO_3^-	**-0.50**	-0.09	**-0.40**	**0.46**	-0.16	0.15	1.00								
NO_2^-	**0.64**	-0.06	-0.12	**-0.60**	0.04	**0.30**	-0.06	1.00							
N	**-0.45**	0.03	**-0.38**	**0.37**	-0.01	**0.26**	**0.95**	-0.04	1.00						
PO_4^{3-}	0.01	0.02	0.00	-0.03	0.11	0.11	-0.02	0.02	0.02	1.00					
P	0.06	0.26	0.00	-0.11	**0.32**	0.11	-0.18	0.08	-0.06	**0.66**	1.00				
Cond	**-0.40**	-0.25	**-0.29**	**0.26**	-0.17	0.15	0.13	**-0.24**	0.09	**-0.25**	-0.06	1.00			
DS	-0.01	-0.41	-0.15	-0.04	-0.15	0.05	0.08	0.12	-0.00	-0.14	0.01	**0.66**	1.00		
SO_4^-	**-0.41**	0.01	**-0.33**	**0.30**	-0.04	-0.01	**0.27**	-0.22	0.19	-0.05	-0.02	**0.43**	**0.35**	1.00	
Cl^-	**-0.36**	-0.07	0.04	**0.32**	**-0.23**	0.17	0.07	**-0.26**	0.04	-0.16	-0.06	**0.56**	**0.34**	0.22	1.00

The significance level p≤0.05 is marked in bold river in the inflow of the Turawa reservoir in 1998–2009, 2011, 2014, 2016 (In_res) as well as in 1998–2006 (In_res*) (Table 8, Fig. 4). The PCA performed reveals that the quality of water of the Mała Panew river flowing into the Turawa reservoir (In_res, In_res*) was differentiated by the indicators concerned with the first five principal components corresponding to the eigenvalues greater than 1. These components have explained 69.97% and 76.08%, respectively, of the overall variability of the water quality indicators being analyzed (Fig. 4, Table 8).

The indicators such as the temperature, dissolved oxygen, ammonia, nitrates and nitrogen had high coefficients for the first principal component, had the biggest influence on the quality of water and explained 23.01% (In_res) and 24.68% (In_res*) of variance, respectively. The water flowing into the reservoir, which contained relatively higher concentrations of indicators that characterize the biogenic conditions, i.e. ammonia, nitrates and nitrogen, had a higher indicator of oxygen conditions – dissolved oxygen and a lower temperature. On the other hand, the reaction, the biochemical demand for oxygen, conductivity, dissolved substances, phosphates and dissolved oxygen had high indicators for the second component, which can be interpreted as the component of the influence of indicators that characterize acidity, salinity and organic pollution of water that flows into the reservoir. The third component was interpreted as the component of the influence of phosphate compounds, the fourth as that of nitrite compounds and the fifth as that of the influence of salinity indicators.

Moreover, the PCA performed has shown that the quality of water from the Mała Panew stored in the Turawa reservoir in years 2011, 2014 and 2016 (W_res) was differentiated by the indicators corresponding to the first four components. These components have explained 96.77% of the overall variability of the water quality parameters being analyzed (Table 9, Fig. 5).

Thus, the PCA can be used to detect the strength of the influence of individual indicators on the variability of water quality in rivers. Hence, it can also help to identify the sources of pollution of these watercourses (De Melo et al. 2017, StatSoft 2011).

The PCA reveals that the water of the Mała Panew stored in the Turawa reservoir, which contains a relatively high amount of biogens i.e. nitrates and nitrites, contained less phosphates and phosphorus and had a lower pH, suspension and biochemical demand for oxygen. These indicators had the biggest influence on the qualitative diversification of water stored in the Turawa reservoir and have explained up to approximately 50% of it. The electrolytic conductivity, dissolved substances, dissolved oxygen and temperature are indicators having the strongest link to the second principal component; they explain 30.85% of variance. The content of oxygen dissolved in water decreased with the growth of salinity indicators. The factor loads of the third and fourth component had little influence on the quality of water stored in the reservoir being analyzed.

