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Trends in water quality variations in the Odra River the day before implementation of the Water Framework Directive

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Abstract

This paper contains an account of UN/EEC-sponsored research on water quality monitoring and assessments in the catchments areas of Europe's 10 transboundary rivers. In this context, water quality assessments established on the basis of monitoring data for Poland's rivers are discussed. Consideration is also given to the water quality assessment methods recommended by the EU Directives. The problem has been exemplified by the analysis of water quality variations in the transboundary river Odra in the time span of 1973–2003. For the years 1993–2003, the trends in water quality variations are calculated and the rates of variation are analysed. The points in time when the water quality will have attained the second class purity values are predicted, taking into account the requirements specified in Polish, Czech and German standards. Analysis of the trends in the variations of pollution parameters has revealed that the achievability of good water quality depends on the limit values adopted for the assessment.

Keywords: Transboundary river; Water quality; Loads of pollution

Introduction

The wide variety of methods that are in use in the European Union for riverine water monitoring and assessment (Report RIZA, 1996) does not allow any water quality comparisons, even with the largest transboundary rivers (Korol, Jaśniewicz, & Strońska, 1997). This was a powerful spur to attempting a unification of relevant monitoring, assessment and classification techniques. For the needs of the UN/EEC Water Convention, the Directives on Transboundary River Monitoring and Assessment have been issued (Guidelines, Report RIZA, 2000), which specify 50 European transboundary streams (including 8 rivers: the Danube, Elbe, Meuse, Mosel, Odra, Rhine, Saar and Schelde) and set international commissions to deal with water pollution control in those streams. Further actions towards unification included the creation of the International Water Assessment Center (IWAC) at the Inland Water Management and Waste Water Treatment (RIZA) in the year 2000. It was the IWAC that enabled comparisons of the monitoring programmes and assessment methods for Europe's 10 major transboundary rivers (Report RIZA, 2001). As shown by the results obtained, the water quality of the River Odra did not very much differ from that of the other 9 transboundary rivers (Table 1).

Poland's access to the EU has triggered the need of implementing the Water Framework Directive (Directive, 2000), which requires a 5-class categorisation of physicochemical pollutants and an assessment of water

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Table 1. Average annual values of some water quality parameters measured in 10 European rivers (Report RIZA, 2001)

River	Average annual concentration								
	mg/l								μg/l
	BOD_5	O_2	P_{tot}	N_{NH_4}	N_{NO_3}	N_{tot}	Cd	Zn	Lindane
Danube	3.0	8.2	0.07	0.4	1.48	Not determined	0.003	0.021	0.04
Rhine	Not determined	10.2	0.21	0.07	3.2	4.33	0.0008	0.023	0.0027
Elbe	Not determined	8.6	0.18	0.24	3.6	4.9	0.0001	0.033	<0.0025
Daugava	1.9	11.3	0.06	Not determined	Not determined	1.6	Not determined	Not determined	Not determined
Odra	**3.9**	**11.1**	**0.25**	**0.068**	**2.4**	**3.75**	**Below detection**	**0.006**	**0.0055**
Tagus	3.3	8.6	0.18	0.18	4.4	Not determined	Not determined	Not determined	Not determined
Tisza	1.9	9.3	0.24	0.12	1.54	2.06	0.0007	0.105	0.012
Meuse	Not determined	9.2	0.19	0.17	4.15	4.83	0.0003	0.034	0.005
Bug	**5.2**	**11.8**	**0.22**	**0.41**	**1.83**	**3.9**	**0.001**	**0.011**	**0.002**
Morava	5.8	Not determined	0.6	1.95	5.67	Not determined	Not determined	Not determined	Not determined

Note: Numbers printed in bold refer to rivers flowing through the territory of Poland.

quality in ecological terms. These requirements also hold for the transboundary river Odra. In this context, we thought it would be advisable to show the water quality variations that occurred over a time span of 30 years. We describe the present state of riverine water pollution in the Polish part of the Odra basin, and establish a forecast of water quality variations for the Odra by analysing the trends observed over the 11 years 1993–2003.

