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Influence of human activities on water quality in two rural catchments – understanding the drivers and relationships for effective restoration

Włodzimierz Kanownik[a], Agnieszka Policht-Latawiec[a], Jolanta Dąbrowska[b,*]

[a]*Department of Land Reclamation, Faculty of Environmental Engineering and Land Surveying, University of Agriculture in Krakow, Al. Mickiewicza 21, 31-120 Kraków, Poland, emails: wlodzimierz.kanownik@urk.edu.pl (W. Kanownik), a.policht@urk.edu.pl (A. Policht-Latawiec)*
[b]*Institute of Building Engineering, Faculty of Environmental Engineering and Geodesy, Wrocław University of Environmental and Life Sciences, ul. Norwida 25, 50-375 Wrocław, Poland, email: jolanta.dabrowska@upwr.edu.pl*

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ABSTRACT

The article presents an evaluation of 12 physicochemical parameters of water in two rural streams in the south-eastern part of Poland. Moreover, a comparative analysis of the impact of human activities on water quality in the studied catchments was carried out. Factor analysis allowed the observation of similarities and differences in physicochemical composition of water of the two catchments. Based on factor analysis of water of catchment areas of the Żyłka and Dopływ z Wiktorca streams, 77.6% and 85.2% of total variance was described by only three factors. Despite the higher proportion of arable land in the Żyłka catchment area, the water here is of very good quality, whereas in the catchment area of the Dopływ z Wiktorca, human-related activities have a significant impact on insufficient water quality. The analyses carried out are essential for effective water management and for the creation of targeted mitigation and remediation plans.

Keywords: Water quality data; River monitoring; Adaptive management; Water reclamation; Factor analysis; Climate change

1. Introduction

The quality of surface water and groundwater is the result of various catchment characteristics [1–8]. These are mainly geological factors (rock composition and mineral solubility) and meteorological conditions that determine the hydrochemical background and the amount of water changing over time and space [9–12]. However, it is human activity that is the most significant: land use–land cover change in the catchment area with negative effects on soil erosion and surface runoff rates, as well as the utilities sector and municipal management ensuring that the needs of the population are met, influence the unsatisfactory ecological and chemical state of the water [13–17]. The effects of anthropopressure are highly visible in urban catchments, where residential, commercial and industrial buildings and traffic routes predominate [18,19]. Agricultural land use plays an important role in shaping the chemical composition of groundwater and surface water [20]. Fertilisers reaching waterbodies and organic matter flushed from the fields are concentrated in a relatively small amount of flowing water [21,22]. This often makes water quality poor in areas with intensive farming.

Observed climatic changes result in significant and rapid transfer of nutrients to surface water as well as increase in aquatic ecosystem productivity. This requires water managers to take additional protective measures. The necessity to further limit nutrient loads contaminating

* Corresponding author.

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water and to take into account threats accelerated by climate change must be recognized by water managers in restoration plans [23–25].

In order to implement an integrated water management strategy that will make full use of technical measures [26–31] and the natural capacity of a catchment area to cope with pollution – environmental carrying capacity [32–35] – it is necessary to know the sources and loads of pollution, as well as the methods and tools to study the relationship between water quality and catchment characteristics. Many authors stress that measures to improve water quality should be strongly linked to spatial planning [36–41].

The basis for effective water quality management is conceptual understanding – of the system, its drivers and relationships. The most common approach used here is adaptive management, understood as "learning to manage by managing to learn". The process consists of five steps: (1) Input data and information (including monitoring of water quality), (2) assessment (evaluation of river health), (3) river restoration plan, (4) implementation of the plan using adaptive management strategy and (5) reporting (Fig. 1). Management goals should be achieved in a cost-effective manner [25,42–45].

A very good example of a resource remediation approach that can be transferred to other case studies is the monitoring and adaptive management process used for the Deepwater Horizon Natural Resource Damage and Assessment (NRDA) restoration plan. The authors described steps 2–5 from the above-described approach: injury assessment, restoration planning, restoration implementation and reporting. An adaptive management feedback loop is included in the phase of restoration implementation [42].

The collection of data from monitoring and assessment (steps 1 and 2) is a starting point for the restoration plan and its implementation (Fig. 1), however, as many authors emphasize, for small catchment areas monitoring is very limited, and thus step 2 – assessment – is often incomplete and burdened with errors. An incorrect assessment of the condition of the catchment area – a poor understanding of the system, its drivers and relationships – affects the effectiveness and costs of further actions. In step 4, water quality data collection and analysis appears again as the basis of evaluation of restoration effectiveness.

Preventing the eutrophication of water requires first of all an understanding of the processes of migration and transfer of nutrients and their quantification in individual catchments, followed by a sustainable management of water resources on a local, regional and transborder scale [46]. For most small catchment areas, there is neither regular water quality monitoring nor hydrological measurements. Evaluation of such catchments for adaptive management is hampered, requiring a special selection of statistical methods for environmental data collected on an irregular basis, or the use of indirect methods based on remote sensing and geospatial analysis [28,47,48].

Various approaches, methods and tools have been proposed in literature for analysing the quality of water resources in catchment areas [42,49–52]. Due to the diversity of various catchments' characteristics, their geographical location, threats to water quality, the type of water quality parameters tested, the set of methods and tools needs to be adapted each time.

The aim of the study is twofold: (i) to extract and recognize the factors or origins responsible for water quality using multivariate statistical methods, (ii) to assess the influence of human-related activities on the quality of surface water as the basis for planning mitigation and remediation actions.