Thanks to the PCA it was also possible to evaluate the strength with which the individual indicators determine the quality of water in the Mała Panew at the outflow from the Turawa reservoir in 1998–2006 (Out_res); these components have explained 79.78% of the overall variability of water quality indicators being analyzed for the water flowing out of the reservoir Turawa (Fig. 6, Table 10).

The indicators such as temperature, dissolved oxygen, nitrates, nitrogen, electrolytic conductivity as well as sulphates and chlorine had high coefficients for the first principal component, had the biggest influence on the quality of water discharged from the reservoir and explained 26.09% of variance. The water flowing out of the reservoir which contained relatively lower concentrations of indicators that characterize the biogenic conditions, i.e. nitrates and nitrogen, had a lower concentration of sulphates and chlorides, lower electrolytic conductivity and lower content of dissolved oxygen.

While the second principal component was related to the dissolved substances – an indicator that explained 14.68% of variance – the third principal component was determined by ammonia and nitrites, the increase of which resulted in the decrease of pH. The fourth principal component is the component of the influence of phosphate and phosphorus compounds on the quality of water discharged from the reservoir; these indicators explain 11.19% of variance in the quality of water.

Similar research using PCA can be found in the literature; however, it is not concerned with analyzing the influence of reservoirs on the quality and flow of water. For example, one of the works deals with ecological capacity assessment, based

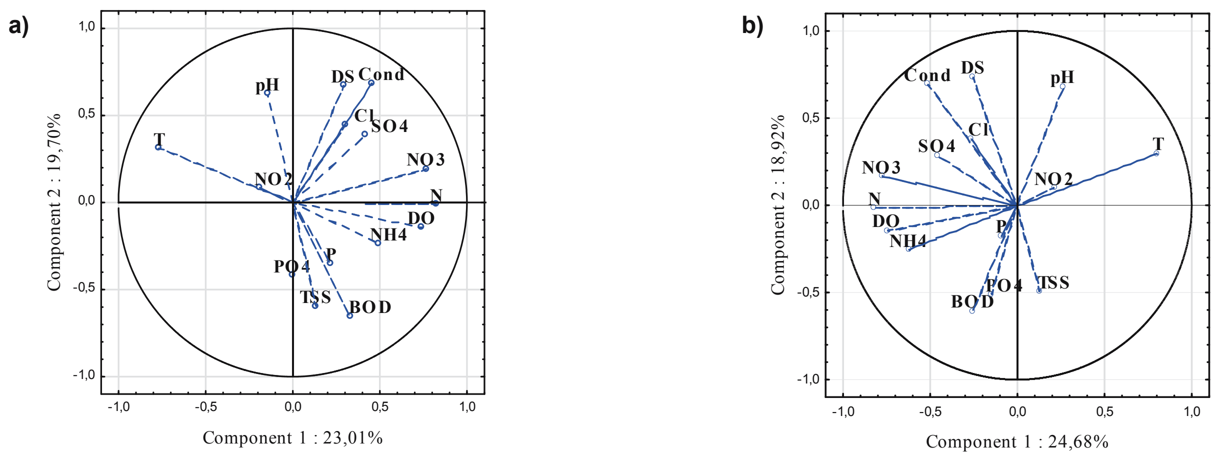

Fig. 4. Plot of the scatter in space of the first and second principal component of water quality indicators for the water flowing into the Turawa reservoir in the period of: a) 1998–2009, 2011, 2014, 2016 (In_res); b) 1998–2006 (In_res*)

Table 8. Factor loads, eigenvalues, variance percentage and cumulative variance percentage of obtained components for water flowing into the Turawa (In_res) 1998–2009, 2011, 2014, 2016 and (In_res*) 1998–2006

