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Status of Environment and Climate in the Western Balkans

Second Edition

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Contents

Abstract

This report provides an up-to-date overview of environment and climate in the Western Balkans (WB) highlighting existing gaps with respect to the EU *acquis*. The aim is to provide accurate and complete environmental information to monitor the progress in the accession process, as well as to support the implementation of the Green Agenda for the WB with particular reference to depollution and decarbonisation pillars and more in general to support environmental management by regional to local level authorities. In this edition, particular emphasis is given to the impacts of climate change on hydrological aspects (rainfall, droughts, surface and groundwater), forest fires and heat waves. This information is also relevant for the EU Green Deal zero pollution ambition, since the depollution in WB economies is expected to reduce the transboundary pollution in neighbouring and in other EU Member States as well.

There has been evident progress in the alignment with EU acquis on environment and climate. However, its implementation is still slow and insufficient to reach the planned targets. Despite the decreasing trends of air pollutant concentrations, air quality remains a significant problem for both the WB and neighbouring EU countries. From the human health perspective, $PM_{2.5}$ has the largest impact on premature deaths and morbidity. Further reducing the concentration of this pollutant would result in economic benefits across the entire region. Increasing absolute sulphur oxides' emission trend is of major concern, which still has the largest exceedance relatively to the defined ceiling. The stagnating GHG emissions trend does not correspond to the emission reduction rate needed to reach 2030 goals.

WB is under the strong influence of climate changes, reflected in the altered precipitation regime, the frequency and intensity of heat waves, as well as the occurrence of forest fires. Major threats such as soil erosion, pollution, sealing, nutrient mismanagement led to widespread soil degradation across the WB region. However, the complexity and diversity of soil types, along with a lack of most recent data, made it difficult to provide a comprehensive assessment within this report.

Efforts were made to improve the status of water through investments in wastewater infrastructure, regulatory improvements aligned with EU standards, and monitoring systems. However, key stressors such as untreated wastewaters, agricultural runoff, and the combined effects of climate change and hydromorphological degradation, strongly affect the water management across the Western Balkans region

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Executive summary

The report provides scientific evidence for monitoring the green transition process in the Western Balkans (WB) region with a special emphasis on depollution and carbon neutrality. In particular, it provides an up-to-date overview of environment and climate in the WB. The main topics are: 1) air quality, emissions of air pollutants, their impact on human health and related costs; 2) emissions of CO_2 from fossil fuels and of other greenhouse gases, compared to biological CO_2 emission; 3) impacts of climate change on the water cycle (including precipitations, droughts and ground waters), forest fires, and heat waves; 4) soil including trends of soil health and its nexus with agriculture; and 5) water quality and management.

Policy context

The EU Green Deal [1]Communication sets out concrete actions in the field of climate, energy, transport, circular economy, depollution, agriculture and ecosystems. The European Commission (EC) also launched the EU Zero Pollution Action Plan[2] aiming to protect ecosystems and human health. Both programs have international implications due to the transboundary nature of climate and pollution. Chapter 27 of the *EU acquis on Environment* is an obligation for countries under the "Stabilisation and Association Agreement" process. In 2024, the EC committed to present pre-enlargement policy reviews focusing on individual sectors, where "keeping climate and environment commitments" is explicitly mentioned, among others.

The Sofia Declaration on the Green Agenda for the WB (GAWB) [3] emerged as a comprehensive development strategy based on the EU Green Deal, aimed at promoting environmental conservation, responses to climate challenges, green growth, and a resilient WB region. The Regional Cooperation Council (RCC) is in charge for the Action Plan to implement the GAWB. At domestic level, all WB countries set energy and climate goals within Nationally Determined Contributions (NDCs) and set GHG emissions reduction targets for 2030 within the Energy Community framework (EnC 2021/14/MC). Integrated National Energy and Climate Plans (NECPs) was adopted as a part of Clean Energy Package in the WB economies. Key financial instruments for the development of the region are the Growth Plan for the Western Balkans, the Reform and Growth Facility for the Western Balkans and the related Reform Agendas.

Key conclusions

Although WB show a commitment in **aligning with EU environment *acquis***, to share the European objectives for climate neutrality and environment deterioration prevention, the delay in the implementation of required measures is evident. The efforts in the latest years include policy adaptation, improvement of monitoring and reporting procedures, and focus on emission reduction targets. Despite a framework for adaptation to climate changes was adopted in some of the WB economies, much still has to be accomplished. Depollution and decarbonisation targets could be achieved by reducing emissions in the sector of energy generation (electricity and heat), by increasing

[1] EU Green Deal (COM(2019)640)

[2] Towards Zero Pollution for Air, Water and Soil (COM(2021) 400)

[3] Guidelines for the implementation of the Green Agenda for the Western Balkans (SWD(2020) 223), accompanying the Economic and Investment Plan for the WB (COM(2020) 641)

energy efficiency, and by using renewable energy sources in the industrial sector. Measures to reduce emissions in the transport and waste management sectors can contribute to achieve the target.

Reliable field data availability is crucial in identifying the critical aspects in the status of air and climate, water and soil, leading to the development of tailored and effective policies. Achieving a **sufficient coverage and completeness of the environmental monitoring networks** in the WB is still a challenge. Thus, their further expansion and constant improvement including data management is a priority for all the environmental matrices considered in this report. This could be achieved by securing the availability and appropriate management of financial and human resources, as well as the transparent reporting aligned with the legislation requirements.

Regional and international cooperation are of the outmost importance in addressing the **transboundary pollution**, by involving all the relevant stakeholders. Cooperation within the WB needs to be further enhanced, due to the highly interconnected ecosystems across and beyond this region. Additional integration and implementation of the environmental legislation is needed in sectors targeted within the GAWB (energy, industry, mobility, waste management). Increasing intensity and frequency of climate disasters (heat and cold waves, floods, droughts, storms, wildfires) require adequate monitoring and early warning systems, as well as designing the appropriate adaptation plans. The **capacity building** activities targeted to all potential contributors (industry, academia, local governments, final users, is among the priorities to ensure effective implementation of legislation with highly specialised technical content. Dissemination of knowledge and best practices involving EU experts should also be promoted and supported.

