Oxygen consuming substances in European rivers

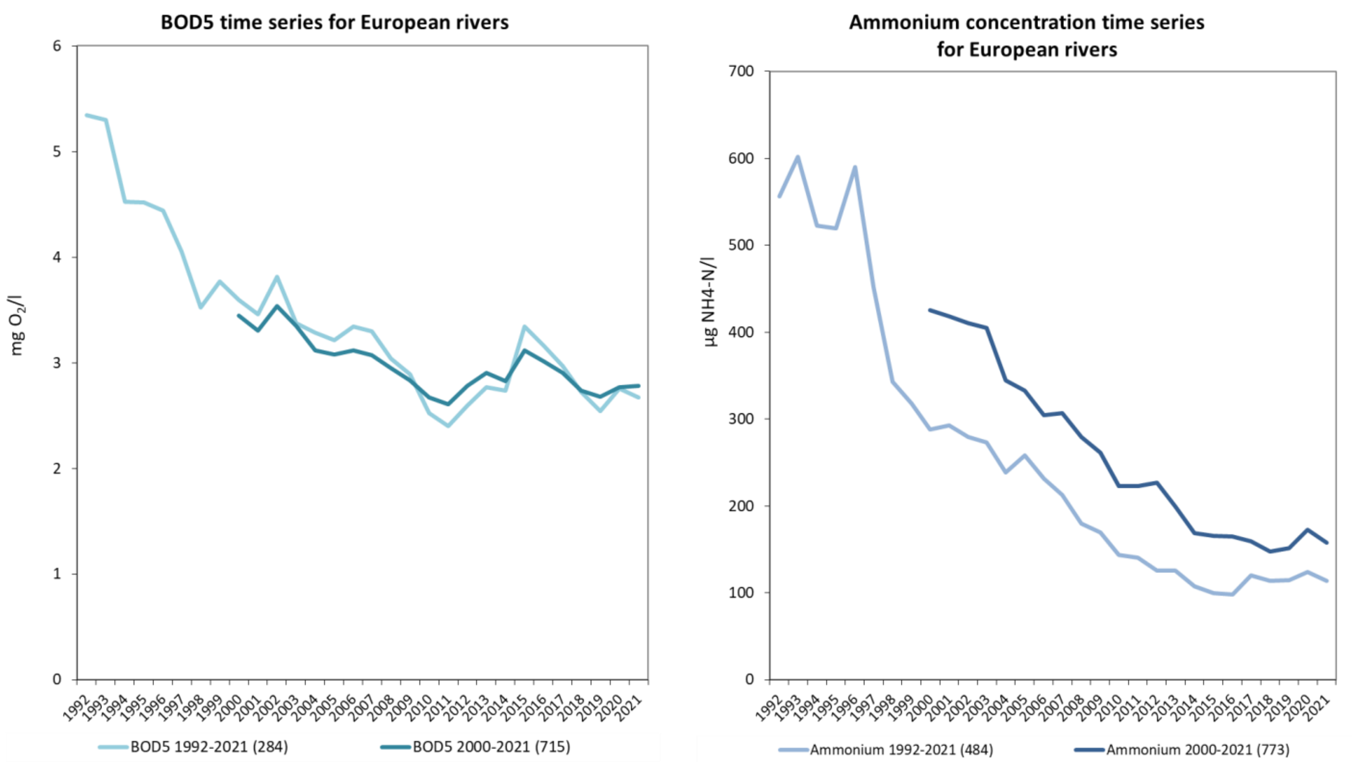
Last update [Publish Date] – next update [Publish Date]

EU level

Summary

In European rivers, oxygen consuming substances decreased over the period 1992 to 2021. Biochemical oxygen demand (BOD) fell to half of the 1992 level, but has remained steady at around 2.8 mg O_2/l since 2010. Ammonium concentrations fell to a 20% of the 1992 level. After 2014, the level stabilised around 110 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 at river sites in Europe. Only complete time series after inter/extrapolation are included (see indicator specification). BOD_7 data has been recalculated into BOD_5 data. Two time series are shown – a longer time series representing fewer water bodies and a shorter time series representing more water bodies.

BOD in rivers: The number of river monitoring sites included per country is given in parenthesis:
1992-2021: Albania (4), Austria (1), Belgium (26), Bulgaria (56), Czechia (22), Estonia (33), Finland (5), Ireland (3), Latvia (13), Lithuania (22), North Macedonia (4), Slovakia (8), Slovenia (8), Spain (78), Sweden (1).
2000-2021: Albania (5), Austria (1), Belgium (36), Bulgaria (73), 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 (33), Slovakia (8), Slovenia (10), Spain (177), Sweden (1).
Ammonium in rivers: The number of reported river monitoring sites per country is given in parenthesis:

1992-2021: Albania (4), Austria (1), Belgium (20), Bulgaria (38), Estonia (35), Finland (59), Germany (119), Ireland (4), Latvia (12), Lithuania (22), North Macedonia (5), Norway (26), Slovenia (7), Spain (22), Sweden (110).