Variable	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5
T	**-0.772** **0.803***	0.309 0.298*	-0.377 -0.282*	-0.003 -0.125*	-0.12 0.091*
TSS	0.134 0.125*	**-0.595** **-0.497***	-0.567 -0.290*	-0.262 -0.115*	0.12 0.259*
pH	-0.143 0.261*	**0.623** **0.682***	-0.321 0.027*	-0.302 0.075*	0.30 -0.062*
DO	**0.744** **-0.747***	-0.143 -0.144*	0.365 0.331*	-0.039 0.313*	0.30 -0.152*
BOD_5	0.332 -0.258*	**-0.654** **-0.605***	-0.403 -0.388*	0.149 0.397*	0.29 0.003*
NH_4^+	**0.495** **-0.624***	-0.235 -0.257*	0.139 -0.050*	0.266 0.238*	0.41 0.139*
NO_3^-	**0.767** **-0.777***	0.193 0.164*	-0.035 0.089*	-0.288 -0.487*	-0.46 0.118*
NO_2^-	-0.192 0.212*	0.083 0.099*	-0.203 -0.329*	**0.574** **0.437***	0.08 0.462*
N	**0.825** **-0.818***	-0.012 -0.016*	-0.107 -0.044*	-0.174 -0.394*	-0.38 0.203*
PO_4^{3-}	-0.003 -0.145*	**-0.420** **-0.515***	0.002 -0.319*	0.449 -0.042*	-0.33 -0.321*
P	0.220 -0.092*	-0.353 -0.176*	**-0.718** **-0.720***	0.034 -0.209*	-0.07 -0.457*
Cond	0.452 -0.517*	**0.685** **0.693***	-0.031 -0.214*	0.354 0.176*	0.02 -0.014*
DS	0.291 -0.253*	**0.672** **0.737***	-0.461 -0.457*	0.123 -0.103*	-0.05 -0.131*
SO_4^-	0.417 -0.460*	0.387 0.286*	-0.128 -0.344*	0.404 0.136*	-0.06 **0.428***
Cl	0.301 -0.262*	0.446 0.381*	-0.108 0.082*	-0.195 0.427*	**0.47** **-0.429***
Eigenvalues	3.452 3.701*	2.954 2.838*	1.692 1.545*	1.241 1.219*	1.156 1.085*
Explained part of variability of accessions [%]	23.011 24.675*	19.695 18.922*	11.278 10.297*	8.276 8.125*	7.708 7.236*
Cumulative part of variability [%]	23.011 24.675*	42.706 43.597*	53.984 53.894*	62.261 62.019*	69.968 76.075*

Table 9. Factor loads, eigenvalues, variance percentage and cumulative variance percentage of obtained components in the Turawa reservoir (W_res) (reservoir 2011, 2014, 2016)

Variable	Factor 1	Factor 2	Factor 3	Factor 4
T	-0.611	**0.741**	0.078	-0.198
TSS	**-0.936**	-0.218	-0.254	-0.020
pH	**-0.830**	-0.187	0.481	0.155
DO	-0.206	**-0.878**	0.253	-0.325
BOD_5	**-0.734**	-0.377	0.055	**-0.560**
NO_3^-	**0.781**	-0.488	-0.324	-0.143
NO_2^-	**0.535**	0.490	-0.498	-0.269
N	**-0.650**	-0.534	**-0.509**	-0.162
PO_4^{3-}	**-0.786**	0.038	-0.262	**0.530**
P	**-0.906**	-0.120	-0.363	0.145
Cond	-0.277	**0.913**	-0.102	-0.149
DS	-0.570	**0.735**	0.128	-0.294
Eigenvalues	5.686	3.702	1.211	1.015
Explained part of variability of accessions [%]	47.385	30.851	10.094	8.462
Cumulative part of variability [%]	47.385	78.237	88.331	96.793

on biological, physical and hydromorphological indicators for eleven water reservoirs located in Poland (Mazur et al. 2017). In this research it has been proved that the first component, which represents the main direction of change, is related to all the biological indicators (phytoplankton and phytobenthos, as well as the indicators of flora). Furthermore, it was determined that the first component was also related to several abiotic parameters, the strongest link was with organic carbon (TOC) and total phosphorus in water. The second direction of change, related to the morphometric parameters, most notably the reservoir's maximum and average depth, proved a strong relationship between total nitrogen and the second main component (Mazur et al. 2017). Similar to this, the PCA method was used in the study of the Jucazinho reservoir in Brazil (De Melo et al. 2017). The aim of this research was to identify the factors with influence on water quality in the Jucazinho reservoir. The analysis using PCA has reduced the ten water quality parameters to two components, which together explained 55% of total variance. The main indicators with influence on temporary water quality changes were thus identified.