Main findings

Air quality has improved in terms of compliance with annual limit values for PM_{10} and $PM_{2.5}$. However, the overall situation in WB region is critical due to the **high acute (daily and hourly) concentrations of all main pollutants** leading to a considerable number of exceedances. The **air quality impact on health,** expressed as mortality rate attributable to exposure to $PM_{2.5,}$ **is considerably higher in WB compared to the EU**. This parameter has increased recently in some WB economies, while it has halved in the EU over the same time window. Costs attributable to $PM_{2.5}$-related premature deaths represent a higher share of GDP compared to the EU and are 6 to 9 times higher than those attributable to NO_2 and O_3.

Despite all economies have set their overall GHG and pollutants' emission reduction targets, there is a **considerable implementation lag**. SOx emissions continued multiple ceiling exceedance with contribution of energy sector over 90% in all WB economies (except Albania). The relative emissions with respect to the ceilings of both NOx and dust show an increasing trend that resulted in non-compliance in 2022 for all the three air pollutants for the first time. **The overall GHG emissions trends are not coherent with the reduction rate for achieving 2030 targets.**

Climate change has a considerable impact on the water cycle and heat waves frequency and intensity**. The precipitation follows a general upward trend, with the exception of the coastal areas**. The highest values are observed during the boreal winter and spring period. Changes in the precipitation regime are associated with hydromorphological and water quality alterations. **The intensity of heat waves** in the summer season, based on Heat Wave Magnitude Index daily, shows **significant growth (40-60%) near the Adriatic coast** and spreads to the north-west. Similar increase is observed in Kosovo*[4] and central and northern Serbia. The increased intensity is mostly associated with longer heat waves rather than higher maximum temperatures during them. Climate change can potentially increase the forest fires risk. Although the number of forest fires in the last few years has decreased in this region, the negligence as one of the causes of forest fire is worrying.

The WB **soils are under significant pressure, leading to widespread degradation across the region**. Unsustainable land use and management practices have resulted in major threats such as soil erosion, pollution, sealing, and nutrient mismanagement. Moreover, **metal contamination** from industry and mining activities aggravate a situation in which the ability of soils to sustain agriculture, ecosystems, and human well-being is compromised. **Soil erosion** remains the most pronounced indicator of soil degradation in WB with average loss of 4.1 t/ha/year. Around 40% of total land in the WB are affected by soil erosion.

The WB region faces **significant challenges in water management,** characterised by underdeveloped infrastructure, insufficient wastewater treatment, and the continued impact of anthropogenic pressures on aquatic ecosystems. Most important stressors include untreated municipal and industrial wastewater, agricultural runoff, and the combined effects of climate change and hydromorphological degradation. Insufficiently developed infrastructure for wastewater treatment and management is reflected by the very low share of population connected to wastewater compared to the EU.

Related and future JRC work

The JRC has been providing scientific support to policy development in South-East Europe in the field of environment and climate since 2013. The work started with the JRC support to the Danube Strategy, followed by the support the EU macro-regional strategies (2016 -2018) and since 2019, through studies dedicated to the WB and other candidate countries. For example, the JRC published in 2020 a first Science for Policy Report on the Status of air and climate in the Western Balkans. The report was launched during the Western Balkans Summit of Sofia in November 2020. In 2022, the JRC published another Science for Policy Report entitled 'Status of Environment and Climate in the Western Balkans' covering air, climate soil and water, launched by Commissioner Gabriel at the Western Balkans Ministerial Meeting in Tirana. In 2023, the JRC carried a study on the impact of air pollution on health and its related costs in 30 WB cities. Moreover, the JRC also focused on capacity building which is essential for depollution and decarbonisation and other objectives of the GAWB.

Quick guide

Chapter 1 provides an introduction to the following chapters. **Chapter 2** describes the status and trends of the main air pollutants, the emissions of air pollutants and GHG, and analyses the influence of air quality on health. **Chapter 3** describes the impact of climate change on the water cycle, with particular reference to precipitation, droughts, surface and ground waters, forest fires trends and heat waves, in terms of magnitude and frequency. **Chapter 4** analyses the status and trends of soil health, including alignment with EU legislation and **Chapter 5** discusses the status of water with a special reference to the presence of contaminants of emerging concern and antimicrobial resistance.

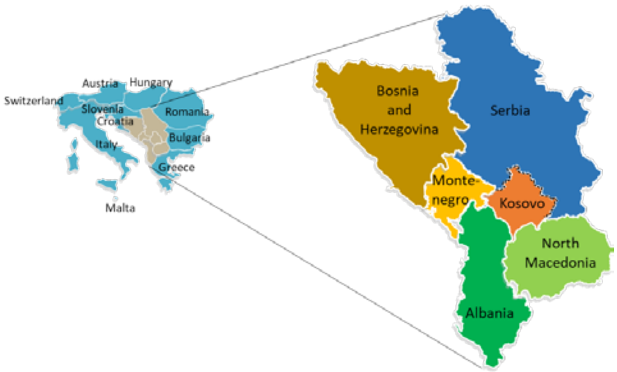
[4] *This designation is without prejudice to positions on status, and is in line with UNSCR 1244 and the ICJ Opinion on the Kosovo declaration of independence, as on the official website of the European Union.

1 Introduction

The Western Balkans (WB) is an area of 218,750 km^2 located at the heart of the Balkan Peninsula and next to the Adriatic Sea. The Dinaric ridge runs across the region from north to south parallel to the Adriatic Sea. The WB climate is Mediterranean in the coast and continental in the inlands. The WB are characterised by a dense hydrological network and precipitation is not evenly distributed during the year, leading to dry or partially dry periods that contribute to water scarcity in some parts of the region. The area is quite heterogeneous in terms of geological substratum, relief, hydrology, climate, etc. and consequently the spatial distributions of flora and fauna are rather complex with high biodiversity (Lopatin, 1995; Bănărescu, 2004). In line with the other components of the WB ecosystem, also the soils present a remarkable variety. Grasslands and croplands are found in alluvial plains next to the main rivers while relatively fertile soils, thanks to their high calcium content, are present in the inlands. The WB region is also rich in mineral resources and boasts some of the largest European deposits of copper, chromite, lead and zinc (UNEP, 2010).

The population of the WB in 2023 was ca. 17 million and its GDP US$ (current) 75 billion (World Bank, 2024). The WB comprises six economies: Albania (AL), Bosnia and Herzegovina (BA), Kosovo*[5] (XK), Montenegro (ME), North Macedonia (MK) and Serbia (RS), with the common perspective of accessing the European Union (EU) (**Figure 1**).

Figure 1. Geographical setting of the Western Balkans.



Source: yourfreetemplates.com CC BY-ND 4.0.

