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Present state of the water quality of European rivers and implications for management

Gerda M. van Dijk^{*a}, Louis van Liere^a, Wim Admiraal^{a,†}, Bert A. Bannink^a,
Jan J. Cappon^b

^a*National Institute of Public Health and Environmental Protection, Laboratory for Water and Drinking Water, P.O. Box 1,
3720 BA Bilthoven, The Netherlands*

^b*Institute for Inland Water Management and Waste Water Treatment, P.O. Box 17, 8200 AA Lelystad, The Netherlands*

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Abstract

This study presents an overview of the present state of the water quality of European rivers. Water quality has been classified according to organic pollution (expressed in oxygen concentration and biological oxygen demand), eutrophication (nitrogen and phosphorus levels) and cadmium concentration. European rivers show various states of pollution. Although most European rivers are well aerated, organic pollution is still a problem and at regional level severe oxygen problems remain. Eutrophication is a serious problem in most rivers and has apparent detrimental effects on the riverine ecosystem. Cadmium pollution is poorly documented, but extremely high cadmium concentrations have been observed in some eastern European and Greek rivers. The availability of appropriate data on river-water quality, especially in eastern European countries, is limited. Substantially improved monitoring is a prerequisite to increasing essential knowledge of riverine ecosystems and to establishing a basis for river basin management on a European scale.

Key words: Water quality; European rivers; Eutrophication; Pollution

1. Introduction

River valleys have attracted human settlements for many centuries. In fact, the regulation or even the reconstruction of many European streams was accomplished as early as the 12th century [1]. Since the beginning of this century anthropogenic

activities influencing riverine ecosystems have increased drastically. Many rivers have been subjected to very marked pollution in their recent history; a series of actions to mitigate and curb water pollution have also been undertaken [2]. Nowadays, direct discharges of pollutants into rivers are undergoing treatment in many countries. Overall regeneration of river systems, including the watersheds and floodplains, diffuse and point sources of pollution, and the biological communities in the rivers, as well as in the receiving

^{*} Corresponding author.

[†] Present address: Department of Aquatic Ecotoxicology, University of Amsterdam, Kruislaan 320, 1098 SM Amsterdam, The Netherlands.

waters, has only been attempted in a few cases. The Commission of the European Communities (CEC) advocates a multifaceted and international river management policy throughout Europe. Such an approach requires knowledge of riverine ecosystems. However, an overall insight into the present state of water quality and pollution problems of European rivers is still lacking. The aim of this study is to overview the present state of the water quality of large European rivers. Their quality will be discussed according to state of organic pollution, eutrophication and cadmium contamination. Contamination with organic micro-pollutants is not considered.

2. Materials and methods

2.1. Data set

The data set used was derived from various sources, a considerable part of which originates from data collection by the European Commission [3,4]. In 1977 the CEC agreed on a common procedure of information exchange on the water quality of freshwater. According to this procedure each member collects data on selected water quality parameters at selected sampling stations according to agreed methods. The Commission aims to report the results every 3 years, even though some countries have, to date, supplied only limited data.

In addition, data from the EUROSTAT 1985 data set were used. The statistics from this set are based on data obtained from the member states via the OECD-EUROSTAT questionnaire on the state of the environment. These data should be interpreted with caution, as they are presented in a highly summarized form, the exact sampling locations are not given, and sampling and analytical procedures vary from country to country. Furthermore, data were obtained from both personal communications and scientific literature in which materials and methods were similar. No rigorous selection was made regarding river size.

2.2. Classification

Classification of water quality requires the selection of representative chemical or physical variables as well as certain 'measuring rods'. Dissolved oxygen and the biological oxygen demand (BOD₅)

were chosen as parameters for organic loading, while total nitrogen and total phosphorus concentrations were taken to represent the degree of eutrophication. The cadmium concentration is used as an example of heavy-metal pollution.

No general agreement exists on water quality standards, but were selected for this study as follows. In The Netherlands, oxygen standards are set at 5 mg O₂ l⁻¹ [5]. Since the classification is based on annual averages of well-aerated natural running waters, a critical oxygen standard of 7 mg O₂ l⁻¹ was adopted in this study. A critical BOD value of 3 mg O₂ l⁻¹ was taken from the CEC guidelines for the preparation of drinking water (highest quality A1G) [6].