Influence of the Turawa reservoir on the quality of water

In order to analyze the influence of the Turawa reservoir on the improvement of water quality in the Mała Panew river, a comparison was made between the water quality entering and leaving the Turawa reservoir. A test for the significance of difference between means for independent samples was used. One of the assumptions of this test is the homogeneity of variance in the groups being compared. In order to verify the

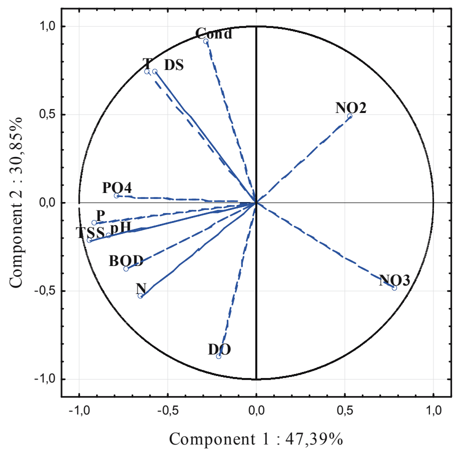

Fig. 5. Plot of the scatter in space of the first and second principal component of water quality indicators (W_res) 2011, 2014, 201

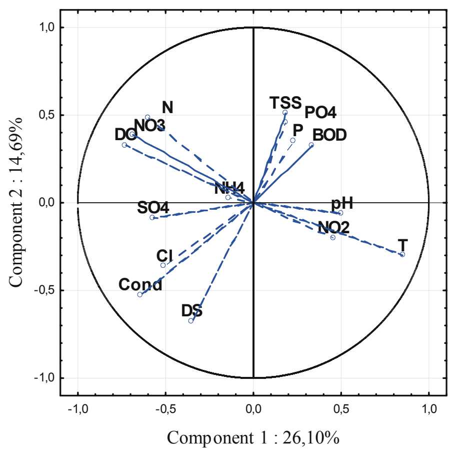

Fig. 6. Plot of the scatter in space of the first and second principal component of water quality indicators (Out_res) 1998–2006

Table 10. Factor loads, eigenvalues, variance percentage and cumulative variance percentage of obtained components for outflowing water (Out_res) 1998–2006

Variable	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5	Factor 6
T	**0.853**	-0.302	0.231	-0.079	-0.040	0.181
TSS	0.182	0.511	-0.138	0.157	**-0.650**	-0.109
pH	0.502	-0.061	**-0.570**	0.021	-0.047	0.154
DO	**-0.727**	0.330	-0.430	-0.009	0.100	-0.014
BOD_5	0.338	0.328	-0.098	0.290	-0.363	**0.566**
NH_4^+	-0.137	0.027	**0.662**	0.177	-0.359	-0.433
NO_3^-	**-0.684**	0.383	0.362	-0.316	0.071	0.232
NO_2^-	0.457	-0.201	**0.724**	-0.114	-0.079	0.100
N	**-0.599**	0.485	0.419	-0.235	-0.052	0.218
PO_4^{3-}	0.184	0.457	0.192	**0.573**	0.519	-0.120
P	0.227	0.354	0.164	**0.803**	0.126	0.013
Cond	**-0.643**	-0.527	0.002	0.347	-0.141	0.059
DS	-0.351	**-0.675**	0.226	0.322	0.092	0.334
SO_4^-	**-0.571**	-0.085	0.003	0.274	-0.117	0.371
Cl^-	**-0.506**	-0.363	-0.202	0.303	-0.251	-0.314
Eigenvalues	3.914	2.203	2.017	1.679	1.101	1.052
Explained part of variability of accessions [%]	26.096	14.685	13.446	11.195	7.340	7.015
Cumulative part of ariability [%]	26.096	40.781	54.227	65.422	72.762	79.777

hypothesis about the equality of variances, the Levene's test was additionally carried out in the groups; the outcome of this test was statistically significant at the assumed significance level ($p \leq 0.05$). Because there was no homogeneity of variance in the groups, in order to compare the significance of the differences, the t test of Cochran-Cox was used with independent estimation of variance. Table 11 shows the statistical significance of the differences of the physicochemical indicators being observed between the water quality entering and leaving the Turawa reservoir in 1998–2006.