In the article, the results of tests of selected parameters in water flowing out of the catchment areas of the Żyłka and the Dopływ z Wiktorca streams in the years 2010–2013 were compared. These years were crucial for water quality, since Poland, as a member state of the EU, had been trying to achieve good status in all bodies of surface water and groundwater by 2015 in accordance with the Water Framework Directive. Two small catchments with different anthropogenic factors occurring in their area were selected for testing. The Żyłka stream catchment is of agricultural and forest character, while the Dopływ z

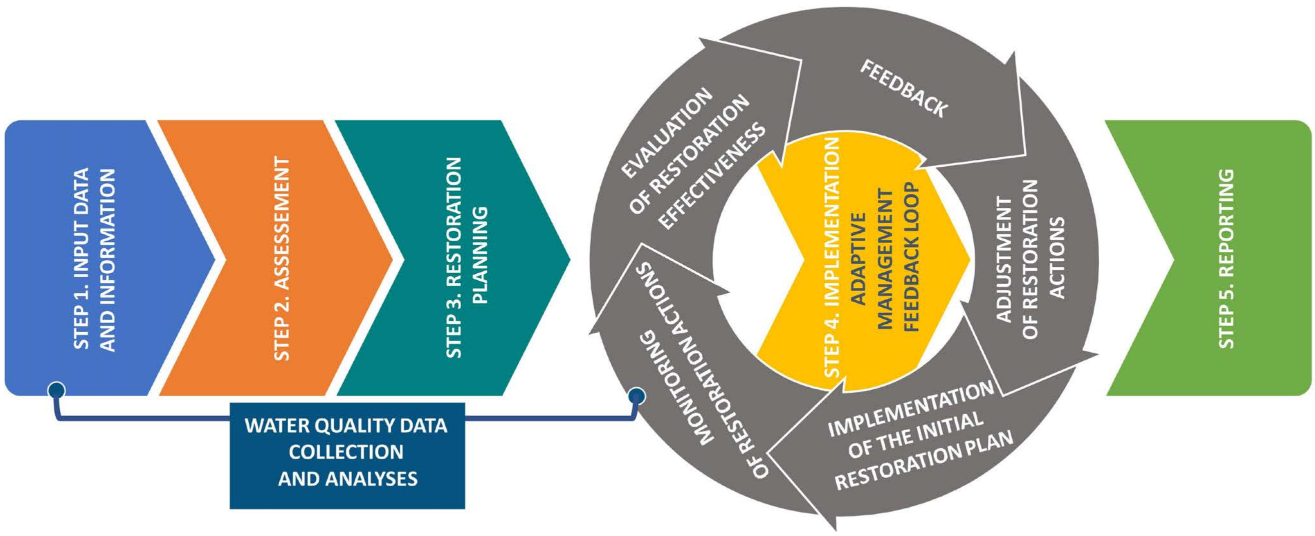

Fig. 1. Monitoring and adaptive management framework for river restoration [42–45].

Wiktorca catchment is, apart from agricultural and wooded lands, also covering areas belonging to the industrial and utilities sector. Anthropogenically transformed, small catchment areas have a small hydrological inertia, therefore the impact of external factors is almost immediately visible and causes high variability of water quality indicators [53].

2. Materials and methods

2.1. Data pretreatment

Water quality indicators selected for the study have a significant impact on the degradation and eutrophication of the water environment and also allow for the identification of a wide range of anthropogenic impacts: dissolved oxygen (DO), biochemical oxygen demand (BOD_5), total organic carbon (TOC), electrical conductivity (EC), total dissolved solids (TDS), pH, ammonium nitrogen ($N–NH_4^+$), total Kjeldahl nitrogen (TKN), nitrate nitrogen ($N–NO_3^-$), total nitrogen (TN), phosphate phosphorus ($P–PO_4^{3-}$) and total phosphorus (TP) in the Żyłka and the Dopływ z Wiktorca streams. The data for 2010–2013 were obtained from the Voivodeship Inspectorate of Environmental Protection in Rzeszów. Water samples were taken at the monitoring point in Wola Zarczycka (N 50°17′27′′, E 22°14′56′′) on the Żyłka stream and in Skrzyszów (N 50°05′44′′, E 21°33′18′′) on the Dopływ z Wiktorca (Fig. 1). The samples were usually collected at monthly intervals, but there were breaks in the testing, which is characteristic for monitoring in small catchments. After 2013, due to improved water quality of the Żyłka stream, monitoring of surface water quality in this catchment area was discontinued.

2.2. Statistical analysis

Analyses were conducted with the use of Statistica v.12 (StatSoft Polska, Kraków, Poland). Among the available statistical methods, the ones that allow for developing data based on the existing monitoring systems of surface water, considering the gaps in measurement strings, lack of normal distribution and variance homogeneity were chosen.

The basic analysis characterizing the physicochemical indicators of water of the examined streams was based on statistical parameters describing the examined set (minimum, maximum, arithmetic mean, standard deviation, coefficient of variation and median, and quartile).

The analysis showing seasonal differences in physicochemical indicators of stream water between catchments and between the growing and out of growing periods in individual catchments was carried out on the basis of results of U Mann–Whitney's non-parametric test. The out of growing period is the part of the year (November to March) in which the average daily air temperature remains below 5°C. The other part of the year (April to October) is the growing season with average daily air temperature above 5°C. The values of water quality indices between these periods were compared in order to determine the influence of vegetation on the change of their size in water in the studied streams. U Mann–Whitney's non-parametric test was chosen because of the lack of normal distribution of most of the analysed indicators according to the results of the Shapiro–Wilk test [54,55] and the inequality of variance determined by the Fisher Snedecor test [56–58].

