Oxygen consuming substances in European rivers

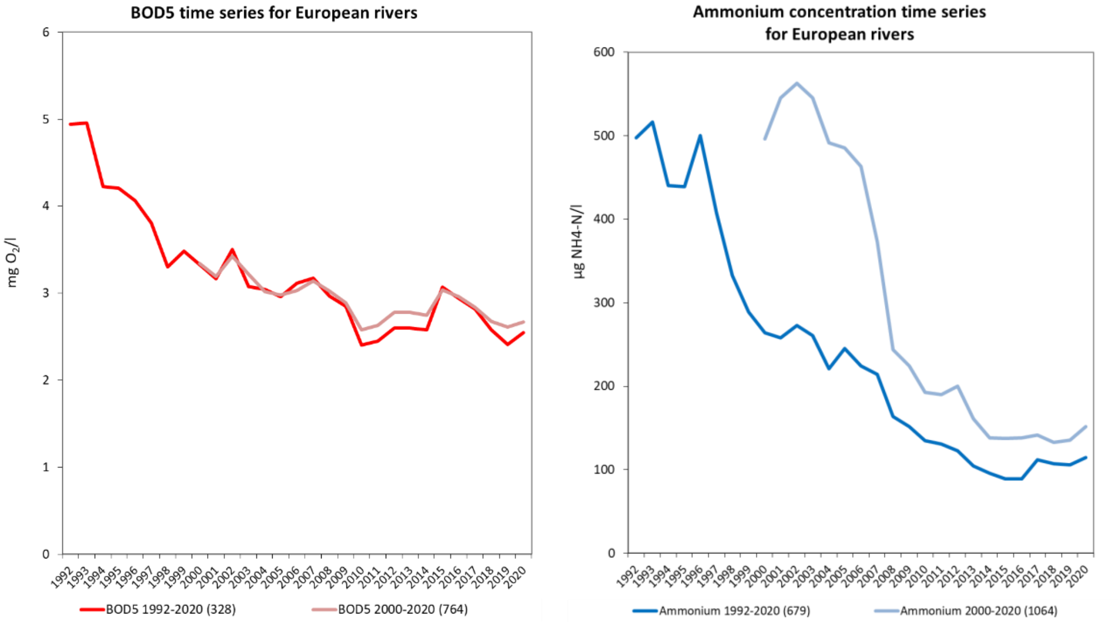
Last update 22/06/2022 – next update

EU level

Summary

In European rivers, oxygen consuming substances decreased over the period 1992 to 2020. Biochemical oxygen demand (BOD) fell to half of the 1992 level, but remained steady at around 2.5 mg O_2/l since 2010. Ammonium concentrations fell to a 23% of the 1992 level. After 2014, the level stabilised around 100 µg N/l. The decrease in BOD and ammonium concentrations is a consequence of the improvement in wastewater treatment. The 1990s economic crisis in central and eastern European countries also resulted in decreasing pollution from manufacturing industries.

Figure 1. Biochemical oxygen demand and ammonium in European rivers



Note: The data series are calculated as the average of annual mean concentrations for river sites in Europe. Only complete time series after inter/extrapolation are included (see indicator specification). BOD7 data has been recalculated into BOD5 data. Two time series are shown – a longer time series representing fewer water bodies and a shorter time series representing more water bodies.

<u>BOD in rivers</u>: The number of river monitoring sites included per country is given in parenthesis:
1992-2020: Albania (4), Austria (44), Belgium (26), Bulgaria (57), Czechia (22), Estonia (33), Finland (5), Ireland (3), Latvia (13), Lithuania (22), North Macedonia (4), Slovakia (8), Slovenia (8), Spain (78), Sweden (1).
2000-2020: Albania (5), Austria (46), Belgium (36), Bulgaria (74), Croatia (23), Cyprus (4), Czechia (22), Estonia (35), Finland (5), Ireland (14), Italy (44), Latvia (16), Lithuania (22), North Macedonia (8), Poland (90), Romania (88), Serbia (34), Slovakia (8), Slovenia (10), Spain (179), Sweden (1).
<u>Ammonium in rivers</u>: The number of river monitoring sites included per country is given in parenthesis:
1992-2020: Albania (4), Austria (30), Belgium (20), Bulgaria (38), Estonia (35), Finland (60), France (160), Germany (119), Ireland (4), Latvia (12), Lithuania (21), North Macedonia (5), Norway (29), Slovenia (9), Spain (22), Sweden (111).
2000-2020: Albania (8), Austria (46), Belgium (23), Bulgaria (57), Croatia (23), Estonia (37), Finland (69), France (237), Germany (122), Iceland (1), Ireland (27), Italy (25), Latvia (15), Lithuania (22), North Macedonia (18), Norway (29), Poland (4), Romania (89), Serbia (34), Slovenia (10), Spain (55), Sweden (113).