Table 11 shows that the average concentrations of the physicochemical parameters such as pH, ammonia, nitrates, nitrogen, phosphorus, conductivity, dissolved substances, sulphates and chlorides in the water inflowing to the reservoir and in the water outflowing from the reservoir differ statistically significantly at the assumed significance level ($p \leq 0.05$). For other indicators the differences observed were statistically insignificant ($p > 0.05$).

Based on the analyses performed, a positive influence of the Turawa reservoir on the quality of water entering the reservoir was observed in terms of the water quality indicators being analyzed. The results obtained show that during the years 1998–2006 the Turawa reservoir decreased the concentrations of dissolved oxygen DO by 5.1%, BOD_5 by 8.1%, ammonia by 14.5%, nitrates by 44.2%, nitrites by 20%, nitrogen by 26.8%, phosphorus by 27.9%, conductivity by 6.7%, dissolved substances by 11.8%, sulphates by 6.6%, and chlorides by 17.5% (Table 11). In the water below the reservoir an increase in water temperature by 2.1%, in suspension by 17.5% and in pH by 3.4% was recorded.

According to the research presented in (Wiatkowski and Czerniawska-Kusza 2009), the Turawa reservoir accumulates approximately 50% of the inflowing load of total phosphorus and total nitrogen. The authors point out that in 2006, the dam reservoir in Turawa underwent eutrophication due to the considerable increase in the nutrients carried by the Mała Panew, but also because of the raw tourist sewage being dumped to water. The worsening of water quality results in changes in the benthonic environment. Moreover, the authors are of the opinion that it is important to ensure correct operation of the pre-dam reservoir located in the backwater area of the Turawa reservoir. The research on the quality of water in water bodies located in Poland, in the river basin of the Upper and Middle Odra, carried by Wiatkowski (2010, 2011, 2015) and Wiatkowski et al. (2015) reveals that in order to ensure appropriate water quality in the reservoirs, the waters that feed them must be of very good or at least good quality. However, the research has proved that the quality of these waters has worsened. In (Wiatkowski 2011, Wiatkowski et al. 2015) the dam reservoirs Bukówka, Mietków and Słup, for which the surface load with nitrogen and phosphorus was calculated, have exceeded several times the standards given by Vollenweider. Currently, researchers are trying to answer the question of whether hydraulic engineering structures worsen or improve water quality. The answer to this question is ambiguous (Wiatkowski and Paul 2009, Wiatkowski 2010, 2011. It is commonly thought and often confirmed in practice that if moderately or weakly polluted water enters a large reservoir, then the quality of water improves (Jaguś and Rzętała 2011, Kasza 2017, Wiatkowski 2015) but if the pollution is high, then the quality actually worsens. Also the worsening of the condition of the reservoirs due to anthropogenic factors or natural processes has an adverse effect on the quality of water and the protection of aquatic life. Therefore, it is important to characterize the water flowing from the catchment area into the reservoirs, as such water has influence on these systems and their spatial variability (Castilla-Hernández et al. 2014). As stated by Zhao et al. (2018), the reduction and control of pollution in the reservoir are the main goals for the preservation of the Huangshi reservoir. Several authors have carried out research into the ecological influence of specific reservoirs on the watercourse below them; however (Braatne et al. 2008) clearly state that there are only a few analyses of research strategies that would allow

Table 11. Statistical significance of the analysed water quality indicators for inflowing (In_res*) 1998–2006 and outflowing (Out_res) water of the Turawa reservoir, 1998–2006