Method and scope of the study

Description of the area

The Odra is a transboundary river and one of the longest watercourses in the Baltic Sea catchment area. The river has its source in the Czech Republic, and its total length amounts to 854.3 km, of which 741.9 km are in the territory of Poland. The Odra basin covers a total surface area of 118,861 km^2. Of these, 106,821 km^2 lie within the borders of Poland; 6453 and 5587 km^2 belong to the Czech Republic and Germany, respectively. The Odra basin has a population of 15.4 million, where Poles, Czechs and German account for 84.4%, 9.0% and 6.5%, respectively (Fig. 1). The river follows a highly variable flow pattern. Table 2 shows the range of flows for 3 characteristic cross-sections: Chałupki (Poland's border with the Czech Republic), Połęcko (border between Poland and Germany), and Gozdowice (where the river divides into Eastern Odra and Western Odra).

Data collection and interpretation

Investigations into the pollution levels in waters of the River Odra and its tributaries have been carried out since 1962. Within the 31-year period under study (1973–2003), the results obtained were interpreted using the Equivalent Concentration (EC) method, developed and commonly applied in Poland. The EC values, i.e. those corresponding to the Mean Low Flow (MLF), were assessed from the hydrochemical profile of the river and calculated with the help of the regression equation describing temporary concentration variations in terms of flow variations at the time of sampling: $EC = f(F)$. Water quality assessments were based on the admissible concentration values for 3 water purity classes, which were in force till 11 February 2004.

In 1973, the publication of the first Riverine Water Pollution Atlas spurred us to adopt this year as the starting point for our investigations into the water quality variations within the Polish part of the Odra basin (including 9 rivers of a total length of 2668 km). Any comparisons of riverine water quality variations were based on the analysis of 8 polluting parameters that had been measured since 1962: dissolved oxygen, BOD_5, COD permanganate value, suspended solids, chlorides, sulphates, dissolved solids and phenol