For phosphorus and nitrogen, critical values of 0.15 mg P l⁻¹ and 2.2 mg N l⁻¹ (both annual averages) were used as a minimum requirement to avoid eutrophication effects [5,7]. These standards correspond to requirements for the preparation of drinking water (class A1G) [6]. It should be noted that the standards for phosphorus and nitrogen are set for stagnant waters. Total nitrogen has been estimated by summing the ammonium and nitrate concentrations, as data on total nitrogen were surprisingly scarce. Thus, the actual number of cases in which the total nitrogen concentration exceeds the standard is underestimated.

For cadmium a critical value of 1 mg Cd kg⁻¹ suspended solids was proposed in the Rhine Action Programme [8]. Assuming an average of 25 mg l⁻¹ of suspended solids, the critical value for total cadmium was set in the present study at 0.04 µg l⁻¹. Remedial actions are regarded as imperative when critical levels are exceeded and drastic sanitation is needed when these levels are exceeded to a large extent as in the following: oxygen concentration by a factor ≤ 0.5, BOD by a factor ≥ 2, phosphorus and nitrogen by a factor ≥ 5 and cadmium by a factor ≥ 25.

3. Results

Table 1 gives a summary of rivers included in the present study, additional information on sites (as far as available), years of sampling, and sources of data. As can be seen, there is a wide variance in river size. Although the present study focused on

Table 1

Summary of European countries and rivers included in the present study, and additional information on mean annual flow, sampling sites (where available), years of sampling and sources of data

Country	River	Flow (m ³ /s)	Sampling location	Source	Year
Denmark	Gudenå	16	Tvilium	[4]	1986
	Skjernå	8	Ahlergard	[4]	1986
Sweden	Torne	421	At the mouth	Wilander (pers. commun.)	1990
	Kalix	306	At the mouth	Wilander (pers. commun.)	1990
	Lule	486	At the mouth	Wilander (pers. commun.)	1990
	Pite	163	At the mouth	Wilander (pers. commun.)	1990
	Skellefte	160	At the mouth	Wilander (pers. commun.)	1990
	Ume	440	At the mouth	Wilander (pers. commun.)	1990
	Indals	453	At the mouth	Wilander (pers. commun.)	1990
	Örekilsälven	—	At the mouth	Wilander (pers. commun.)	1990
	Lagan	—	At the mouth	Wilander (pers. commun.)	1990
	Göta	—	At the mouth	Wilander (pers. commun.)	1990
	Ätran	—	At the mouth	Wilander (pers. commun.)	1990
	Dalälven	—	At the mouth	Wilander (pers. commun.)	1990
	Norrström	—	At the mouth	Wilander (pers. commun.)	1990
	Emån	—	At the mouth	Wilander (pers. commun.)	1990
Finland	Kymijoki	367	At the mouth	Kaupilla (pers. commun.)	1984–1987
	Kokemäenjoki	274	At the mouth	Kaupilla (pers. commun.)	1984–1987
	Lijoki	169	At the mouth	Kaupilla (pers. commun.)	1984–1987
	Oulujoki	267	At the mouth	Kaupilla (pers. commun.)	1984–1987
	Kemijoki	571	At the mouth	Kaupilla (pers. commun.)	1984–1987
	Tornionjoki	419	At the mouth	Kaupilla (pers. commun.)	1984–1987
Norway	Glomma	589	At the mouth	[9]	1991
	Drammenselva	222	At the mouth	[9]	1991
	Numedalslågen	93	At the mouth	[9]	1991
	Skienelva	195	At the mouth	[9]	1991
	Otra	132	At the mouth	[9]	1991
	Suldalslågen	78	At the mouth	[9]	1991
	Orkla	55	At the mouth	[9]	1991
	Vefsna	190	At the mouth	[9]	1991
Poland	Alta	107	At the mouth	[9]	1991
Poland	Odra	312	At the mouth	Rybinski (pers. commun.)	1990
	Wisla	774	At the mouth	Rybinski (pers. commun.)	1990
Germany	Elbe	313	CSFR-DDR border	[10];Pütz (pers. commun.)	1989–1990
	Elbe	—	Dresden	[10];Pütz (pers. commun.)	1989–1990
	Elbe	750	Geesthacht	[4]	1986
	Weser	140	Hemeln	[4]	1986
	Weser	340	Intschede	[4]	1986
	Ems	85	—	[4]	1986
Germany	Rhein	1300	Maxau	[4]	1986
	Rhein	1700	Mainz	[4]	1986
Netherlands	Rijn	2000	Lobith	[11]	1989
	Rijn	—	Brienoord	[4]	1986
Belgium	Meuse	—	Heer-Agimont	[4]	1986
Netherlands	Maas	223	Eijsden	[11]	1989
	Maas	273	Keizersveer	[11]	1989