Aggregate level assessment

Organic pollution of rivers from waste water, both municipal and industrial, as well as diffuse runoff from agriculture, negatively affect aquatic ecosystems, causing loss of oxygen and changes in species composition (i.e. deterioration of ecological status). Severe organic pollution may lead to the rapid de-oxygenation of river water, high concentration of hazardous ammonia and disappearance of fish and aquatic invertebrates. In addition, it can have negative effects on the use of the water for human purposes such as drinking, bathing and recreation. Without treatment, organic pollution is slowly diluted and degraded naturally along the river course. Biochemical oxygen demand (BOD) and ammonium are key indicators of organic pollution in water. BOD is the amount of dissolved oxygen needed (i.e. demanded) by aerobic biological organisms to break down organic matter present in a given water sample at a certain temperature over a specific time period. The BOD value is most commonly expressed in milligrams of oxygen consumed per litre of sample during 5 days of incubation at 20°C. Ammonium is toxic to aquatic life at certain concentrations in relation to water temperature, salinity and pH. BOD and ammonium increase with higher loads of biologically degradable organic matter.

Key sources of organic pollution are municipal waste water; industrial waste water, especially from paper or food processing industries, and agricultural emissions, especially from surface runoff of silage, manure and slurry from intensive livestock farms.

BOD

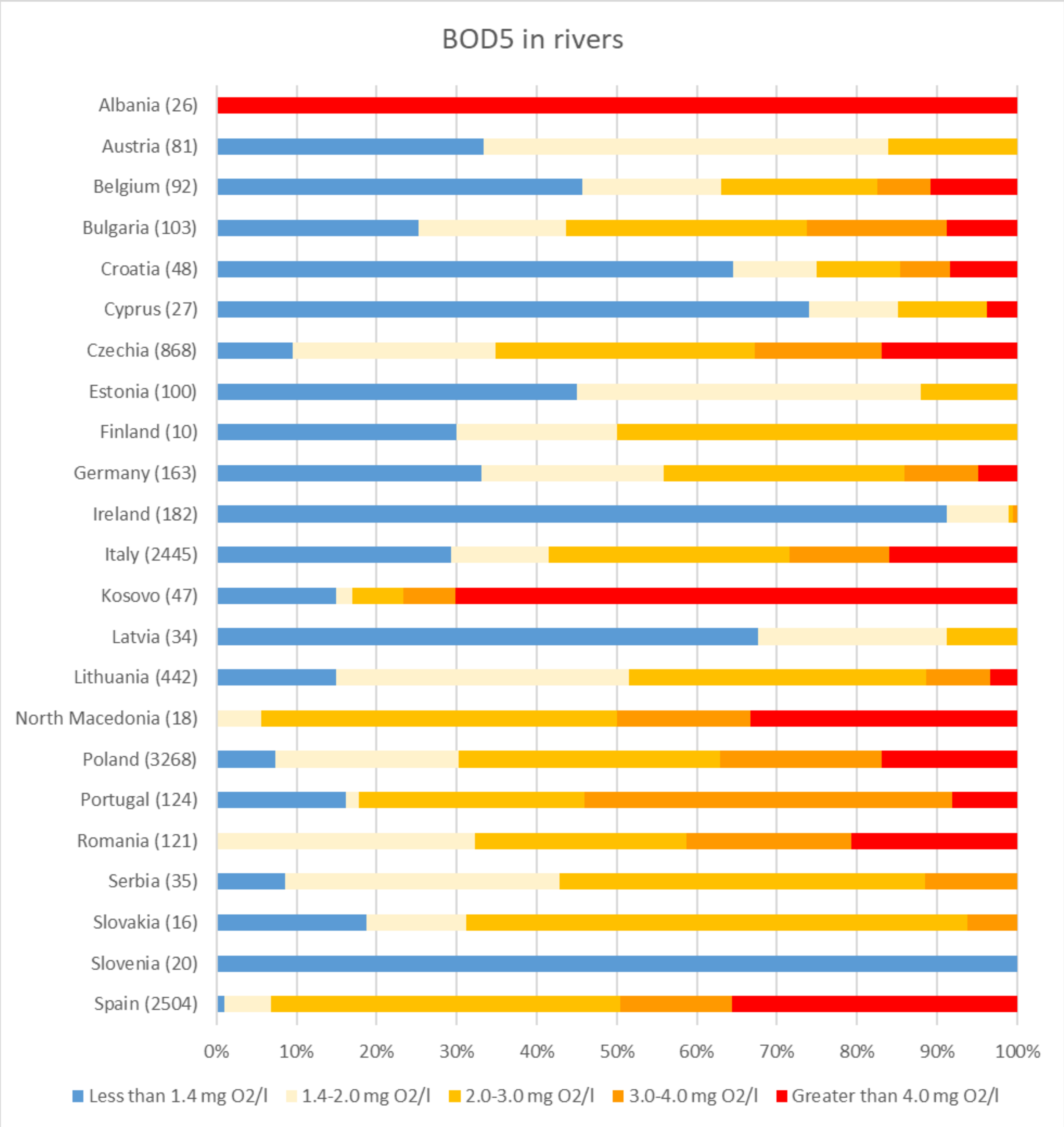
In European rivers, BOD levels have generally been decreasing between 1992 and 2020 (Figure 1a), with an average annual decrease in BOD of 0.06 mg/l (0.7% per year). The BOD reached its lowest level (2.4 mg/l) in 2010 and has only surpassed 3.0 mg/l once since then (in 2015). A significant decrease is evident at 44% of the river sites, with an additional 7% of the rivers having a marginally decreasing trend. A significantly increasing BOD trend is recorded at 12% of the sites.