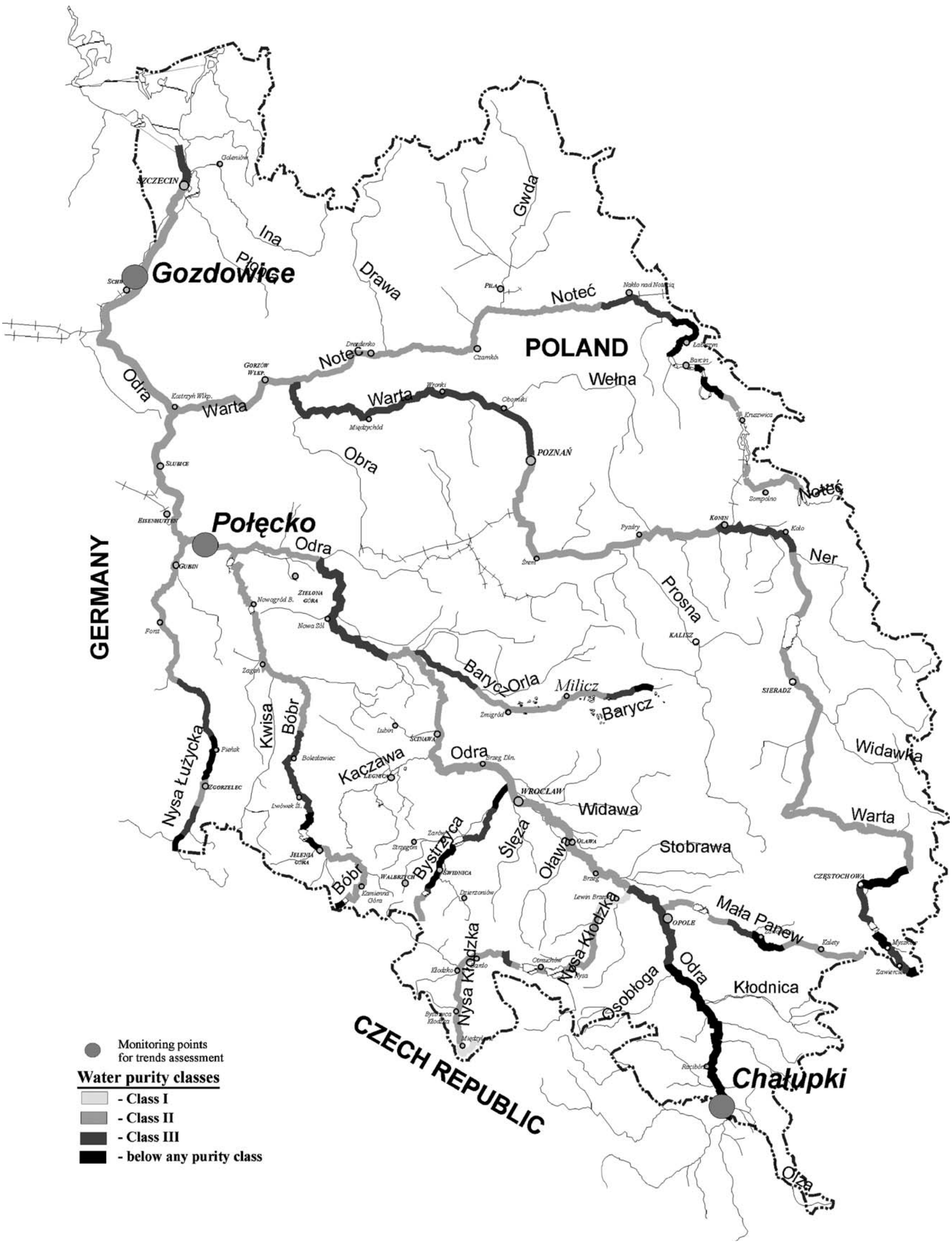

Fig. 1. Water quality assessments for the Odra River and its tributaries according to 28 physicochemical parameters in 2003 (see Table 3)

Table 2. Type of flow at gauge stations of choice along the Odra River over the period 1951–2000

Cross sections	Km of the River Odra	Type of flow (m^3/s)				
		HHF (high high flow)	MHF (mean high flow)	MMF (mean mean flow)	MLF (mean low flow)	LLF (low low flow)
Chałupki	20.0	2160	433	41.9	9.04	4.22
Połęcko	530.6	1680	820	264	109	52.3
Gozdowice	690.0	3403	247	537	254	156

Table 3. Admissible concentrations of physicochemical pollutants made use of for the assessment of Poland's watercourses up to 11 February 2004

No.	Parameter	Unit	Limit values for water quality		
			Class I	Class II	Class III
1	pH	pH	6.5–8.5	6.5–9.0	6.0–9.0
2	Total suspended solids	mg/l	$\leqslant 20$	$\leqslant 30$	$\leqslant 50$
3	BOD_5	mg O_2/l	$\leqslant 4$	$\leqslant 8$	$\leqslant 12$
4	COD-permanganate value	mg O_2/l	$\leqslant 10$	$\leqslant 20$	$\leqslant 30$
5	COD-Cr	mg O_2/l	$\leqslant 25$	$\leqslant 70$	$\leqslant 100$
6	Dissolved oxygen	mg O_2/l	$\geqslant 6$	$\geqslant 5$	$\geqslant 4$
7	Ammonia nitrogen	mg N_{NH_4}/l	$\leqslant 1$	$\leqslant 3$	$\leqslant 6$
8	Nitrate nitrogen	mg N_{NO_3}/l	$\leqslant 5$	$\leqslant 7$	$\leqslant 15$
9	Nitrite nitrogen	mg N_{NO_2}/l	$\leqslant 0.02$	$\leqslant 0.03$	$\leqslant 0.06$
10	Total nitrogen	mg N/l	$\leqslant 5$	$\leqslant 10$	$\leqslant 15$
11	Phosphates	mg PO_4/l	$\leqslant 0.2$	$\leqslant 0.6$	$\leqslant 1$
12	Total phosphorus	mg P/l	$\leqslant 0.1$	$\leqslant 0.25$	$\leqslant 0.4$
13	Conductivity	μS/cm	$\leqslant 800$	$\leqslant 900$	$\leqslant 1200$
14	Chlorides	mg Cl/l	$\leqslant 250$	$\leqslant 300$	$\leqslant 400$
15	Sulphates	mg SO_4/l	$\leqslant 150$	$\leqslant 200$	$\leqslant 250$
16	Total dissolved solids	mg /l	$\leqslant 500$	$\leqslant 1000$	$\leqslant 1200$
17	Total iron	mg Fe/l	$\leqslant 1$	$\leqslant 1.5$	$\leqslant 2$
18	Zinc	mg Zn/l	$\leqslant 0.2$	$\leqslant 0.2$	$\leqslant 0.2$
19	Chromium +3	mg Cr/l	$\leqslant 0.05$	$\leqslant 0.1$	$\leqslant 0.1$
20	Chromium +6	mg Cr/l	$\leqslant 0.05$	$\leqslant 0.05$	$\leqslant 0.05$
21	Cadmium	mg Cd/l	$\leqslant 0.005$	$\leqslant 0.03$	$\leqslant 0.1$
22	Copper	mg Cu/l	$\leqslant 0.05$	$\leqslant 0.05$	$\leqslant 0.05$
23	Nickel	mg Ni/l	$\leqslant 1$	$\leqslant 1$	$\leqslant 1$
24	Lead	mg Pb/l	$\leqslant 0.05$	$\leqslant 0.05$	$\leqslant 0.05$
25	Mercury	mg Hg/l	$\leqslant 0.001$	$\leqslant 0.005$	$\leqslant 0.01$
26	Phenols	mg/l	$\leqslant 0.005$	$\leqslant 0.02$	$\leqslant 0.05$
27	Anionic detergents	mg/l	$\leqslant 0.2$	$\leqslant 0.5$	$\leqslant 1$
28	Cationic detergents	mg/l	$\leqslant 0.5$	$\leqslant 1$	$\leqslant 2$