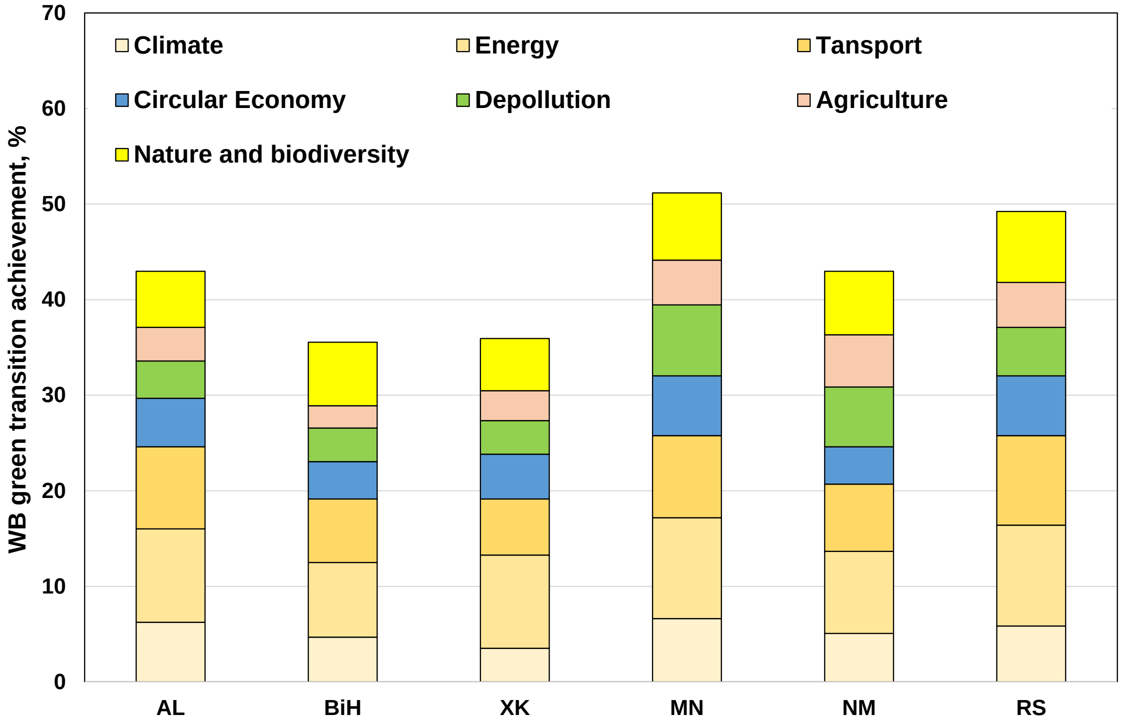
The EU accession process requires the alignment of the national legislations with the EU body of rights and obligations that binds all the EU Member States, known as EU acquis. Chapter 27 – "Environment and Climate Change", is the largest of the 35 chapters of the EU acquis with more than 200 legislative acts including: air quality, waste management, water management, nature protection, industrial pollution, chemicals, noise and civil protection. Montenegro and Serbia have opened the negotiation on Chapter 27 while Albania have not yet opened it despite opening first negotiation chapters in October 2024. North Macedonia opened negotiations and completed the screening process, but is yet to open chapters. The European Council decided to open negotiations with Bosnia

[5] *This designation is without prejudice to positions on status, and is in line with UNSCR 1244 and the ICJ Opinion on the Kosovo declaration of independence, as on the official website of the European Union

and Herzegovina in March 2024, but the screening process has not yet started. Kosovo has been identified as potential candidate.

The assessment of the achievement of the green transition in the WB economies aligned with the European Green Deal is shown in **Figure 2**. It is based on the descriptive results presented in the Green Agenda for the Western Balkans (GAWB) Action Plan Implementation Report (RCC, 2023) and quantified in Djatkov *et al.* (2024). The overall achievement across all the WB economies rates 43.0%, whereby the achievement per economies indicates varying levels of progress: Montenegro 51.2%, Serbia 49.2%, North Macedonia and Albania 43.0%, Kosovo 35.9%, Bosnia and Herzegovina 35.5%. The assessment by pillars shows the achievement with respect to the Decarbonisation (Pillar 1) is the highest with 49.7%, whereby for the majority of the remaining pillars the level of achievement is notably lower: Moving to a Circular economy (Pillar 2) 45.8%; Depolluting air, water and soil (Pillar 3) 31.7%; Building sustainable agriculture and food systems (Pillar 4) 36.3%; Protecting biodiversity and ecosystems (Pillar 5) 37.9%.

Figure 2. Overall quantification of the green transition in the WB economies aligned with the European Green Deal.



Source: Regional Cooperation Council (Elaboration Djatkov et al., 2024).

2 Ambient air quality and greenhouse gases

2.1 Ambient air quality

In this chapter an updated status of air quality in WB is provided. In the previous JRC Science for policy report: Status of environment and climate in the Western Balkans (JRC, 2022), the last reported year was 2020. In this report, the analysis is performed for the period 2019-2023 to include in the analysis the year prior to COVID-19 and compare it with the aftermath of the pandemic.

The air quality analysis in the following is obtained by collecting Eionet validated data that meet the 75% coverage criterion (EIONET, 2024), for the period 2019-2023. The available data for Albania do not meet this criterion for any of the considered pollutants, except in 2023 and, therefore, this is the only year of the 2019 -2023 period included in the analysis. Results for Montenegro in 2020 include data with coverage in the interval 50-75% while in 2022 data are missing, with the exception of O_3. In 2023, PM_{10}, $PM_{2.5}$ and O_3 data for Montenegro are also missing.

All WB economies with sufficient data coverage have achieved values below the limit (see **Annex 1**) and show decreasing trends of PM_{10} and $PM_{2.5}$ annual averages. The decreasing trend is also observed in the PM_{10} daily maximum. However, none of the WB economies managed to reach values below the limit. The SO_2 daily maximum values are below the limit only in North Macedonia and Kosovo and SO_2 hourly maximum values only in Kosovo. Bosnia and Herzegovina and North Macedonia present average values above the NO_2 hourly limit with upward trends. The O_3 maximum daily eight-hour mean with decreasing trend and below the limit is observed only in Albania and North Macedonia.