To identify the sources of supply and origin of substances shaping the physicochemical composition of stream water, factor analysis (FA) was carried out [59–61]. At the initial stage of analysis of physicochemical indicators, outliers were rejected. The values of indicators not showing normal distribution were normalized using transformational functions. Due to different units of the examined indices, before the analyses started, the variables had been standardized. The prepared data set was subjected to FA with varimax rotation method, which reduces the ambiguity of interpretation. Thanks to rotation, it is easier to identify each factor with variables (physicochemical indicators), with which it is strongly correlated [62–64].

FA is very useful in water management as it helps to link the distribution of quality parameters to different possible sources, which usually have heterogeneous chemical signatures. The exact number of factors was selected according to the Kaiser criterion [65,66], which does not take into account factors with own values below one. It was assumed that factor loadings greater than 0.75 were statistically significant and loadings smaller than 0.75 were considered insignificant. Moreover, factor loadings above 0.75 were classified as high, between 0.50 and 0.75 as medium, and below 0.50 as weak [67,68].

2.3. Description of the studied streams' catchments

The article compares water quality of two catchments with similar geographical location and climatic conditions, but with different intensity of activity in the industrial and utilities sector. The catchment areas of the analysed streams are located in the Western Carpathians in the Sandomierz Basin, which as a macro-region is the largest part of Northern Subcarpathia [69]. The catchment area of the Żyłka stream is 24.32 km^2, defined as a uniform body of surface water with code PLRW20001722748. The Dopływ z Wiktorca has catchment area of 16.32 km^2 and code PLRW20006218872 (Table 1). Both streams' catchments differ not only in surface areas but also in length and circumference. The length of the Żyłka stream catchment area is 10.29 km and is almost twice as long as the length of the Wiktorca tributary catchment area with similar widths of 2.36 and 2.84 km, respectively. The catchment area of the Żyłka stream is less concentrated, as evidenced by lower values of the form, elongation and circularity indices and higher values of the Gravelius index, that is, the development of the watershed (Table 1). In the studied area, July is the warmest month of the year, with an average temperature of 18.6 C, and January with an average temperature of –5.9°C has the lowest average temperature in the whole year. The annual rainfall is around 615 mm. No mitigation measures to reduce the negative impact of agricultural diffuse pollution have been introduced in both catchments.

The Żyłka stream flows in a south-eastern direction through the Kamień commune and then through the Nowa Sarzyna commune in the Leżajsk county, it flows into the Trzebośnica River, a tributary of the San River in the northern part of the Subcarpathian voivodeship. In the stream's catchment area, the main form of land use is arable land

(45.2% of the total area) and forests and tree patches (26.1%). Developed areas account for 7.1%, and land under roads 3.7% (Table 2; Fig. 2). In 2010, the commune of Kamień completed the implementation of a project related to the ordering of water and sewage management, as well as the expansion of the sewage treatment plant and construction of a sanitary sewage system. The scope of the project included, among others, the extension of the existing biological and chemical sewage treatment plant in Nowy Kamień with a capacity of 300 to 730 $m^3 d^{-1}$, and the construction of a 28.3 km sanitary sewage network in Łowisko.

The Dopływ z Wiktorca stream flows through arable land, in Skrzyszów it flows into the Wielopolka River (tributary to the Wisłoka). The stream's catchment area is dominated by forests and tree patches (38.1% of total area), grassland occupies 31.1% and arable land 21.1%. On the other hand, urban area and land under roads occupy only 5.8% of the total area (Table 2; Fig. 2). In the catchment, there is the Mielecko-Kolbuszowsko-Głogowski Protected Landscape Area with significant natural values. Potential sources of water pollution of the Dopływ z Wiktorca stream include: the inflow of municipal and industrial wastewater from the Skrzyszów wastewater treatment plant (Ostrów commune), waste landfills in Kozodrza and the sugar

Table 1
Dimensions and shape characteristics of catchments

Parameters	Żyłka	Dopływ z Wiktorca
Area (km^2)	24.32	16.32
Length (km)	10.29	5.75
Average width (km)	2.36	2.84
Circumference (km)	23.73	17.31
Index of form (–)	0.23	0.49
Index of elongation (–)	0.54	0.79
Index of circularity (–)	0.54	0.68
Gravelius index (–)	1.36	1.21

Table 2
Land use pattern in catchments

Land use type	Żyłka		Dopływ z Wiktorca	
	(ha)	(%)	(ha)	(%)
Arable land	1,097	45.2	346	21.2
Grassland	417	17.1	508	31.1
Orchard	14	0.6	5	0.3
Non-agricultural use	0	0.0	5	0.3
Forest and tree patches	631	26.1	622	38.1
Land under water	5	0.2	52	3.2
Urban area	172	7.1	51	3.1
Land under roads	89	3.7	44	2.7
Total	2,432	100.0	1,632	100.0