compounds (Table 3). In the following years the list of the investigated pollutants was increased from 8 to 52 items. Since 1989, the results of river monitoring have been collected in the JaWo Data Base, IMGW, Wrocław. The annual data sets of National Water Monitoring include 2100–5317 samples, where 54,200–104,080 parameters of pollution have been classified.

The results obtained over the time span of 1993–2003 served as a basis of water quality assessments for 9 rivers. The assessments involved 28 pollution parameters grouped into 3 categories (organic substances, salinity parameters, biogens) and an overall assessment for the physicochemical pollutants tested.

The trends in water quality variations for the River Odra over the period 1993–2003 were calculated for 3 characteristic monitoring cross-sections: Chałupki (Czech–Polish border), Połęcko (Polish–German border) and Gozdowice (where the river divides into Eastern Odra and Western Odra). The calculations included only BOD_5, total nitrogen and total phosphorus; firstly because their concentrations are of importance to the control of Baltic water pollution, and secondly because their determination is postulated in the EU Water Framework Directive 2000. The calculated trends are to show when the mean values of the investigated pollutants will have reached the values required for class II water quality (according to the 5-class classification of the Water Framework Directive) in Poland, in the Czech Republic and in Germany.

Results

The time span when the water quality assessments were carried out was characterised by a remarkably variable total discharge. The years 1973, 1983, 1991, 1992 and 1993 were dry. Over the period of 1994–1997, the discharge was an average one. The year 1998 was a wet year, 1999 was a limit year between wet and very wet years. Over the time span of 2000–2003, the discharge was, again, an average one. Despite those great differences in the hydrological characteristics between particular years, it is possible to create a homogeneous database that will allow water quality assessments for the whole range of flow (from low flow to high water), but the 'image' of water quality variations may then become blurry and distorted. However, when use is made of a unified method of assessing water quality which refers to MLF-type flow, this will allow not only comparisons of the pollution levels assessed for particular rivers, but also conclusions about the trends in water quality variations.

The comparison of long-term water quality variations in the Odra basin (making use of the results of river classifications in 1973, 1983, 1993 and 2003; Table 4) has produced the following findings. The decade 1973–1983 witnessed a considerable rise in riverine water pollution: the length of rivers carrying class II waters decreased from 26.3% to 20%, the length of rivers with class III waters dropped from 31.8% to 29.6%, while the length of excessively polluted rivers increased from 36.9% to 45%. The time span of 1983–1993 was characterised by an improvement in riverine water quality: the length of rivers carrying class I waters accounted for 26.1% and that of excessively polluted rivers decreased to 13.8% (Table 4). The next decade saw a further riverine water quality improvement: class I and class II waters accounted for 46.3% and 40.3%, respectively, whereas the proportion of class III and excessively polluted water was 6.8% and only 6.6%, respectively.