Table 1. Situation with respect to the limit value in 2023 and trend in the period 2019-2023. Above limit value: > LV; below limit value: < LV; downward trend: ↓, stable trend: →, upward trend: ↑, non available: na

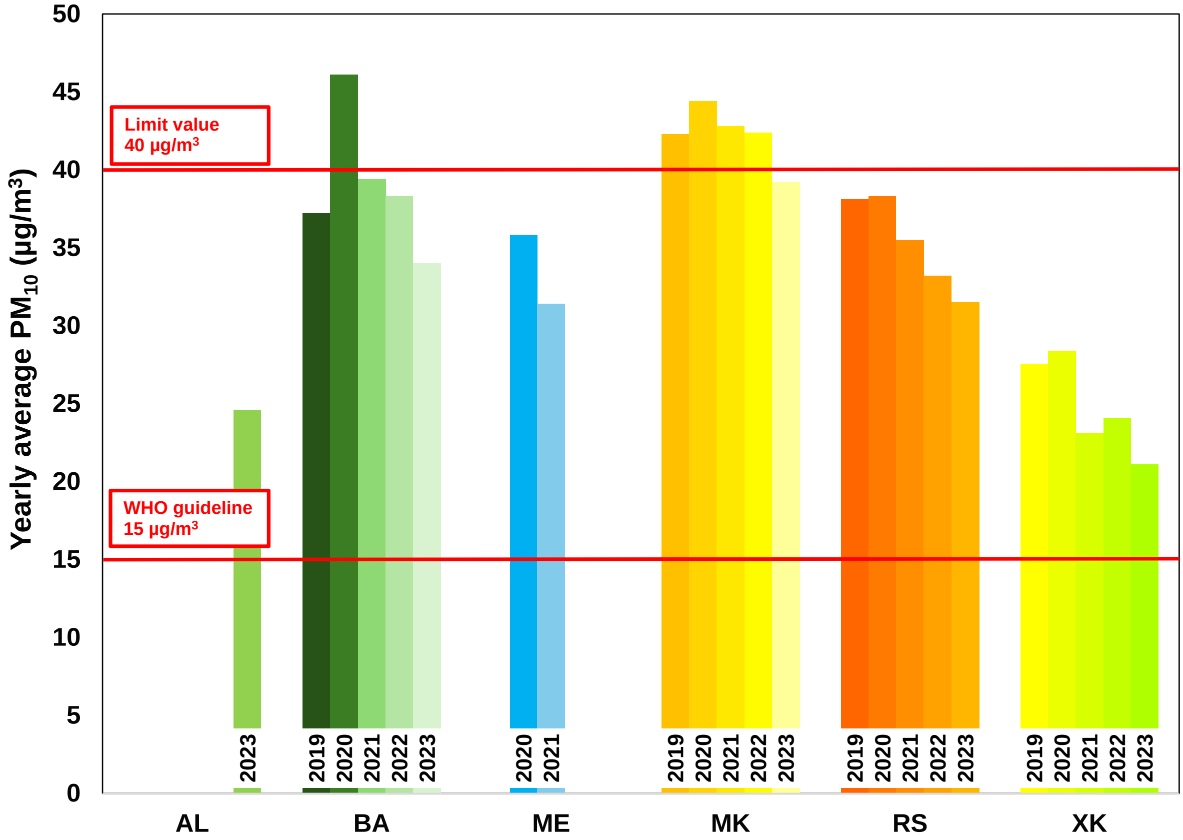
	PM_{10}		$PM_{2.5}$	SO_2		NO_2	O_3
	P1Y	P1Y-day-max	P1Y	P1Y-day-max	P1Y-hr-max	P1Y-hr-max	P1Y-dmax
AL	< LV	> LV	< LV	< LV	< LV	< LV	< LV
trend 2017-2023	↓	→	→	↑	→	↑	↓
BA	< LV	> LV	< LV	> LV	> LV	> LV	> LV
trend 2019-2023	↓	↓	↓	↓	↑	↑	↑
ME	< LV	> LV	< LV	< LV	> LV	< LV	< LV
trend 2019-2023	↓	↓	na	↓	↓	↓	→
MK	< LV	> LV	< LV	> LV	> LV	> LV	< LV
trend 2019-2023	↓	↓	↓	↑	↑	↑	↓
RS	< LV	> LV	< LV	> LV	> LV	< LV	> LV
trend 2019-2023	↓	↓	↓	↑	↓	↓	↓
XK	< LV	> LV	< LV	< LV	< LV	< LV	> LV
trend 2019-2023	↓	↓	↓	↓	↓	↓	→

Source: EIONET (JRC elaboration).

Although the PM_{10} annual averages are decreasing and the value in 2023 was below the limit, Bosnia and Herzegovina showed values above the limit in 2020 and North Macedonia in the 2019-2022 period (**Figure 3**). If the stricter WHO recommendation for the annual value of 15 μg/m^3 is considered, none of the WB economies for the entire analysed period fulfils this criterion. In 2023, the PM_{10} annual average concentrations were below the limit in nearly 70% of the total WB monitoring stations. The number of stations that meet the minimum data coverage to estimate the annual PM_{10} concentration has doubled in Bosnia and Herzegovina (2019-2022) and North Macedonia (2019-2020). In Kosovo and Serbia, the number of stations with valid measurements is relatively stable. Also, in Albania and

Montenegro, the number of monitoring stations is stable, however, the data availability is discontinuous.

Figure 3. Trend of PM_{10} annual average concentrations in WB economies, 2019-2023.