2000-2021: Albania (8), Austria (1), Belgium (23), Bulgaria (56), Croatia (23), Estonia (37), Finland (68), Germany (122), Iceland (1), Ireland (28), Italy (25), Latvia (15), Lithuania (22), North Macedonia (17), Norway (26), Poland (4), Romania (89), Serbia (33), Slovenia (8), Spain (55), Sweden (112).

Aggregate level assessment

Organic pollution of rivers from wastewater, both municipal and industrial, 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 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 by aerobic biological organisms to break down organic matter present in a given water sample at a certain temperature over a specific time period. BOD and ammonium increase with higher loads of biologically degradable organic matter.

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

BOD

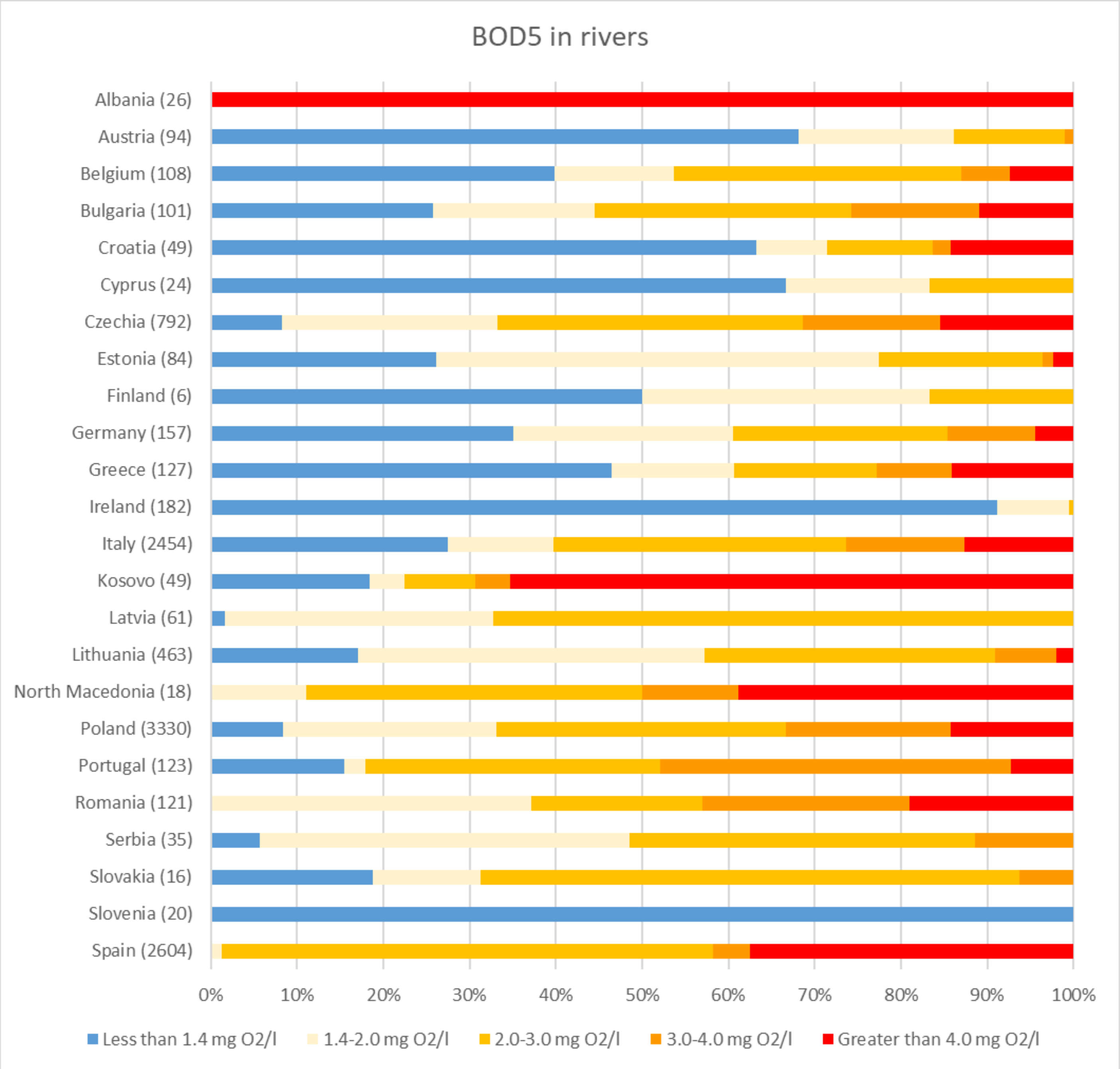
In European rivers, BOD levels have generally been decreasing between 1992 and 2021 (Figure 1a), with an average annual decrease in BOD of 0.07 mg/l (0.7% per year). The BOD reached its lowest level (2.4 mg/l) in 2011 but has surpassed 3.0 mg/l in the period 2015–2016. A significant decrease is evident at 45% of the river sites, with an additional 4% of the rivers having a marginally decreasing trend. A significantly increasing BOD trend is recorded at 9% of the sites. The shorter, more representative time series of 2000–2021 closely follow the longer one.