Parameters	In_res – Out_res				
	t	df	p	F quotient Variances	p Variances
Water temperature T	-0.487	210	0.6270	1.2	0.3649
Suspension TSS	-1.371	208	0.1717	2.0	0.0006
pH	-4.296	212	**0.0000**	4.6	0.0000
Dissolved oxygen DO	1.268	211	0.2063	1.6	0.02331
BOD	1.650	212	0.1004	2.3	0.00002
Ammonia NH_4^+	3.732	212	**0.0002**	1.9	0.0010
Nitrates NO_3^-	8.224	212	**0.0000**	1.1	0.4973
Nitrites NO_2^-	1.481	212	0.1401	8.2	0.0000
Nitrogen N	6.257	193	**0.0000**	1.5	0.0539
Phosphates PO_4^{3-}	1.093	207	0.2758	2.3	0.00002
Phosphorus P	3.780	212	**0.0002**	3.1	0.0000
Conductivity Cond	4.918	188	**0.0000**	1.4	0.1131
Dissolved substances DS	5.726	184	**0.0000**	1.9	0.0026
Sulphates SO_4^-	2.398	186	**0.0174**	1.1	0.8060
Chlorides Cl^-	3.826	188	**0.0001**	4.8	0.0000

The significance level $p \leq 0.05$ is marked in bold the reservoirs' influence on flows and quality of water, and also that rigorous research plans for environmental analyses of new reservoirs are required (Braatne et al. 2008). As shown by the work of Nyanti et al. (2018), the Batang Ai reservoir influences not only the hydrological characteristics and physicochemical parameters of water, but also the fish life and even the river valley as a whole downstream of the reservoir.

Conclusions

The analyses performed reveal the following:

1. The Turawa reservoir has smoothed the water flows on the Mała Panew river. During the period of 1998–2009 and 2011–2016 the volume of water flowing out of the Turawa reservoir (Out_res) and that of water flowing into it (In_res) were statistically significantly correlated ($r = 0.57$). In the year 2010, which was analyzed separately because of extremely high water levels (flood), the dependence between the volume of outflowing water and that of inflowing water was high ($r = 0.74$). The analysis of flows for 2010, singled out from the research period 1998–2016 and comparison with this period shows a twofold increase in the mean flow and time of water retention in the reservoir, as well as an increase of the reservoir's volume by 20.96%.
2. During the period under the analysis, the Turawa reservoir contributed to the change in water quality of the Mała Panew river:
   a) the water from the Turawa reservoir area has exceeded the threshold values for water quality class II. At the sampling point In_res, the reason for this were the values of water temperature, total suspended solids, reaction, BOD_5, ammonia, nitrates, total nitrogen, phosphates, total phosphorus and chlorides. At the sampling point W_res, it was because of the values of water temperature, reaction, BOD_5, phosphates and total phosphorus. The water flowing out of the reservoir has exceeded the threshold values for the total suspended solids, reaction, BOD_5, ammonia, nitrates, total nitrogen, phosphates, total phosphorus and sulphates.
   b) an analysis of average concentrations of water quality indicators for water flowing into (In_res) and out of (Out_res) the reservoir reveals that the Turawa reservoir had an influence on the improvement of water quality in the Mała Panew river. The statistically significant differences of average concentrations ($p \leq 0.05$) between the inflowing and outflowing water have been proved for the indicators that characterize biogenic conditions: ammonia, nitrates, nitrogen, phosphorus and the indicators that characterise salinity: electrolytic conductivity, dissolved substances, sulphates and chlorides.
3. The PCA has allowed the structures formed by the physicochemical indicators of water being analyzed to be identified:
   a) the quality of water of the Mała Panew river, flowing into the Turawa reservoir (In_res) was differentiated by the indicators related to the first five principal components, which explained approximately 70% of the total variability of water quality parameters under the analysis. The results obtained indicate that, statistically speaking, indicators such as ammonia, nitrates, nitrogen, temperature and dissolved oxygen determine the quality of water of the Mała Panew river flowing into the reservoir to the greatest extent.
   b) the quality of water stored in the Turawa reservoir (W_res) was differentiated by the indicators related to four principal components, which explained approximately 96% of the total variability of the indicators under analysis. The indicators having the greatest influence on the quality of water stored in the reservoir are as follows: nitrates and nitrites, phosphates and phosphorus, pH, suspension and biochemical oxygen demand.
   c) the quality of water outflowing from the Turawa reservoir (Out_res) was differentiated by six principal components, which explained approximately 79% of the total variability of indicators. Indicators such as nitrites, nitrogen, temperature, dissolved oxygen, electrolytic conductivity and sulphates and chlorides were those that shaped the quality of water in the Mała Panew on its section outflowing from the reservoir.
4. The PCA has allowed the sources of pollution of the Mała Panew river to be identified. It was shown that the main source of such pollution is the run off of biogens from agriculture to the Mała Panew, whose catchment area mainly consists of agricultural land. In order to protect the Turawa reservoir from pollution inflowing from the catchment area of the Mała Panew, a system of protection and buffer zones along the watercourse and the direct reservoir catchment area was proposed.
5. The analysis of research results reveals that EDA techniques are a useful tool for the analysis of complexity of problems related to the quality of water resources. They allow one to extract new information from large sets of hydrological observations in order to model the influence of environmental components on the quality of water and to determine the sources of pollution.