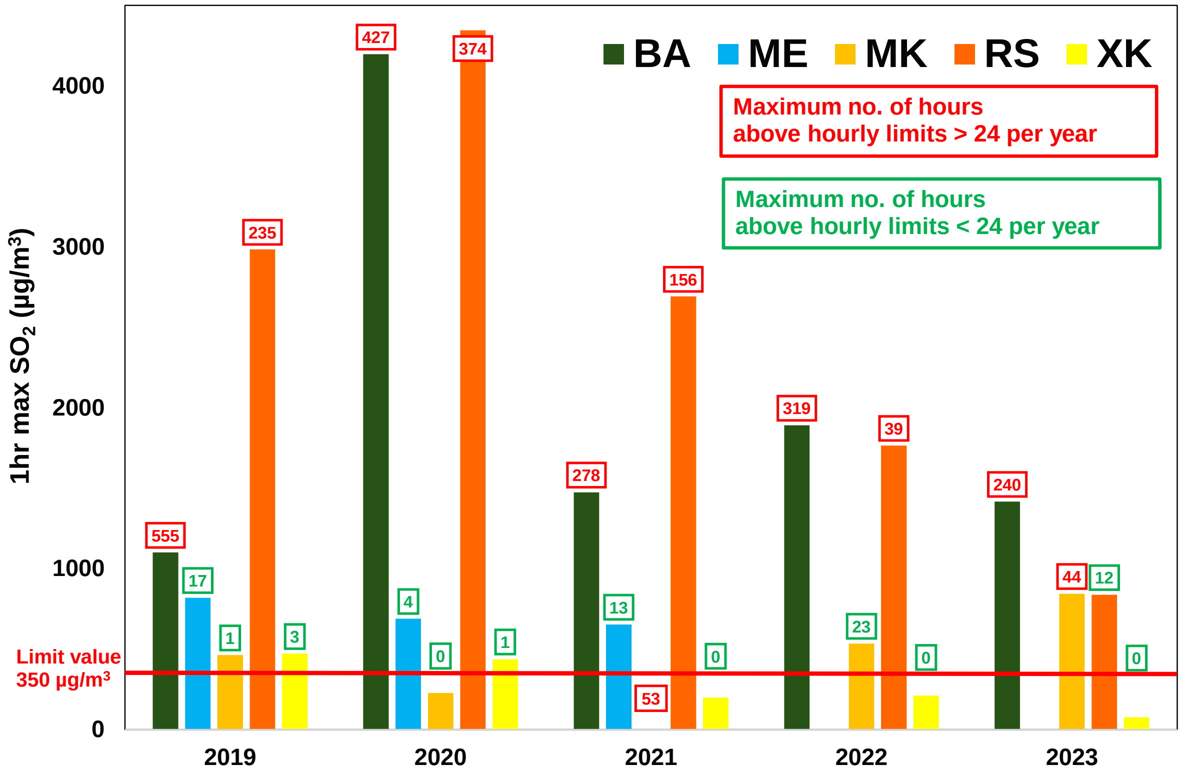


Source: Eionet (JRC elaboration).

The $PM_{2.5}$ annual average concentration values show a downward trend in the period 2019-2023 and in 2023 the limit value is met in all WB economies with available data.

The highest values of SO_2 hourly maximum concentrations were recorded in 2020 in Bosnia and Herzegovina and Serbia, and are approximately 12 times higher than the limit (**Figure 4**). The values of all monitoring stations are below the limit only in Kosovo (2021-2023) and North Macedonia (2020-2021). The SO_2 hourly maximum concentrations show an overall upward trend in Bosnia and Herzegovina and North Macedonia between 2019 and 2023. The maximum allowed number of exceedances of the SO_2 hourly limit (24 times per year) was not fulfilled throughout the entire period in Bosnia and Herzegovina nor in Serbia (except in 2023, 12 times). However, the share of monitoring stations with less than 24 exceedances of the SO_2 hourly limit in the period 2019-2023 ranges between 77 and 85% of the total monitoring stations in the WB.

Figure 4. Trend of maximum of SO_2 hourly maximum concentrations and maximum number of hours with concentrations above the limit value in WB economies, 2019-2023.



Source: Eionet (JRC elaboration).

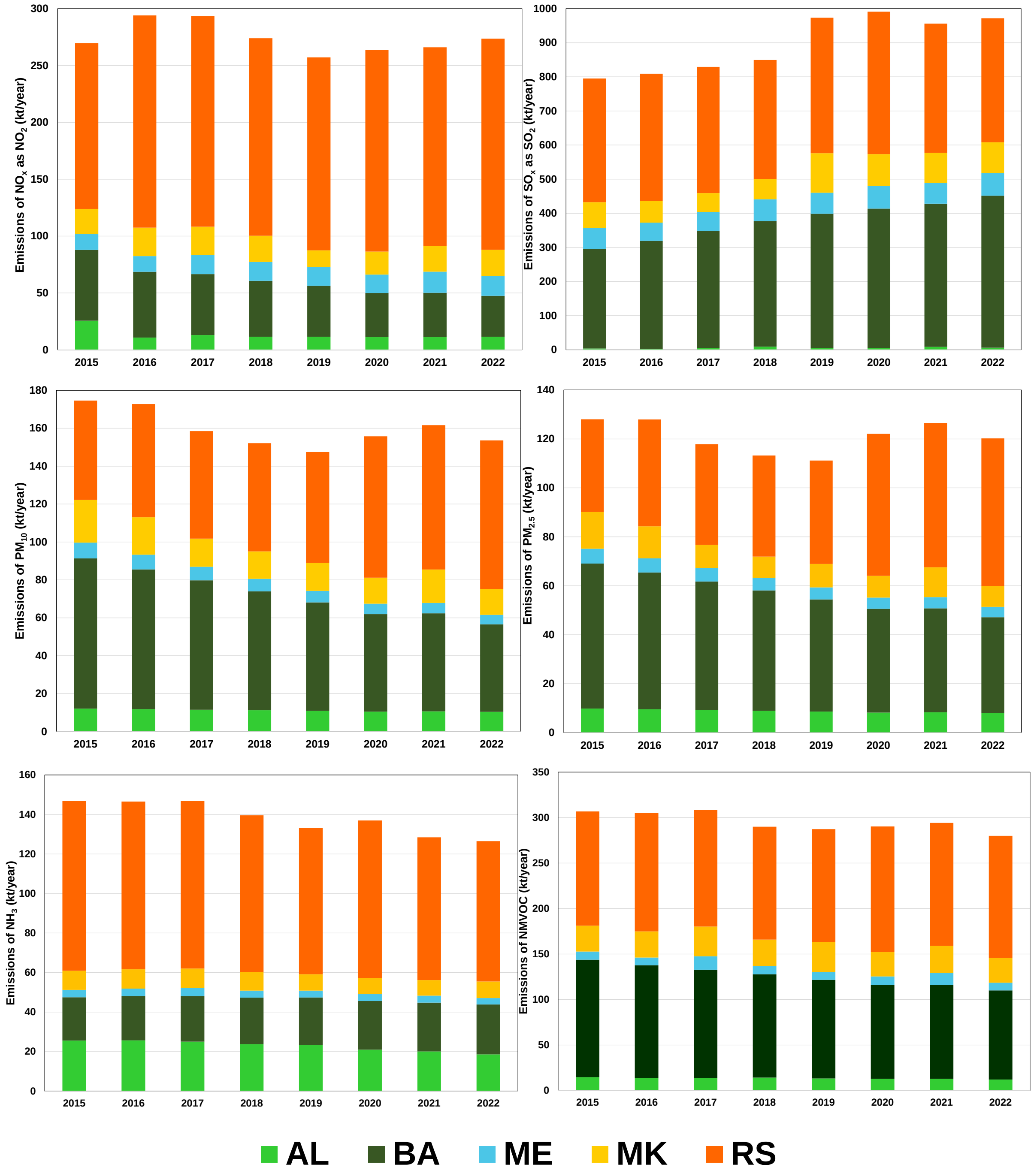
In the period 2019-2023 there was no exceedance of NO_2 annual average concentrations in WB economies. In 2023, 13% of all monitoring stations that fulfil data coverage criterion reported NO_2 annual average concentrations below the WHO guideline value of 10 µg/m^3. The O_3 maximum daily eight-hour mean was met at 73% of monitoring stations in 2023. The highest concentrations were found in Bosnia and Herzegovina in 2021 and 2023.