A more detailed analysis of the water quality variations observed over the period of 1993–2003 with 28 pollution parameters (expressed in terms of the lengths of the river sections assigned to particular purity classes) has revealed that (Table 5):

- *water pollution by organic substances* decreased at the fastest rate: the length of rivers carrying water classified as class I purity rose from 651.3 to 1488.5 km, while that of class III purity rivers and excessively polluted watercourses decreased from 645.2 to 32.4 km;
- *salinity parameters* showed a poorer dynamics of variations: the length of class I purity waters increased from 1836.7 to 2003.7 km only, and the length of rivers carrying high-salinity waters decreased from 324.5 to 167.5 km;
- *biogenic pollution* in clean watercourses decreased only slightly, since the range of class I purity water extended from 291.4 to 1701.6 km and the length of excessively polluted rivers decreased from 1664.6 to 317.8 km;
- when assessed in terms of the *28 physicochemical parameters*, the length of class I purity rivers did not undergo substantial changes, the length of rivers with class II purity waters rose from 283.9 km (10.1%) to 1722.6 km (61.7%), and the length of extremely polluted rivers decreased from 1700.9 km (~61%) to 327.3 km (11.7%).

The improvement in riverine water quality in the Odra basin should be attributed to the notably reduced point discharge of pollutants as a result of erecting new wastewater treatment plants, or modernising those in operation, in Poland and the Czech Republic (Dubicki, Florczyk-Gołowin, & Korol, 2003). The results of assessments performed in 2003 are shown in Fig. 1.

Analysis of the trends in mean concentration variations has substantiated a continuing improvement. However, the equations describing the variability of BOD_5 show a low correlation, but the correlations for the equations that characterise the variability of total nitrogen and total phosphorus being satisfactory. Irrespective of the mathematical assessment of the equations, it is obvious that the BOD_5 levels in the riverine water entering Poland's territories have met the class II purity requirements since 2003 according to Czech and German standards and that relevant Polish standards will not have been met before 2006 (Figs. 2a–c). In terms of Polish requirements, admissible total nitrogen concentrations have been measured since 2001, but according to German standards they will be attained in 2007. Similar differences are found to occur with the admissible values of total phosphorus. According to Polish standards, they were achieved in 1997, but in terms of relevant Czech or German standards, they will be obtained in 2005 (Figs. 2a–c). The forecasts for the riverine water monitored at Połęcko and Gozdowice say that BOD_5 will not comply with the requirements of the Polish standard until 2010, but according to German standards, the requirements of class II purity have already been fulfilled. As far as the total nitrogen concentrations are concerned, the class II purity requirement has been met since 1997 according to

Table 4. Water quality variations in the Odra basin over the period of 1973–2003 expressed as length of the river divided into purity classes

Period		River										
		Odra	Mała Panew	Nysa Kłodzka	Bystrzyca	Barycz	Bóbr	Nysa Łużycka	Warta	Noteć	Total length (km)	Proportion (%)
Total length of river sections divided into the purity classes (km)												
1973	I	—	39.4	4	—	13.5	61	—	13	—	130.9	4.9
	II	128.6	—	52.5	12.3	104.9	159.2	96.8	73.9	76.6	704.8	26.4
	III	91.6	9	108.4	21.4	5	27.3	41	446.5	97.6	847.8	31.8
	Out of class	521.7	75.8	—	55.6	—	6.8	60	244.1	20.5	984.5	36.9
1983	I	—	—	—	—	—	26.6	—	12.5	104.1	143.2	5.4
	II	77.3	25.3	72.3	—	117.2	111.6	59	15.2	57.2	535.1	20.0
	III	263.9	1.5	91.8	28	6.2	75.2	66.5	251.3	5.9	790.3	29.6
	Out of class	400.7	97.4	0.8	61.3	—	40.9	72.3	498.5	27.5	1199.4	45.0
1993	I	—	73.5	59.6	30.2	11.5	174.5	40.9	214.2	91	695.4	26.1
	II	370.3	50.7	105.3	31.3	111.9	79.8	88.3	400.5	—	1238.1	46.4
	III	148.9	—	—	—	—	—	68.6	148.2	—	365.7	13.7
	Out of class	222.7	—	—	27.8	—	—	—	14.6	103.7	368.8	13.8
2003	I	35.4	100.8	119.4	74.0	33.9	240.2	83.2	459.3	88.1	1234.3	46.3
	II	481.0	23.4	45.5	—	66.7	14.1	114.6	307.2	22.9	1075.4	40.3
	III	128.6	—	—	—	13.3	—	—	11.0	28.4	181.3	6.8
	Out of class	96.9	—	—	15.3	9.5	—	—	—	55.3	177.0	6.6
Classified river length in Poland (km)		741.9	124.2	164.9	89.3	123.4	254.3	197.8	777.5	194.7	2668.0	100
Total river length in Poland (km)		741.9	131.8	181.7	95.2	133.0	269.6	197.8	808.2	388.4	2947.6	