Table 1 (continued)

Country	River	Flow (m ³ /s)	Sampling location	Source	Year
Belgium	Escaut	—	Bleharies	[4]	1986
	Escaut	—	Doel	[4]	1986
United Kingdom	Tyne	50	Wylam Bridge	[4]	1986
	Trent	103	Nottingham	[4]	1986
	Thames	85	Teddington Weir	[4]	1986
	Mersey	—	—	EUROSTAT, 1989 ^a	1985
Ireland	Boyne	43	Slane Bridge	[4]	1986
	Barrow	29	Graiguenamanagh Bridge	[4]	1986
	Blackwater	20	Killavullen Bridge	[4]	1986
France	Seine	280	Paris	[4]	1986
	Loire	59	Roanne	[4]	1986
	Loire	300	Orleans	[4]	1986
	Loire	60	Nantes	[4]	1986
	Garonne	45	Couthures	[4]	1986
	Rhône	400	Pont-Carnot (L.Leman)	[4]	1986
	Rhône	520	Lyon (Saone)	[4]	1986
	Rhône	900	Saint-Vaillier (Isere)	[4]	1986
Spain	Guadalquivir	24	Sevilla	Padilla (pers. commun.)	1990
	Guadiana	41	Badajoz	Padilla (pers. commun.)	1990
	Duero	150	Puente Pino	Padilla (pers. commun.)	1990.
	Tajo	250	Alcantara	Padilla (pers. commun.)	1990
	Ebro	119	Tortosa	Padilla (pers. commun.)	1990
	Ebro	550	At the mouth	[12]	1986–1987
	Segura	7	Segura en Archena	Padilla (pers. commun.)	1989–1990
Portugal	Tejo	—	—	EUROSTAT, 1989	1985
	Minho	—	—	EUROSTAT, 1989	1985
	Duero	—	At the mouth	Cortes (pers. commun.)	1989
Italy	Tevere	—	Ponte Felcino	[4]	1986
	Tevere	—	Ponte Nuovo	[4]	1986
	Tevere	232	At the mouth	EUROSTAT, 1989	1985
	Po	1050	Cremona	[4]; ECE/IEDS ^b	1986; 1988
	Po	1200	Boretto	[4]; ECE/IEDS ^b	1986; 1988
	Po	1440	At the mouth	[4]; ECE/IEDS ^b	1986; 1988
	Adigo	235	At the mouth	ECE/IEDS	1988
	Tevere	232	At the mouth	ECE/IEDS	1988
	Arno	100	At the mouth	ECE/IEDS	1988
Greece	Acheloos	150	Agrinion	[4]	1986
	Pinios	50	Larissa	[4]	1986
	Aliakmon	63	Kozani	[4,13]	1986; 1983–1984
	Axios	170	Thessaloniki	[4,13]	1986; 1983–1984
	Strymon	130	Serres	[4,13]	1986; 1983–1984
	Nestos	35	Drama	[4,13]	1986; 1983–1984
Germany	Donau	—	Jochenstein	[14]	1985
Austria	Donau	—	Vienna	[15]	1986
				[16]	1979–1986
				[14]	1985
Czechoslovakia	Duna	—	Karlova	[14]	1985

Table 1 (continued)

Country	River	Flow (m ³ /s)	Sampling location	Source	Year
Hungary	Duna	—	Budapest	[17] [14]	1982–1983 1985
Yugoslavia	Duna	—	Beograd/Vinca	[18] [17]	1985–1987 1982–1983
Romania	Duna	—	Bazias	ECE/IEDS	1988
	Duna	—	Chiciu	ECE/IEDS	1988
Bulgaria	Duna	—	Silistra	ECE/IEDS	1988
Romania	Duna	—	Delta	[18]; ECE/IEDS	1988; 1982–1983

^aEnvironment statistics, Statistical Office of the European Community.

^bEconomic Commission for Europe, Statistical Division.

large rivers, some smaller rivers (e.g. some Irish and Norwegian ones) were included to cover most regions of Europe.