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Zmiany przepływów i jakości wód zbiornika zaporowego w zlewni rzeki Mała Panew (południowa Polska) określone z zastosowaniem wielowymiarowych analiz danych

Streszczenie: Eksploracyjne techniki wielowymiarowe, takie jak analiza składowych głównych (PCA), zostały zastosowane w celu analizy wieloletnich (lata 1998–2016) zmian przepływów i jakości wód nizinnego zbiornika zaporowego Turawa (południowo-zachodnia Polska) w zlewni rzeki Mała Panew (dopływ rzeki Odry). W pracy wykazano, że w okresie 1998–2016 zbiornik Turawa w znacznym stopniu wyrównywał przepływy wód rzeki Mała Panew. Analizowano również wskaźniki fizykochemiczne jakości wód na trzech stanowiskach pomiarowych (dopływ do zbiornika, w zbiorniku i na odpływie ze zbiornika). Ocenę jakości wody wykonano analizując wskaźniki fizykochemiczne takie jak: temperaturę wody, zawiesinę ogólną, pH, tlen rozpuszczony, BOD_5, NH_4^+, NO_3^-, NO_2^-, N, PO_4^{3-}, P, przewodność elektrolityczną, substancje rozpuszczone, siarczany SO_4^{2-} i chlorki Cl^-. Analizie statystycznej poddano również związki korelacyjne pomiędzy wszystkimi wskaźnikami jakości wody na poszczególnych stanowiskach pomiarowych, istotne statystycznie na poziomie $p \leq 0,05$. W celu wykrycia struktur zachodzących między wskaźnikami jakości wody na każdym stanowisku pomiarowym, zastosowano analizę składowych głównych (PCA) (Principal Components Analysis), w efekcie której otrzymano teoretyczny model opisujący prawidłowości w zależnościach między analizowanymi wskaźnikami jakości wód. Analiza składowych głównych (PCA) wykazała, że jakość wody rzeki Mała Panew najsilniej determinowały wskaźniki biogenne. Analizowano również istotność różnic między średnimi stężeniami wskaźników jakości wody dopływającej do zbiornika i wody odpływającej ze zbiornika. Na podstawie zastosowanych metod eksploracyjnej analizy danych możliwe było rozpoznanie struktur i złożoności powiązań zachodzących pomiędzy przepływami wód oraz wskaźnikami jakości wód w rzece Mała Panew. W pracy wykazano, że metody te mogą stanowić niezbędne narzędzie w zakresie podejmowania strategicznych decyzji i rozwiązań w zakresie racjonalnego gospodarowania wodą zarówno w zlewni zbiornika jak i w zbiorniku wodnym.