Ammonium

Annual ammonium concentrations decreased by 10.93 µg/l per year (-2.6% per year) on average over the period 1992-2020 (Figure 1b). Significantly decreasing concentrations were observed at 74% of the sites, with an additional 4% of the sites showing a marginal decrease. No change has been observed at 20% of the river monitoring sites. A significant increase was evident at 1% of the sites.

Country level

Figure 2. Status of biochemical oxygen demand in rivers in European countries



Notes: This figure shows the current status of biochemical oxygen demand in rivers in European Countries

The geographical coverage is the 38 EEA member countries.
Kosovo*: Kosovo (under UNSC Resolution 1244/99).

The current BOD level per river monitoring site is calculated as the average of available annual mean concentrations for the years 2018-2020. BOD is given as mg oxygen per litre (mg O2/l).

The river monitoring sites are assigned to different BOD classes. The number of river monitoring sites per country is given in parenthesis.

Sweden, with BOD data for only two sites, is excluded from the chart since the sites may not be representative for the whole country.

Disaggregate level assessment

The current BOD, averaged for the period 2017-2020, is 3.1 mg O2/l for 24 countries of Europe for which data are available (10 776 sites). Almost two thirds of the river monitoring sites in Europe fall into the three best BOD classes, which is also the recommended water quality for salmonid fish (less than 3 mg/l according to the Fish Directive 2006/44/EC) and recommended water quality for water intended for the abstraction of drinking water (according to the Directive concerning the quality required of surface water intended for the abstraction of drinking water 75/440/EEC).