Table 5. Assessments of quality of waters of 9 rivers (by Equivalent Concentration Method) in particular years of the time span 1993–2003 according to the method applied.

Class of purity	Lengths of rivers (km) assigned to purity classes in										
	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
Assessed according to organic matter content											
Class I	651.3	458.7	755.4	750.4	606.5	751.8	1074.9	1102.5	1632.0	1046.2	1488.5
Class II	1493.4	1830.3	1650.4	1876.7	1970.5	1654.0	1577.8	1452.2	1112.1	1699.8	1267.6
Class III	587.0	427.5	355.8	150.3	185.1	350.2	137.2	233.4	45.8	35.8	24.3
Out of class	58.2	73.4	28.3	12.5	27.8	33.9	0.0	1.8	0.0	8.1	9.5
Assessed according to salinity parameters											
Class I	1836.7	1821.6	1980.5	1813.7	1848.9	2011.6	2031.4	2018.4	2012.5	2033.8	2003.7
Class II	518.9	555.4	489.3	663.5	648.5	533.9	539.4	552.4	579.0	500.7	461.7
Class III	109.8	115.5	105.6	93.6	76.1	86.6	22.8	33.0	88.2	169.5	157.0
Out of class	324.5	297.4	214.5	219.1	216.4	157.8	196.3	186.1	110.2	85.9	167.5
Assessed according to the content of biogens											
Class I	17.7	17.7	43.6	71.3	46.5	45.5	114.9	2141.8	226.7	136.2	135.3
Class II	291.4	269.1	475.8	558.6	751.7	825.6	656.2	517.6	723.5	915.9	1701.6
Class III	816.2	814.7	957.2	961.3	1103.5	838.7	1055.7	130.5	1205.2	1267.9	635.2
Out of class	1664.6	1688.4	1313.3	1198.7	888.2	1080.1	963.1	0.0	634.5	469.9	317.8
Assessed according to the concentrations of 28 physicochemical pollutants (*see Table 3*)											
Class I	17.7	—	25.1	64.3	41.6	45.5	114.9	72.4	56.7	43.6	42.4
Class II	283.1	286.4	467.1	563.1	756.6	625.0	656.2	872.2	893.6	895.0	1722.6
Class III	787.4	814.7	896.6	963.8	1103.5	1017.0	1055.7	1251.3	1205.2	1375.8	697.6
Out of class	1700.9	1688.4	1401.1	1198.7	888.2	1102.4	963.1	593.7	634.5	472.8	327.3

Polish standards. In terms of German standards, the values required for class II purity waters have been measured in Połęcko and Gozdowice since 2001 and 2003, respectively. Water pollution due to total phosphorus has not exceeded the admissible values in Połęcko and Gozdowice since 1997 and 1993, respectively, according to Polish standards. In terms of Czech and German standards, admissible phosphorus values have been measured in Połęcko since 2003. As far as Gozdowice is concerned, they will not be achieved until 2008.

The comparison of the water quality variation forecasts based on trend analysis has revealed unequivocally that the differences in the admissible concentration values specified in the water quality standards for the Odra basin, which are in force in Poland, Germany and in the Czech Republic, noticeably affected the classification of riverine water quality. Regrettably, the Water Framework Directive does not offer much help.

Conclusions

Continuing improvement in riverine water quality has been observed in the whole of the Odra basin.

The classifications of the rivers in 1973, 1983, 1993 and 2003 have produced the following finding: The decade 1973–1983 witnessed a notable decline in riverine water quality, which should be attributed to the industrial development in those days. As a result the length of rivers carrying class I and class II waters decreased by about 6%, whereas the length of excessively polluted rivers increased by approximately 8%. Over the period of 1983–2003, the quality of riverine water in the Odra basin continued to improve.