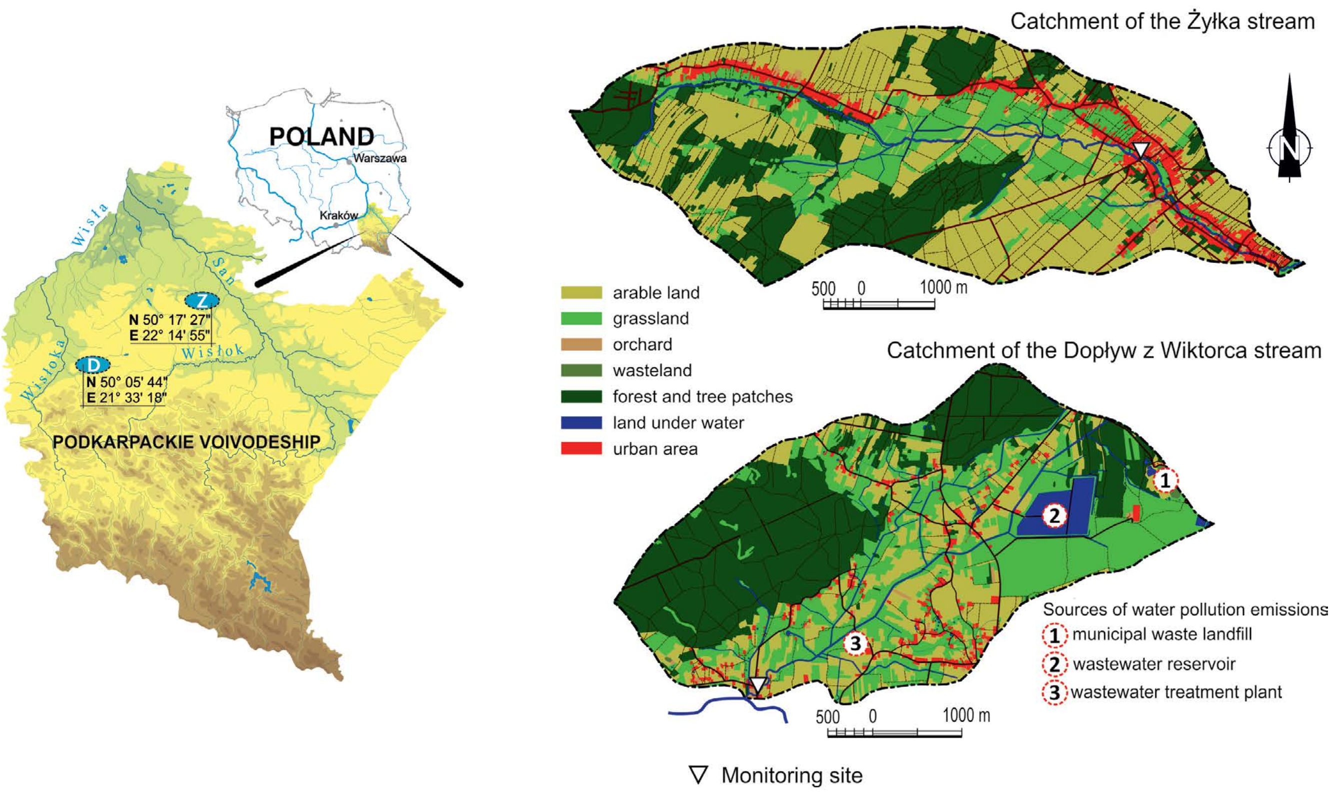

Fig. 2. Study area and location of monitoring points.

plant "Cukrownia Ropczyce" SUDZUCKER POLSKA S.A. Wrocław (Fig. 2).

Public Utilities Department in Ostrów operates a biological wastewater treatment plant with a capacity of 710 m^3/d and population equivalent = 6,113. Municipal wastewater from nearby towns and treated leachate from landfill in Kozodrza is discharged to the wastewater treatment plant. Treated wastewater is directed to the Dopływ z Wiktorca stream on 1+980 km. The Kozodrza landfill site for non-hazardous and non-neutral waste is also a potential source of water pollution of the stream due to the possibility of migration of hazardous substances from the area of the landfill through a system of ditches to the stream. Stormwater from the landfill area is discharged into a drainage ditch, which is a tributary of the source section of the Dopływ z Wiktorca. On the other hand, the Sugar Plant "Cukrownia Ropczyce" uses an installation for the production of sugar from raw plant products with a processing capacity of over 300 tons of finished products per day and a fuel combustion plant with a capacity of over 50 MW. This plant is a source of water pollution of the stream by industrial waste water from sugar production as well as from heat and power plant. The resulting industrial wastewater is collected in special reservoirs and is used in a closed circuit. The first stage of the technological process in the sugar factory is cleaning of the delivered beets. Water is used as a washing agent and beet transporting agent during unloading and further transport to the cleaning station. The water used during these operations is recirculated between the beet cleaning station and settling ponds. In the final stage of beet washing, ammonia solution is additionally supplied from outside the closed circuit. During the campaign period, there is a potential need to empty one of the reservoirs and the wastewater is discharged directly into the stream on 4+120 km. The allowable emission of industrial wastewater from the sugar production plant and from the combined heat and power plant is 3,500 m^3/d. The settlement areas in the catchment area are equipped with a sanitary sewage system, so a negative impact of water and sewage management on the water quality of the stream can be excluded.

In both catchments, agricultural activity may negatively affect water quality. This influence is related to runoff from fields, containing nutrients from natural and artificial fertilisers.