Countries with the highest share of river sites in the best quality class (less than 1.4 mg/l) are Slovenia (all sites), Ireland (91 % of sites), and Cyprus (74 %). The share of monitored river sites with BOD not satisfying recommendations for salmonid waters is particularly high (more than 50%) in Albania, Kosovo under UNSCR 1244/99, and Portugal. Higher BOD is observed in agriculturally and industrially developed lowlands of Europe, such as the Po valley, and lower BOD in the highlands of Europe such as Scotland, the Alps, and the Dinaric Alps.

Supporting information

Definition

The key indicators for oxygenation of water bodies are biochemical oxygen demand (BOD), which is the amount of oxygen needed by microorganisms for aerobic decomposition of organic matter; and ammonium (NH4+), which is oxygenated by bacteria into nitrate, an important nutrient also increasing eutrophication. The indicator illustrates spatial variations in current state and temporal trends of BOD and ammonium concentration in rivers.
Methodology

Annual mean concentrations are used as a basis in the indicator analyses. Unless the country reports aggregated data, the aggregation to annual mean concentrations is done by the EEA.

Automatic quality control procedures are applied both to the disaggregated and aggregated data, excluding data failing the tests from further analysis. In addition, a semi-manual procedure is applied, focusing on suspicious values having a major impact on the country time series and on the most recently reported data. This comprises e.g.:

• outliers;

• consecutive values deviating strongly from the rest of the time series;

• whole time series deviating strongly in level compared to other time series for that country and determinand;

• where values for a specific year are consistently far higher or lower than the remaining values for that country and determinand.

Such values are removed from the analysis and checked with the country.

For time series analyses, only complete series after inter/extrapolation are used. This is to ensure that the aggregated time series are consistent, i.e. including the same sites throughout. Inter/extrapolation of gaps up to 3 years are allowed, to increase the number of available time series. At the beginning or end of the data series, missing values are replaced by the first or last value of the original data series, respectively. In the middle of the data series, missing values are linearly interpolated. The selected time series are aggregated to country and European level by averaging across all sites for each year.

Trends are analysed by the Mann-Kendall method[1] in the free software R[2], using the wql package. This is a non-parametric test suggested by Mann (1945)[3] and has been extensively used for environmental time series[4]. Mann-Kendall is a test for a monotonic trend in a time series y(x), which in this analysis is nutrient concentration (y) as a function of year (x). The size of the change is estimated by calculating the Sen slope[5,6]. The same time series as for the time series analysis, but without gap filling.

For analysis of the present state, average concentrations are calculated across the last 3 years to remove some inter-annual variability. The sites are assigned to different concentration classes and summarised per country.

Policy/environmental relevance

Several EU directives aim at improving water quality and reducing the loads and impacts of organic matter. Water Framework Directive (WFD) requires the achievement of good ecological status or good ecological potential of surface waters across the EU by 2015 and repeals step by step several older water-related directives. The following directives are complementary to the WFD: the Urban Waste Water Treatment Directive (91/271/EEC), aimed at reducing pollution from sewage treatment works and certain industries; the Nitrates Directive (91/676/EEC), aimed at reducing nitrate and organic matter pollution from agricultural land; and the Industrial Emissions Directive (2010/75/EU), aimed at reducing emissions from industry to air, water and land.
Accuracy and uncertainties

Methodology uncertainty

The methodologies used for aggregating and testing trends in concentrations illustrate the overall European trends. Organic and oxygen conditions vary throughout the year, depending especially on flow conditions, affected by weather events etc. Hence, the annual average concentrations should ideally be based on samples collected as often as possible. Using annual averages representing only part of the year introduces some uncertainty, but it also makes it possible to include more river sites, which reduces the uncertainty in spatial coverage. Moreover, the majority of the annual averages represent the whole year.

Data sets uncertainty

The indicator is meant to give a representative overview of oxygenation availability conditions in European rivers. This means it should reflect the variability in conditions in space and time. Countries are asked to provide data on rivers according to specified criteria.

The datasets for rivers include almost all countries within the EEA, but the time coverage varies from country to country, both through the analysed period and within the year for which the aggregated mean value is provided. It is assumed that the data from each country represents the variability in space in their country. Likewise, it is assumed that the sampling frequency is sufficiently high to reflect variability in time. In practice, the representativeness will vary between countries.