The assessments of water quality variations over the decade 1993–2003 have revealed that water pollution due to organic substances decreased at the fastest rate. The length of class I purity rivers rose by 837.2 km (30%), while that of class III purity rivers and excessively polluted watercourses decreased by 611.4 km (22%). Riverine water classification involving 28 physicochemical parameters has shown that the lengths of excessively polluted watercourses decreased from 1700.9 km (~61%) to 327.3 km (11.7%).

The improvement in riverine water quality in the Odra basin should be attributed to the construction of new wastewater treatment plants receiving municipal sewage and to the modernisation of the existing ones.

Analysis of the trends in the variations of pollution parameters (recommended by the Water Framework Directive as a method of predicting water quality variations) has revealed that the achievability of good water quality depends on the limit values adopted for the assessment. It is therefore advisable to reach

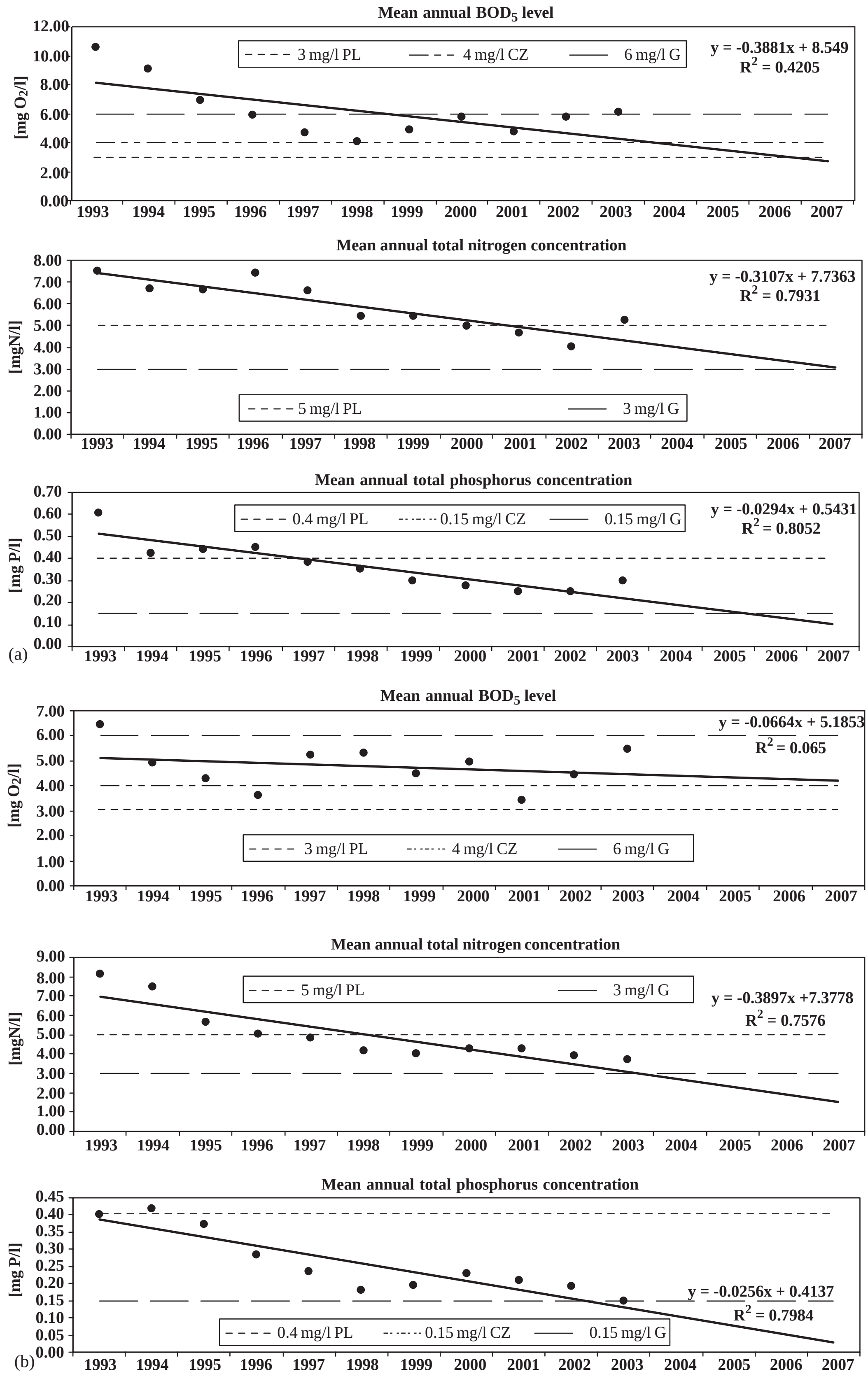

Fig. 2. (a) Trends in BOD_5, total nitrogen and total phosphorus concentration variations measured at Chałupki and comparison with Polish (PL), Czech (CZ) and Germany (G) standards. (b) Trends in BOD_5, total nitrogen and total phosphorus concentration variations measured at Połęcko and comparison with Polish (PL), Czech (CZ) and Germany (G) standards. (c) Trends in BOD_5, total nitrogen and total phosphorus concentration variations measured at Gozdowice and comparison with Polish (PL), Czech (CZ) and Germany (G) standards.

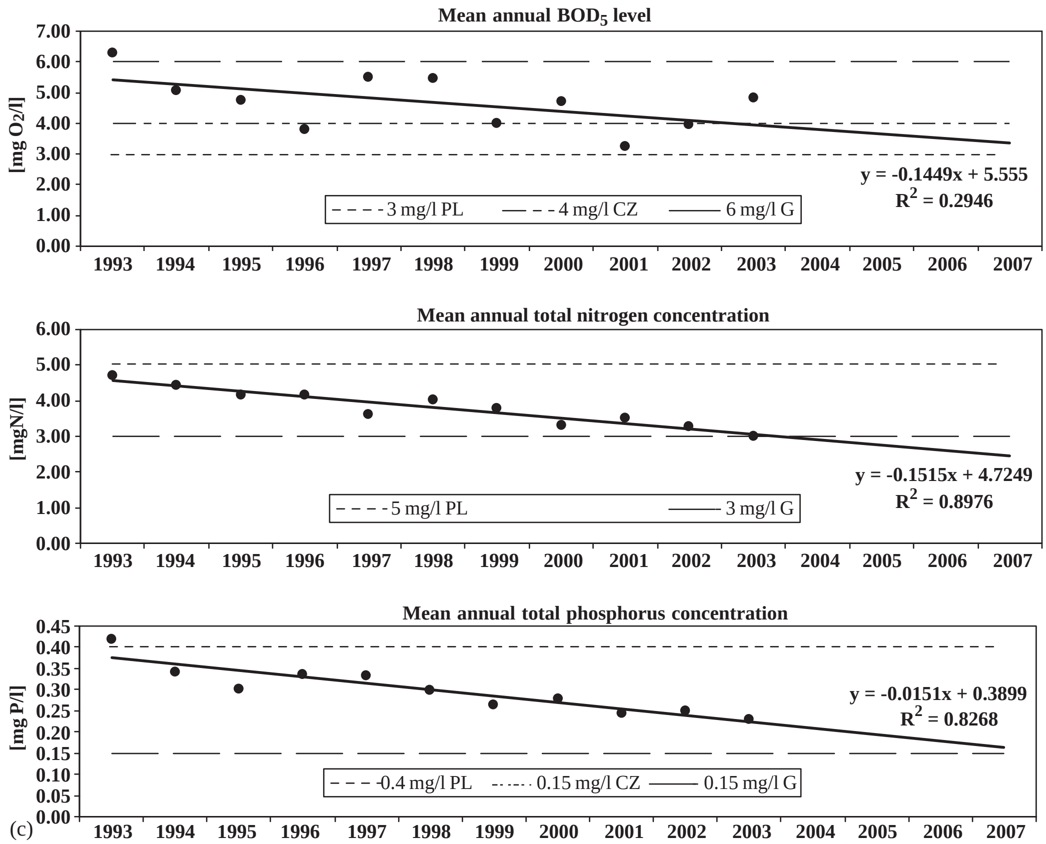

Fig. 2. (*Continued*)

agreement about the criteria for the physicochemical assessment of water quality in the entire basin. Such an approach is of particular importance when assessing transboundary rivers.

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