3. Results and discussion

3.1. Water quality in both catchments – general overview

The water of the Żyłka stream are characterized by good oxygenation – the average DO value is 9.0 mg dm^{-3} – as well as by low concentrations of nitrogen and phosphorus forms, EC is in the range 191–327 μS cm^{-1}, and TDS 163–260 mg dm^{-3} (Table 3). All the examined indices show no load of nutrients from sewage or area pollution of agricultural type and low levels of dissolved substances of natural origin. Although arable land occupies as much as 45.2%, forest and tree patches 26.1%, and urban area 7.1%, against the background of research carried out in Poland and worldwide, the water of the stream are only slightly polluted. Physicochemical parameters of the Żyłka stream may be compared with Carpathian streams and rivers, for example, the Sucha Woda, the Rybi Potok and the Białka Tatrzańska characterized by low contents of nutrients and chemical oxygen demand [70], as well as to the upland watercourse Krzyworzeka [53]. Halecki et al. [6] for the mountain river Skawa obtained similar concentrations of nutrients and oxygen indices, with EC reaching 1,305 μS cm^{-1} and TDS reaching 671 mg dm^{-3}. A different situation is observed in the Dopływ z Wiktorca stream. BOD_5 reaches 28.0 mg O_2 dm^{-3}, ammonium nitrogen 23.0 mg dm^{-3}, and total nitrogen 47.6 mg dm^{-3}, EC is within the range 289–1,300 μS cm^{-1}. Nutrient concentrations

Table 3
Statistical parameters describing the quality of water in the Żyłka and the Dopływ z Wiktorca streams

Indicator	Min. – Max.		Average		Standard deviation		Coefficient of variation (%)	
	Żyłka	Dopływ z Wiktorca	Żyłka	Dopływ z Wiktorca	Żyłka	Dopływ z Wiktorca	Żyłka	Dopływ z Wiktorca
Dissolved oxygen, mg dm^{-3}	5.7–12.2	4.1–11.3	9.0	7.7	1.9	2.6	21	34
Biochemical oxygen demand, mgO_2 dm^{-3}	1.2–5.0	3.3–28.0	2.4	6.8	0.9	6.5	36	96
Total organic carbon, mg dm^{-3}	4.9–25.4	8.6–30.0	9.1	19.5	4.3	7.7	47	40
Electrical conductivity , μS cm^{-1}	191–327	289–1,300	277	704	31	345	11	49
Total dissolved solids, mg dm^{-3}	163–260	138–935	216	412	26	260	12	63
pH	7.4–8.4	7.4–8.3	7.7	7.8	0.3	0.3	4	3
Ammonium nitrogen ($N–NH_4^+$), mg dm^{-3}	0.03–1.05	0.03–23.0	0.20	7.5	0.22	7.5	97	100
Total Kjeldahl nitrogen, mg dm^{-3}	0.25–3.12	1.6–27.4	1.14	10.0	0.66	8.38	58	84
Nitrate nitrogen ($N–NO_3^-$), mg dm^{-3}	0.5–1.6	0.5–24.2	1.0	6.7	0.24	7.6	23	113
Total nitrogen, mg dm^{-3}	0.9–4.4	2.9–47.6	2.2	17.2	0.73	14.4	34	83
Phosphate phosphorus ($P–PO_4^{3-}$), mg dm^{-3}	0.022–0.120	0.068–1.69	0.045	0.49	0.024	0.51	54	104
Total phosphorus, mg dm^{-3}	0.05–0.22	0.19–3.0	0.10	0.99	0.04	0.92	41	93

here reach values characteristic of water heavily affected by sewage and pollution from agricultural sources [71]. Similar results were obtained for the hydrologically sensitive to rainfall upland Szreniawa River, where water quality is affected by surface runoff from agricultural areas [72], for the lowland Trzemna and Selle rivers exposed to pollution by nitrates from agricultural sources and nitrogen and phosphorus compounds from insufficiently treated wastewater, in the lowland water of the Dojca River and the eutrophied water of the Sulejów Reservoir [47,73] and the Kowalski Reservoir [74]. High BOD_5 and COD values are characteristic not only of water charged with urban wastewater, where high concentrations of nitrogen and phosphorus occur simultaneously, but also of water contaminated by sugar plant wastewater, where high values are primarily recorded for BOD_5 and COD [47,75,76]. Water quality of the Dopływ z Wiktorca is, therefore, similar to upland and lowland water bodies located in areas with intensive human-related activities, and differ significantly from the clean water of upland, submontane and mountain catchments.

In this catchment area, arable land occupies 21.2%, forests and tree patches as much as 38.1%, and urban area 3.1%. A comparison of the land use itself in both catchments would suggest that the water of the Dopływ z Wiktorca stream should contain less nutrients.

Table 4 shows the results of the U Mann–Whitney's test at the significance level α = 0.05, which confirmed that in most cases significantly higher values of physicochemical indices were found in samples of water from the Dopływ z Wiktorca. These results may provide evidence of adverse anthropogenic effects on the stream. Moreover, it was observed that the water in this stream was less oxygenated in comparison with the water of the Żyłka, and the pH value did not cause any significant changes in the water quality of the assessed rivers.

3.2. Seasonal changes

In the next step, seasonal differences in surface water quality of the two streams in different periods of the year (out of growing season – OGS and growing season – GS) were analysed with U Mann–Whitney's non-parametric test (Table 5). The water studied in out of growing season was well oxygenated (above 10 mg dm^{-3}), similar to mountain streams and rivers [70]. Whereas during the growing season, the DO concentration in the water decreased even to 5.7 mg dm^{-3} in the Dopływ z Wiktorca stream. Statistically lower values of oxygen dissolved in the water of both streams during the growing season were found, which can be explained by physical, chemical, biological and biogeochemical processes taking place in the water [77–80]. The concentration of dissolved oxygen is inversely related to water temperature, in summer, when water temperature is high, the DO concentrations are usually lower [81]. Only in water of the Żyłka stream, the values $N–NH_4$ were statistically lower in the GS. These were small values (0.176 mg dm^{-3}) in relation to the median in the water of the Dopływ z Wiktorca stream which amounted to 5.1 mg dm^{-3} (OGS) and 6.9 mg dm^{-3} (GS). The inhibition of biological life and the leaching of nitrogen from bare soil increase the concentration of all nitrogen compounds in surface water in winter, maximum concentrations are usually observed in February and March and minimum in July. The concentrations of phosphates and phosphorus are the highest during the growing season (July and August), which is typical for small agricultural catchments. Seasonality is sometimes disturbed in catchment areas where watercourses are loaded with nutrients from sewage [82–85]. Statistically significantly higher TOC values were found in water in both examined watercourses during the growing season, and in the Żyłka water also statistically significant differences for the values