Each annual update of the indicator is based on the updated set of monitoring sites. This also means that due to changes in the database, including changes in the QC procedure that excludes or re-includes individual sites or samples and retroactive reporting of data for the past periods, which may re-introduce lost time series that were not used in the recent indicator assessments, the derived results of the assessment vary in comparison to previous assessments. As an example, the 2016-2018 assessment of current concentrations of ammonium in rivers is based on as many as 13,266 sites, compared to 7,797 sites in the assessment of 2016-2018 (i.e. the last year assessment). However, some sites available in the previous assessment are not part of this year's assessment and vice versa.

Waterbase contains a large amount of data collected throughout many years. Ensuring the quality of the data has always been a high priority. A revision of Waterbase reporting and the database-composition process took place in the period 2015-2017. This included restructuring of the data model and corresponding reporting templates; transformation of the legacy data (i.e. data reported in the past, for the period up to and including 2012); re-definition of specific data fields, such as aggregation period defining the length of aggregation in a year; update of the datasets according to correspondence with national reporters; re-codification of monitoring site codes across Eionet dataflows; and connection of the legacy data time series with the newly-reported data in restructured reporting templates. Still, suspicious values or time series are sometimes detected and the automatic QC routines exclude some of the data. Through the communication with the reporting countries, the quality of the database can be further improved.

Rationale uncertainty

Biochemical Oxygen Demand and ammonium are well suited for indicating organic pollution. However, using annual average values does not reflect the variability during the year and can therefore underestimate the severity of short-term low oxygen conditions.

Data sources and providers:
Waterbase

Institutional mandate:
WISE SoE - Water quality (WISE-6)

DPSIR:
State

Topics:
Water and marine environment

Tags:
WAT002; Freshwater; BOD5; Ammonium

Temporal coverage
1992-2020

Geographic coverage

- Albania
- Austria
- Belgium
- Bosnia and Herzegovina
- Bulgaria
- Croatia
- Cyprus
- Czechia
- Denmark
- Estonia
- Finland
- France
- Germany
- Greece
- Hungary
- Iceland
- Ireland

- Italy
- Latvia
- Liechtenstein
- Lithuania
- Luxembourg
- Malta
- Montenegro
- Netherlands
- North Macedonia
- Norway
- Poland
- Portugal
- Romania
- Serbia
- Slovakia
- Slovenia
- Spain
- Sweden
- Switzerland
- Turkey

Typology:
Descriptive indicator (Type A - What is happening to the environment and to humans?)

UN SDGs

Unit of measure:

Biochemical oxygen demand (BOD) after five days of incubation (BOD5) is expressed as milligrams of oxygen per litre (mg O_2/l). Ammonium concentration is expressed as micrograms of ammonium–nitrogen per litre (µg N/l).

Frequency of dissemination:
Once a year

Contact:
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References

1. Jassby, A. D., Cloern, J. E. and Stachelek, J., 2017, 'Exploring water quality monitoring data', (https://cran.r-project.org/web/packages/wql/vignettes/wql-package.html) accessed March 25, 2022.

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3. Mann, H. B., 1945, 'Nonparametric Tests Against Trend', Econometrica 13(3), pp. 245–259 (https://www.jstor.org/stable/1907187) accessed March 25, 2022.

4. Hipel, K. and McLeod, A., 2005, 'Time Series Modelling of Water Resources and Environmental Systems, Volume 45 - 1st Edition', (https://www.elsevier.com/books/time-series-modelling-of-water-resources-and-environmental-systems/hipel/978-0-444-89270-6) accessed March 25, 2022.

5. Theil, H., 1992, 'A Rank-Invariant Method of Linear and Polynomial Regression Analysis', in: Raj, B. and Koerts, J. (eds), Henri Theil's Contributions to Economics and Econometrics: Econometric Theory and Methodology, Springer Netherlands, Dordrecht, pp. 345–381.

6. Sen, P. K., 1968, 'Estimates of the Regression Coefficient Based on Kendall's Tau', Journal of the American Statistical Association 63(324), pp. 1379–1389 (https://www.tandfonline.com/doi/abs/10.1080/01621459.1968.10480934) accessed March 25, 2022.