2.2 Air pollutants' emissions & NERP

This chapter presents the emissions of air pollutants in the WB5 region (Kosovo is not available in the source dataset) from 2015 to 2022. The analysed dataset by CEIP and EMEP includes data officially reported to the UNECE Air Convention (Convention on Long Range Transboundary Air Pollution). The Air Convention Gothenburg protocol, to abate acidification, eutrophication and ground-level ozone, establishes emission ceilings for atmospheric pollutants and is implemented in the EU through the National Emissions reductions Commitment Directive (NECD)[6]. The analysis includes PM_{10}, $PM_{2.5}$, SOx as SO_2, and NOx as NO_2, to emphasize the most significant changes comparing to the previous JRC Science for policy report (JRC, 2022).

[6] National Emissions reduction Commitments (NEC) Directive (2016/2284/EU)

Figure 5. NECD pollutants emissions in WB5 region 2015-2022.



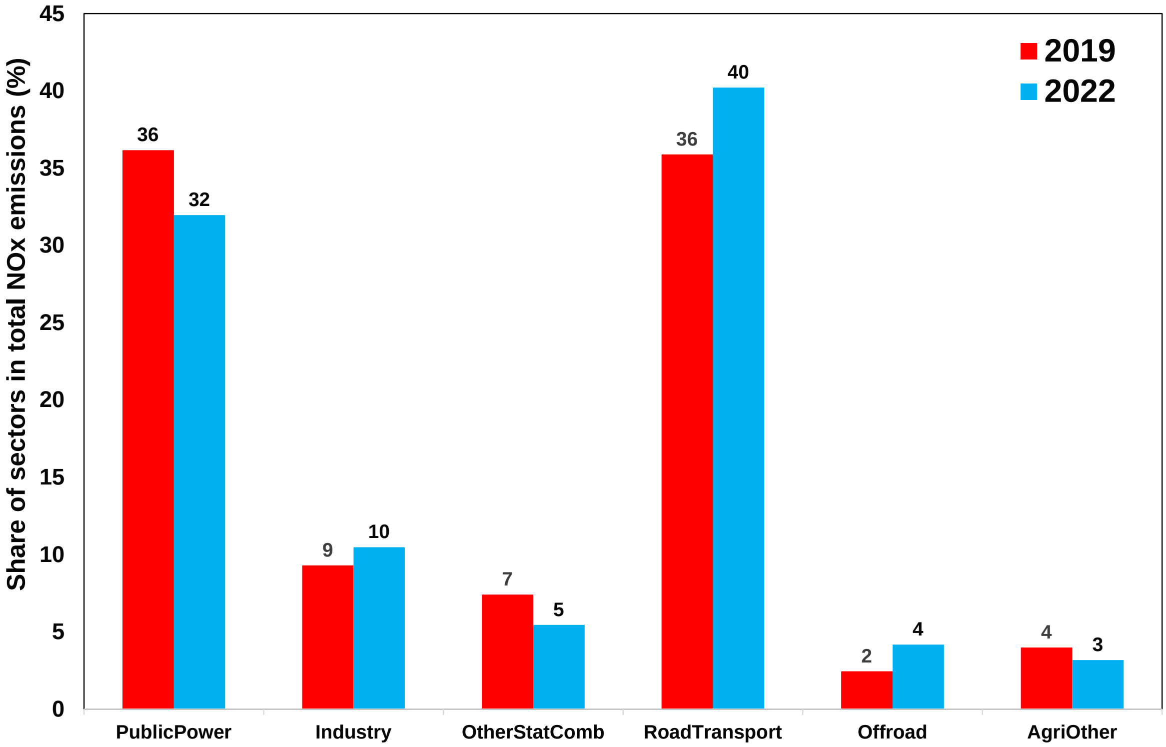
Source: Convention on Long Range Transboundary Air Pollution (JRC elaboration).

The trend in emissions of pollutants by country over the period 2015-2022 is presented in **Figure 5** (EMEP, 2024). In the period of 2019-2022, emissions of NOx increased more than 6%, while the share of Serbia in the total NOx emissions from the WB region increased from 54% to 68%. In the same period, PM_{10} emissions increased by 4%, while Serbia increased absolute emissions by 34% and its share of the total PM emissions increased from 40% to 51%. Although SO_2 emissions changed negligibly from 2019 to 2022, the overall increase in the period 2015-2022 is 18%. The share of Bosnia and Herzegovina rose from 37% in 2015 to 46% in 2022, due to the increase in absolute SO_2 emissions from this economy by 35%. On the contrary, the share of Serbia decreased from 46% in

2015 to 37% in 2022. NH_3 and NMVOC emissions decreased over the period 2015-2022 by 16% and 10%, respectively.

Figures 6 and **7** depict changes over the period 2019-2022 in the individual sectors' share of total NOx and total PM_{10} emissions in the WB5 region (EMEP, 2024), respectively. In 2022, the road transport sector became dominant source of NOx, since the absolute emissions in this sector increased by 19% and those in the sector public power decreased by 6%.