Table 4
Comparison of the water quality parameters in the studied catchments using U Mann–Whitney's non-parametric test

Indices	Median		Quartile				Results of U Mann–Whitney's test	
			Q_1	Q_3	Q_1	Q_3		
	Żyłka	Dopływ z Wiktorca	Żyłka		Dopływ z Wiktorca		Values of statistic (Z)	Probability test (*p*)
Dissolved oxygen, mgO_2 dm^{-3}	8.7	7.4	7.6	10.4	5.7	9.9	–1.80	0.07
Biochemical oxygen demand, mgO_2 dm^{-3}	*2.4*	*5.0*	*1.9*	*2.7*	*3.8*	*6.9*	*4.42*	*<0.001*
Total organic carbon, mg dm^{-3}	*8.6*	*18.6*	*6.9*	*10.3*	*13.5*	*25.7*	*3.81*	*<0.001*
Electrical conductivity, µS cm^{-1}	*277*	*556*	*272*	*296*	*435*	*952*	*4.53*	*<0.001*
Total dissolved solids, mg dm^{-3}	*222*	*294*	*196*	*239*	*226*	*603*	*3.15*	*0.002*
pH	7.75	7.70	7.45	7.95	7.60	7.90	0.68	0.50
Ammonium nitrogen ($N–NH_4^+$), mg dm^{-3}	*0.12*	*6.9*	*0.09*	*0.19*	*1.22*	*9.6*	*4.03*	*<0.001*
Total Kjeldahl nitrogen, mg dm^{-3}	*1.0*	*8.8*	*0.9*	*1.3*	*3.5*	*13.0*	*4.59*	*<0.001*
Nitrate nitrogen ($N–NO_3^-$), mg dm^{-3}	*1.0*	*2.6*	*0.9*	*1.2*	*1.6*	*12.0*	*3.61*	*<0.001*
Total nitrogen, mg dm^{-3}	*2.1*	*11.0*	*1.8*	*2.5*	*6.2*	*23.6*	*4.66*	*<0.001*
Phosphate phosphorus ($P–PO_4^{3-}$), mg dm^{-3}	*0.038*	*0.30*	*0.030*	*0.057*	*0.10*	*0.69*	*4.48*	*<0.001*
Total phosphorus, mg dm^{-3}	*0.09*	*0.51*	*0.07*	*0.12*	*0.43*	*1.20*	*4.73*	*<0.001*

The statistical values in italics indicate that the differences are statistically important on the level α = 0.05.

$P–PO_4^{3-}$ and TP were discovered. These results indicate the natural seasonality of the chemical composition of water of the Żyłka stream and the seasonal variability of the tested parameters for the water in the Dopływ z Wiktorca disturbed by the strong influence of anthropopressure.

3.3. Relationship between the ratios of tested parameters and water quality

The analysis of nitrogen and phosphorus content (Table 3) showed that the TN:TP ratio was lower in contaminated water. In the Żyłka TN:TP = 22, in the Dopływ z Wiktorca, the TN:TP ratio is equal to 17.4. If the N:P ratio (TN:TP) is less than 10, algae growth is limited by nitrogen, when it is 10–20, there is a cumulative limiting by both biogenic elements, while N:P is greater than 20, phytoplankton production is limited by phosphorus. For both examined watercourses, the N:P ratio was greater than 20, that is, in both catchments the factor limiting algae development is phosphorus. In the study by Solovey [86] carried out in many monitoring points of the Pregoła, Narew and Vistula rivers, it was observed that algae development is limited: in 50% of cases by both biogenic elements, in 40% by nitrogen and in 10% by phosphorus. Dąbrowska et al. [47,82] demonstrated that for the submontane water of the Strzegomka River the N:P ratio was about 36:1 (the limiting factor for phytoplankton development was phosphorus), while for the lowland Trzemna River the N:P ratio was 9:1 before modernisation of the sewage treatment plant (in this period nitrogen was the limiting factor) and 39:1 after modernisation of the sewage treatment plant (in this period phosphorus was the limiting factor). By analysing the individual forms of nitrogen, it was found that in the water of the Żyłka stream the ratio of $TN:N–NH_4:TKN:N–NO_3$ was ~100:9:52:45, which means that the concentration of total nitrogen was mainly shaped by nitrate and Kjeldahl nitrogen. In the water of the Dopływ z Wiktorca, on the other hand, the ratio of $TN:N–NH_4:TKN:N–NO_3$ was ~100:44:58:39, which means that the concentration of total nitrogen was significantly influenced by the concentration of Kjeldahl nitrogen and ammonium nitrogen. The ratio of total phosphorus to phosphate phosphorus in both streams was similar, ($TP:P–PO_4$ = 2.2) in the Żyłka and ($TP:P–PO_4$ = 2.0) in the Dopływ z Wiktorca.

Dissolved oxygen content in relation to BOD_5 in water of the Żyłka (BOD_5:DO = 0.27) was over three times higher than in water of the Dopływ z Wiktorca (BOD_5:DO = 0.88).