Appropriate water quality data for European rivers, especially in Eastern Europe, are limited. This is partly due to a lack in standardization of methods and probably to hampered information exchange. At present the CEC programme is the most comprehensive monitoring programme on European river-water quality, however, the programme covers only a limited number of rivers and parameters, as not all member states supply their data to the CEC. Data from other sources are usually difficult to obtain or are not based on similar methods.

Despite this scarcity of data, some general trends can be recognized. Water quality standards are often not met in many of the European rivers (Fig. 1). Only the Scandinavian countries, Norway, Sweden and Finland, show a relatively good river water quality. They do not exceed the standards for organic pollution and eutrophication. Some, however, are cadmium polluted. Most of the rivers in Central and Eastern Europe show a rather poor water quality. The rivers Elbe, Oder, and Vistula are highly polluted. They are well aerated, but exceed the standards for organic pollution, eutrophication and cadmium concentration. Conditions for river-water quality in the

Mediterranean countries are poor, e.g. Qualdquivir and Po. In Greece, organic pollution and eutrophication is limited. Some rivers in Greece are seriously cadmium polluted, with concentrations of more than 25 times the critical level. The western European rivers vary largely in water quality. On the whole, most are well aerated, considering the mean annual oxygen concentrations. At the regional level, however, serious oxygen problems remain (e.g. Scheldt and Meuse). If and when the mean annual oxygen concentration does not meet the standards, anoxic conditions can evidently occur. This is a common phenomenon in summer. It is known that in many western European rivers, organic pollution has, as a result of municipal sewage treatment facilities, been reduced during the last 20 years e.g. in the rivers Rhine and Thames. Nevertheless, organic pollution is still a serious problem in various rivers: for instance, BOD exceeds the standards as much as 2-fold in the rivers Elbe, Weser, and Seine. In highly eutrophic rivers high BOD levels may also result from a high primary production, especially in downstream reaches and impounded sections. Most western European rivers are severely eutrophicated. The nitrogen and phosphorus concentrations of the rivers Scheldt and Mersey exceed the standards 5-fold or more.

From Fig. 1 it can be seen that the critical cad-

	O ₂ mg/l	BOD mg/l	tot-P P mg/l	tot-N N mg/l	Cd ug/l
	> 7	< 3	< 0.15	< 2.2	< 0.04
	3.5 - 7	3 - 6	0.15 - 0.75	2.2 - 11	0.04 - 1
	< 3.5	≥ 6	≥ 0.75	≥ 11	≥ 1
	below detection limit:			< 11	< 1
	below detection limit:				< 5

Fig. 1. Water quality classification of European rivers. A blank indicates that no data were available.

mium level ($0.04 \mu\text{g l}^{-1}$) is exceeded in various western European rivers (e.g. Meuse, Mersey and Scheldt).

4. Discussion

European rivers show a wide variation in pollution problems. Although most did not show low averages of oxygen concentration, organic pollution is a problem; regionally and locally severe oxygen shortages occur. In some western European countries most of the domestic waste water is now being purified. Swedish rivers, and the rivers Rhine and Thames are examples illustrating substantial reductions in organic pollution during the past decade or so. In contrast, the central and eastern European rivers shown (Vistula, Odra, and Elbe) reveal heavy organic pollution. This is due to the fact that in most eastern European countries only a limited portion of the population and industry is connected to sewage treatment plants. For instance, along the River Vistula most of the sewage and waste water discharged into surface waters is either untreated or treated insufficiently [19].

Nowadays, most European rivers are affected by eutrophication. The ammonium concentration regularly amounts to $>1 \text{ mg N l}^{-1}$, a value which is extremely high for surface waters. The (microbial) oxidation of ammonium to nitrate in the river requires substantial amounts of oxygen. This oxidation, which should in fact be completed in waste water treatment plants, is at present a main oxygen-consuming process in rivers. This process is, for example, most likely responsible for the $\sim 20\%$ undersaturation of oxygen occasionally observed in Rhine water [20]. Undersaturation of $\sim 30\%$ is assumed to be inhibitory to sensitive forms of life such as some insect larvae [21].