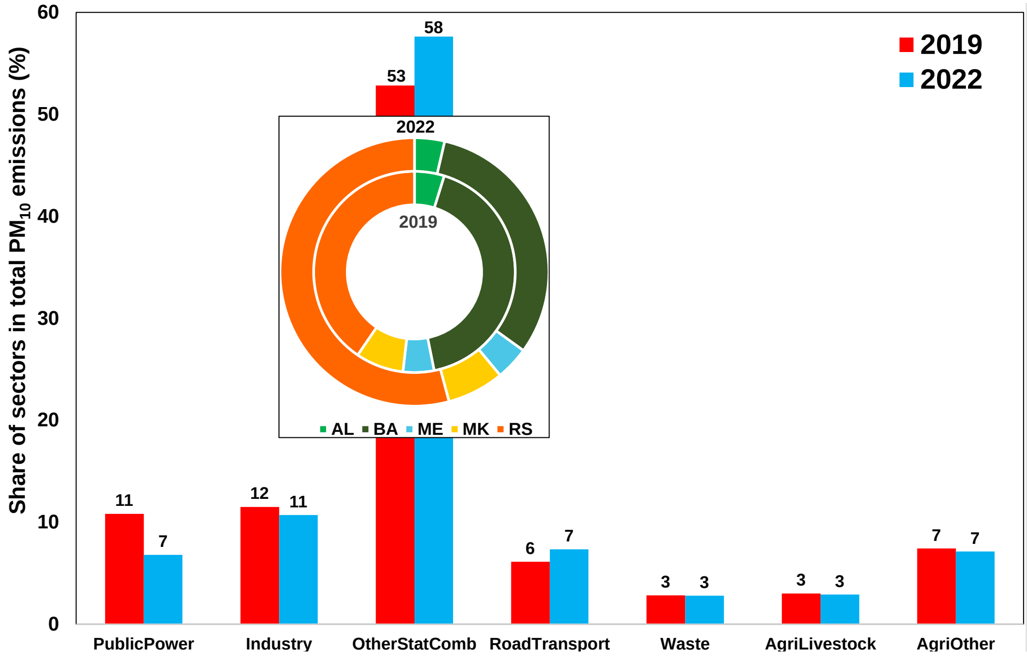
Figure 6. Change in contributions of individual sectors in total NOx emissions in WB5 region 2019-2022.



Source: Convention on Long Range Transboundary Air Pollution (JRC elaboration).

In 2022, the other stationary combustion sector became an even more significant source of PM_{10} (almost 60%), since the absolute emissions in this sector increased by 14% and those in the public power sector decreased by 35%. Similarly, around 70% of total $PM_{2.5}$ emissions originate from the other stationary combustion sector. Absolute emissions of PM_{10} in the other stationary combustion sector in Serbia increased by 52% in the period 2019-2022, while in Albania and Bosnia and Herzegovina decreased by approximately 15%. This means, combustion of primarily solid fuels in small appliances in households relatively increased their contribution among other sources of particulate matter (PM) emissions. Over 90% of total SOx emissions originate from the public power sector, as well as over 80% of the emissions are from Bosnia and Herzegovina and Serbia.

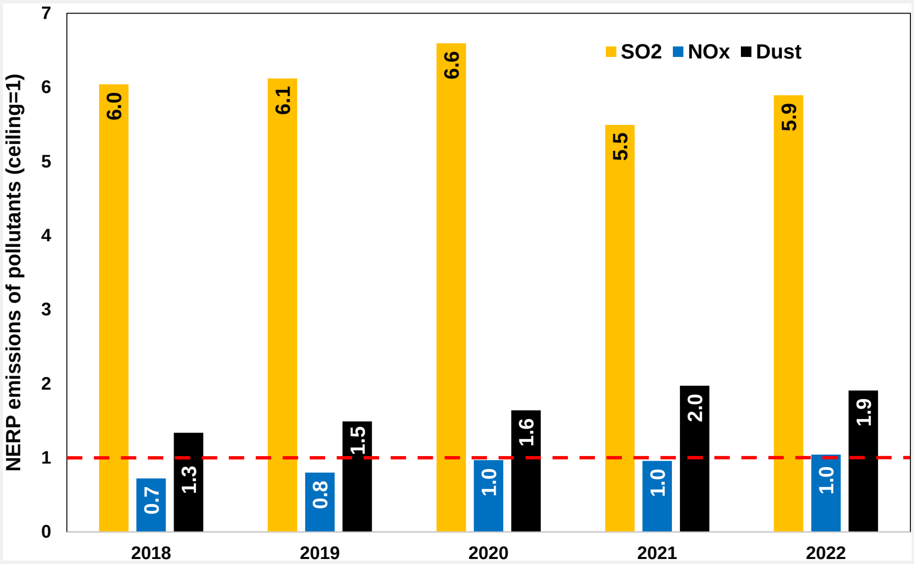
Figure 7. Change in contributions of individual sectors in total PM_{10} emissions in WB5 region 2019-2022.



Source: Convention on Long Range Transboundary Air Pollution (JRC elaboration).

Box 1. Emission trend of air pollutants included in the NERP

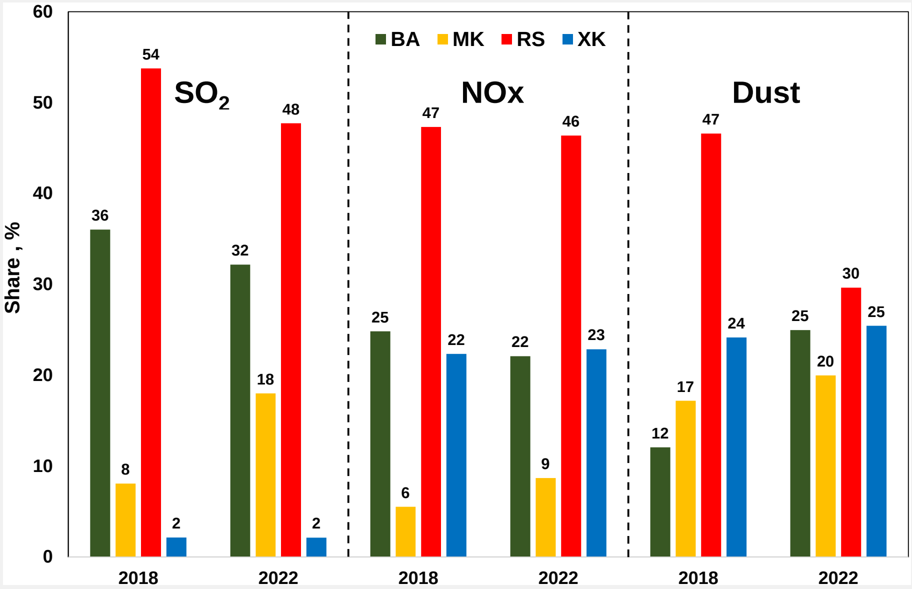
The emissions of air pollutants between 2018 and 2022 from the Large Combustion Plants (LCP) in WB4 countries (BA, MK, RS, XK) reported in the NERP (National Emission Reduction Plan) under the Energy Community Treaty are shown in the following figure. The emissions are normalised by the ceiling values (ceiling=1). Although only the absolute dust emissions increased over the observed period, both the relative NOx and dust emissions showed an increasing trend with respect to the ceilings. The main reasons are more than doubled dust emissions in 2022 with respect to 2018 in Bosnia & Herzegovina and a significant reduction in the ceiling value for Kosovo. The relative emissions of SO_2 showed a stable trend with values about 6 times higher than the ceilings. In 2022, NOx emission ceilings are met only in North Macedonia, and Serbia (close to the limit), and those for dust only in Serbia. In 2022, all the three air pollutants are non-compliant for the first time, considering the entire WB region.