Table 5
Comparison of the water quality parameters between the growing season (GS) and outside the growing season (OGS) in the Żyłka (Z) and the Dopływ z Wiktorca (D) streams – results of U Mann–Whitney's test

Indices	Stream	Median		Values of statistic (U)	Probability test (p)
		OGS	GS		
Dissolved oxygen, mgO_2 dm^{-3}	Z	*10.4*	*7.6*	*7*	*0.001*
	D	*10.5*	*5.7*	*0.5*	*0.004*
Biochemical oxygen demand, mgO_2 dm^{-3}	Z	2.5	2.1	39	0.43
	D	6.5	4.6	15	0.43
Total organic carbon, mg dm^{-3}	Z	*7.5*	*10.2*	*17*	*0.02*
	D	*12.8*	*24.1*	*5*	*0.03*
Electrical conductivity , µS cm^{-1}	Z	276	285	35	0.27
	D	510	627	17	0.62
Total dissolved solids, mg dm^{-3}	Z	210	225	31	0.15
	D	291	294	20	0.94
pH	Z	7.8	7.6	30	0.13
	D	7.8	7.7	16	0.46
Ammonium nitrogen ($N–NH_4^+$), mg dm^{-3}	Z	*0.176*	*0.115*	*22*	*0.04*
	D	5.1	6.9	20	0.94
Total Kjeldahl nitrogen, mg dm^{-3}	Z	0.955	1.30	35	0.27
	D	6.4	8.8	19	0.83
Nitrate nitrogen ($N–NO_3^-$), mg dm^{-3}	Z	1.05	0.95	31	0.15
	D	2.85	1.60	14	0.35
Total nitrogen, mg dm^{-3}	Z	2.05	2.25	44	0.68
	D	11.1	11.0	20	0.87
Phosphate phosphorus ($P–PO_4^{3-}$), mg dm^{-3}	Z	*0.033*	*0.057*	*21*	*0.03*
	D	0.208	0.490	17	0.61
Total phosphorus (P), mg dm^{-3}	Z	*0.08*	*0.12*	*11*	*0.003*
	D	0.52	0.51	20	0.94

Statistical values in italics indicate that the differences are statistically important on the level α = 0.05.

In research conducted by Quirós [87] for more than 400 lakes in various locations, the following ratios were found: TN:TP = 32.4, $N–NO_3$:$N–NH_4$ = 5.0, $N–NO_3$:TP = 7.87, $N–NO_3$:TN = 0.17, $N–NH_4$:TP = 1.91, $N–NH_4$:TN = 0.08. Melvin and Gardner [88] proposed that the BOD_5:DO ratio as a new tool for water quality assessment. For the creeks and rivers they studied, this ratio came to 2.0. In most cases, the unpolluted water BOD_5:DO was about 0.1 and was higher in summer than in winter. They concluded that under normal conditions this value should range from 0.075 to 0.3, for contaminated watercourses 0.5 to 0.65. Values over 0.65 indicate high contamination of rivers and streams. BOD_5:DO is a parameter for a quick assessment of river health. BOD_5:DO for the Żyłka is 0.27, which indicates good water quality, and for the Dopływ z Wiktorca it is 0.88, which according to the above-mentioned classification shows high water pollution.

3.4. Extraction of factors affecting water quality

FA was used to detect the drivers which affect water quality in the analysed streams. The results presented in Table 6 demonstrate the existence of three main factors in the Żyłka catchment area as well as in the Dopływ z Wiktorca catchment area, which explain, respectively, 77.6% and 85.2% of the total variability of the examined water quality indicators. The dominant factor (VF1), which affects the quality of surface water of the Żyłka stream, explains 33.4% of the total variance and includes strong positive loadings on TP, TOC and $P–PO_4^{3-}$, and strong negative loadings on DO. The second factor (VF2) accounts for 24.3% of the total variance and includes $N–NH_4^+$, TKN and TN with strong positive loadings. The third factor (VF3) explains 19.9% of the total variance and includes EC and TDS with strong negative loadings. In case of the Dopływ z Wiktorca, the dominant factor (VF1), which impacts the quality of surface water of the stream, accounts for 41.7% of the total variance and includes strong positive loadings on TOC, EC, TDS, $N–NO_3^-$, $P–PO_4^{3-}$ and TP. The second factor (VF2) explains 28.9% of the total variance and includes strong positive loadings on $N–NH_4^+$, TKN and TN. The third factor (VF3) accounts for 14.6% of the total variance and covers DO and BOD_5 with strong positive loadings. The VF defined above indicates that the composition of surface water in the studied area is to a large extent shaped by anthropogenic activities; however, similar relationships were shown by Kazi et al. [89] and Fito et al. [75] for catchments threatened by municipal and industrial effluents including sugar production by-products. However, the analyses in the previous subsections show that water quality is definitely worse for the Dopływ z Wiktorca stream.