Ammonium

Annual ammonium concentrations decreased by 11.5 µg/l per year (-2.3%) on average over the period 1992-2021 (Figure 1b). Significantly decreasing concentrations were observed at 72% of the sites, with an additional 4% of the sites showing a marginal decrease. No change has been observed at 22% of the river monitoring sites. A significant increase was evident at only 2% of the sites. The shorter, more representative time series of 2000–2021 shows higher concentrations with a similar trend of overall decrease.

Country level

Figure 2. Biochemical oxygen demand in rivers in European countries



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

*: 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 2019-2021. BOD is given as mg oxygen per litre (mg O2/l).

The river monitoring sites are assigned to different BOD classes to visualise the distribution of data in the dataset. The number of river monitoring sites per country is given in parenthesis.

Sweden, with BOD data for only one site, is excluded from the chart for representativity reasons.

Disaggregate level assessment

The current mean concentration of BOD for the period 2019-2021 is 3.0 mg O2/l for 25 European countries (11 045 sites). 71% of the river monitoring sites have a BOD of less than 3 mg/L.

Countries with the highest share of river sites in the best quality class (i.e. less than 1.4 mg/l) are Slovenia (100%), Ireland (91%), and Austria (68%). The share of monitored river sites with BOD equal to or higher than 3 mg/L is particularly high (50% or more) in Albania, Kosovo under UNSCR 1244/99, and North Macedonia. High BOD level 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 the Alps, and the Dinaric Alps.

Supporting information

Definition

The key indicators for oxygenation of water bodies are biochemical oxygen demand (BOD) and ammonium. BOD is most commonly expressed in milligrams of oxygen consumed per litre of sample during 5 days of incubation at 20°C. This is the amount of oxygen needed by microorganisms for aerobic decomposition of organic matter. Ammonium, when oxygenated by bacteria to nitrate, is toxic to aquatic life at certain concentrations in relation to water temperature, salinity and pH. 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. The aggregation to annual mean concentrations is done by the EEA, unless the country has reported aggregated data only.

Automatic quality control procedures are applied both to the disaggregated and aggregated data, and data failing certain tests are excluded 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 were analysed by the Mann-Kendall method in the free software R, using the wql package. This is a non-parametric test suggested by Mann (1945) and has been extensively used for environmental time series. 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 . Absolute and relative Sen slopes are summarized across Europe and countries by averaging. For the trend analysis the same time series as for the time series analysis are used, but without gap filling.

For analysis of the present state, average concentrations are calculated across the last 3 years with data. In this way data from far more groundwater bodies and lake and river sites can be used than in the time series analysis. The 3-year average is used to remove some inter-annual variability. Also, since data are not available for all sites each year, selecting data from three years gives more sites. The sites are assigned to different concentration classes and summarised per country (percentage of sites per concentration class).

The purpose of the analysis is to compare the distribution of BOD-concentrations among countries. The class boundaries are thus mainly selected to represent the range of concentrations and are neither linked to targets and goals of specific policies nor to national based thresholds.

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 and temperature, affected by weather events etc. Hence, the annual average concentrations should ideally be based on samples collected as often as possible. Using annual averages based on only part of the year (e.g. spring or autumn samples) introduces some uncertainty, but it also makes it possible to include more river sites, which reduces the uncertainty in spatial coverage. However, the majority of the 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, the derived results of the assessment vary in comparison to previous assessments. Such changes involve the updates in 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. 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 12 919 sites in the assessment of 2019–2021 (i.e. the last year's 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. 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 – Water quality ICM, available at the EEA Datahub. The processed data used for the indicator can be queried using the EEA Discodata platform under [WISE_Indicators].[v4r1].

Institutional mandate:

EEA AWP

DPSIR:

State

Topics:

Water and marine environment

Tags:

WAT002; Freshwater; Rivers; BOD5; Ammonium

Temporal coverage

1992-2021

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 O2/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

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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-environmentalsystems/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