The consequences of eutrophication for river communities are not documented as extensively as for lentic waters. However, abundant macro-algal and dense plankton growth, leading to organic enrichment, especially at downstream locations, is evident. This is illustrated in the rivers Rhine [22], Loire [23] and Vistula [24] in which summer chlorophyll levels of $100\text{--}200 \mu\text{g l}^{-1}$ are observed. High algal densities may have consequences for

the river ecosystem. For instance, it probably enhances the abundance of opportunistic herbivores, such as the filter-feeders *Dreissena polymorpha* [25] and *Corophium curvispinum* [26], which are now abundant in the River Rhine. A substantial occurrence of opportunistic species is a general characteristic of disturbed water systems [27]. The detrimental effects of eutrophication are generally enhanced by river regulation, which increases water residence time through dam construction, weirs, etc. It has been shown that regulation of the River Ebro has led to an increase in phytoplankton biomass, and concurrently, a high density of filter feeders such as *Hydropsyche* and *Ephoron virgo* in the downstream parts of the river [12]. Eutrophication not only affects the ecosystems of the river itself, but also those of receiving backwaters and coastal waters. For example, Dutch coastal waters show a close correlation between the Rhine discharge and coastal chlorophyll concentrations [28].

Recent considerations on the nutrient ratios in rivers have led to support for choosing critical N and P values. Values $>0.15 \text{ mg P l}^{-1}$ and 2.2 mg N l^{-1} lead to high N:Si and P:Si ratios in river-water. Under these conditions riverine and coastal diatom populations are unable to exhaust the N and P contents of, for instance, Rhine water since Si limits diatom growth [29]. Consequently, flagellate blooms in the North Sea may increase [30]. Eutrophication is also shown in the Baltic Sea by increasing N:Si and P:Si ratios [31].

Critical values of nitrogen and phosphorus are much higher than the average background concentrations in unpolluted large rivers. The average nutrient levels in unpolluted major rivers of the world amount to $\sim 0.375 \text{ mg N l}^{-1}$ (total dissolved N) and $\sim 0.025 \text{ mg P l}^{-1}$ (total dissolved P) [32]. The human influence on surface water has now greatly increased nutrient levels. Total dissolved P and N have by-and-large increased worldwide by a factor of two, and by factors of 10–50 in some western European and North American rivers [32].

Cadmium pollution is poorly documented, but probably widespread. On various sampling sites, the detection limit surpasses the critical value. These sites may be considered as potentially cadmium polluted.

This overview of European river-water quality is far from complete. Only a selected group of parameters has been taken into consideration. Other important parameters, such as pH, salinity and contamination with organic micro-pollutants were not included. Contamination with micro-pollutants is a more recent phenomenon, which is even more difficult to demonstrate due to lack of appropriate monitoring. Another problem in assessing the quality of European rivers is that spatial variation in climatic and geomorphological conditions plays an important role. The combination of different sources of constituents and different seasonal flow regimes accounts for the appearance of seasonal patterns for constituents that are area specific. For example, many southern European rivers can be distinguished by water regimes high in winter and spring and low in summer, whereas many eastern European rivers exhibit typical hydrographs of one big snow-melting flood in spring and small rain floods in autumn. As little information is available on the impact of the seasonal variation in flow on annual means, comparison of annual means among various rivers should be interpreted with caution.

The main channels of rivers can be considered 'integrators' of environmental conditions in their catchments [33,34]. The need for a coordinated approach to river basin planning and development has become increasingly evident during the recent decades. The simultaneous use of river systems for transport and fisheries, production of drinking water, recreation and nature conservation requires concerted environmental action based on knowledge of riverine ecosystems. The necessary interdisciplinary procedures for river basin management are for several systems in a developmental stage [5]; this approach needs to be promoted. Recently, a comprehensive manual has been developed as a current state-of-the-art on river project appraisal within the developing concept of river basin management [35]. It provides a checklist for those familiar with river basin management based on experiences of various national river projects in the United Kingdom. Management of international rivers and catchments, however, requires international commitment and coordination. Examples of such international bodies are the

International Rhine and the International Elbe Commissions.

These organizations for river basin management have to be supported by baseline surveys of water quality. Despite marked efforts during the past decades to improve river-water monitoring, the availability of data on river-water quality is limited due to a lack of standardized methods and/or a hampered exchange of information. Substantial enhancement at the monitoring level is a prerequisite to increasing knowledge of riverine ecosystems and to establishing a basis for integrated river basin management to be implemented throughout Europe.

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