VF1 demonstrates an influence of humans on water quality in the studied streams. The second factor (VF2) in both catchments results from the relationships between different forms of nitrogen. The third factor in the Żyłka catchment is a simple and known relationship between EC and TDS. Measurements of EC indicate the presence of dissolved salts and electrolytic impurities, but do not give information about specific ion compositions [90]. Similar analyses were conducted for the Mała Wełna River by Sojka et al. [91] and for the Huaihe River by Wang et al. [92]. These authors confirmed the applicability of FA in assessing river water quality. FA was used to reduce a large number of variables (water quality parameters) into fewer numbers of factors, which facilitates finding indicators that have a significant impact on water quality. For the Mała Wełna River, a set of 16 parameters was reduced to four factors (VF – verificators) necessary to assess water pollution sources; whereas for the Huaihe, 13 water quality indicators were reduced to three factors. Similar research was

Table 6
Loadings of 12 parameters on significant VFs for groups

Indices	Żyłka			Dopływ z Wiktorca		
	VF1	VF2	VF3	VF1	VF2	VF3
Dissolved oxygen, mgO_2 dm^{-3}	*–0.779*	–0.071	0.452	–0.382	–0.028	*0.784*
Biochemical oxygen demand, mgO_2 dm^{-3}	0.433	0.396	0.549	0.210	0.618	*0.708*
Total organic carbon, mg dm^{-3}	*0.889*	0.018	0.410	*0.782*	0.369	–0.350
Electrical conductivity, μS cm^{-1}	–0.392	0.095	*–0.832*	*0.933*	0.294	–0.069
Total dissolved solids, mg dm^{-3}	0.142	0.012	*–0.886*	*0.906*	–0.005	–0.268
pH	–0.396	0.548	–0.336	–0.053	–0.506	0.522
Ammonium nitrogen ($N–NH_4^+$), mg dm^{-3}	–0.351	*0.778*	–0.171	0.187	*0.951*	0.097
Total Kjeldahl nitrogen, mg dm^{-3}	0.326	*0.861*	–0.005	0.298	*0.927*	–0.022
Nitrate nitrogen ($N–NO_3^-$), mg dm^{-3}	–0.488	0.434	0.273	*0.835*	0.289	0.070
Total nitrogen, mg dm^{-3}	0.144	*0.946*	0.076	0.656	*0.716*	0.018
Phosphate phosphorus ($P–PO_4^{3-}$), mg dm^{-3}	*0.872*	0.100	0.053	*0.820*	0.291	0.040
Total phosphorus (P), mg dm^{-3}	*0.922*	0.050	0.113	*0.764*	0.403	0.376
Eigen value	4.013	2.914	2.389	5.002	3.470	1.747
% Total variance	33.4	24.3	19.9	41.7	28.9	14.6
Cumulative % variance	33.4	57.7	77.6	41.7	70.6	85.2

Values in italics indicate strong loadings.

carried out by Singh et al. [93] for the Gomti River, where 24 parameters were reduced to six factors. In the Gomti River, water quality depended on natural soluble salts and anthropogenic organic pollution load. Gao et al. [94] found that by using FA to assess the quality of these water objectively and reasonably, it is possible to better understand the trend and diversity of water quality on a regional scale. FA is a very useful tool in planning pollution control for the region environmental systems.

3.5. Recommendations and future outlook

An unexpected outcome of the connected research was a good quality of the Żyłka stream water. Despite the large proportion of arable land in the catchment area, the water here is of very good quality. The composition of water is characteristic for areas not influenced by human activity, low values of EC are evidence of a low content of pollutants of natural origin. In the catchment area, work is constantly being carried out to improve water and sewage management. A major downside is the fact that after 2013, water monitoring was discontinued due to its good quality. Progressive climate change and dynamic development of rural areas may significantly affect the condition of surface water resources, further monitoring and trend observation necessary. Furthermore, research related to environmental carrying capacity would provide valuable information on how the catchment copes with pollution.

The water of the Dopływ z Wiktorca stream is under a strong negative impact of human-related activities. Water quality is most affected by the negative impact of urban and industrial wastewater. High concentrations of nitrate nitrogen may be indicative of the impact of area-based pollution of an agricultural type. For the catchment area, activities related to the provision of effective sewage treatment and the reduction of surface runoffs from fields are recommended. For the indication of surface runoff transport pathways, a method based on commonly available remote sensing and spatial data is recommended here, which was used to plan mitigation measures for the Dobromierz Reservoir catchment by Dąbrowska et al. [28]. The method allows to determine catchment areas with highest risk of transfer of pollutants to receiving water bodies and cost-effective location of riparian buffers, Rural Sustainable Drainage Systems (RSuDS) and other nature-based solutions used for controlling agricultural diffuse pollution.

4. Conclusions

The combination of multivariate statistical methods used in the study was proved to be a relevant tool for assessment and comparison of the quality of water for catchments differing in water quality and pollution sources. The application of FA with varimax rotation enabled to identify pollution sources and factors, as well as significant controlling parameters.

The Dopływ z Wiktorca stream was identified as polluted, the water was characterized by high contents of BOD_5, TOC, EC, N–NH_4^-, TKN, TN, P–PO_4^{3-} and TP, which is typical for catchment areas where insufficiently treated wastewater is discharged into the water and agricultural type of area pollution occurs. The Żyłka stream was considered to be a watercourse not influenced by strong anthropopressure, low concentrations of most of the examined parameters were found in it.

Moreover, the parameters that are the most important in the assessment of seasonal variations of water quality were determined. For the Żyłka catchment, DO, TOC, N–NH_4^-, P–PO_4^{3-}, TP. For the Dopływ z Wiktorca, seasonality was disturbed, which is observed for contaminated watercourses in agricultural catchments. Statistically significant differences were detected only for DO and TOC.

The results of the study indicate the necessity to improve treatment methods of industrial and municipal wastewater in the catchment of the Dopływ z Wiktorca. Furthermore, it is recommended to continue and resume the monitoring of the Żyłka stream in order to identify the phenomena allowing to maintain good water quality, with strong anthropopressure and possible negative impact of progressive climate change. Understanding how the relationship between human activity and water quality changes over time will help policy makers and water resources managers to improve management practices and to find appropriate mitigation measures.

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