Source: European Environmental Agency (JRC elaboration).

Box 2. Contribution of individual economies in total air pollutants emissions from plants under NERP

The overview of contribution of individual WB4 economies (BA, MK, RS, XK) in total air pollutants emissions from plants under NERP in 2018 and 2022 are shown in the following figure. The most significant changes related to the SO_2 emissions are reductions for Bosnia and Herzegovina and Serbia, opposed to increase for North Macedonia. Serbia significantly reduced, whereby Bosnia and Herzegovina increased its contribution in the dust emissions relevant for the entire WB region.

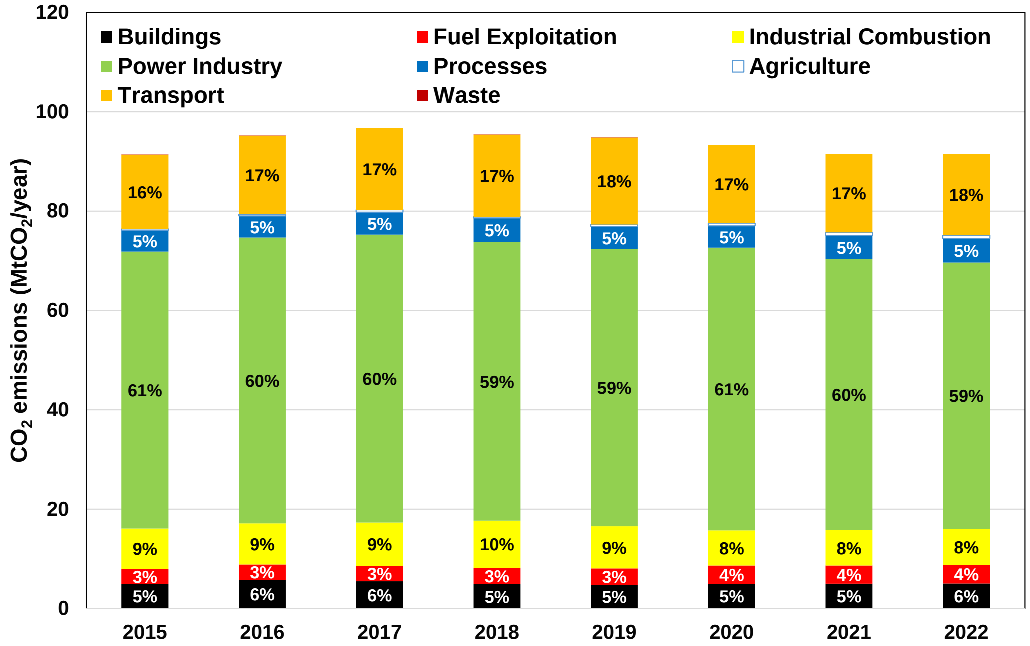


Source: European Environmental Agency (JRC elaboration).

2.3 CO_2 & other GHG emissions

This chapter presents the emissions that contribute to global warming, *i.e.* to climate change. The CO_2 originating from fossil fuels (combustion and production) are first discussed separately and then together with the other GHGs. In 2022, the fossil CO_2 emissions in the WB5 region (excluding Kosovo because it is not available as a separate entry in the database) rated nearly 95 Mt (**Figure 8**), about 16% lower than in the reference year of 1990. This decrease of CO_2 emissions at the WB level was mainly due to the reduction of emissions in the sectors that contribute the most, *i.e.* power industry 6% and industrial combustion 63% (Crippa *et al.*, 2023).

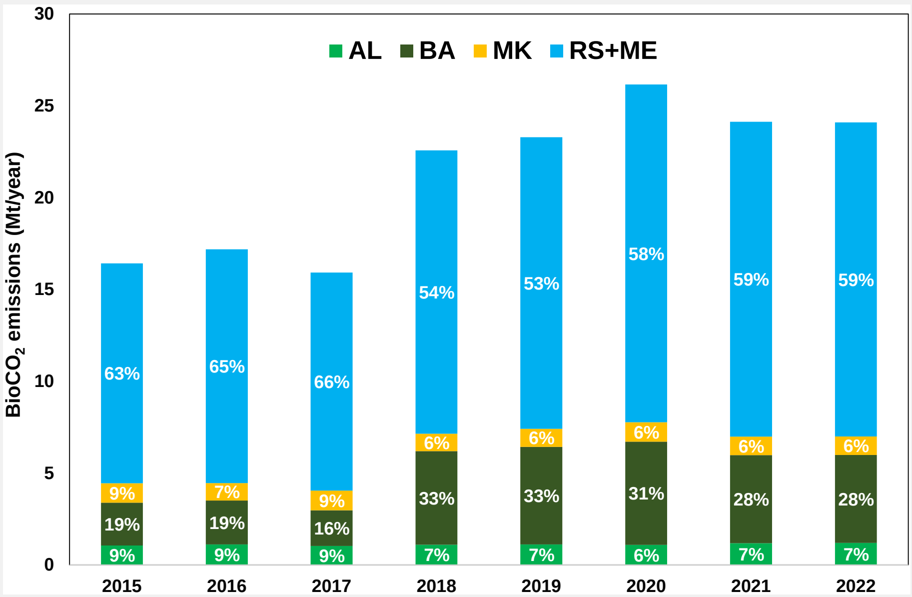
Figure 8. Trend of "fossil CO_2" emissions in WB5 region (excluding Kosovo) 2015-2022 with contribution of individual sectors.



Source: EDGAR JRC.

Box 3. Trend of biological CO_2 emissions in WB5 region

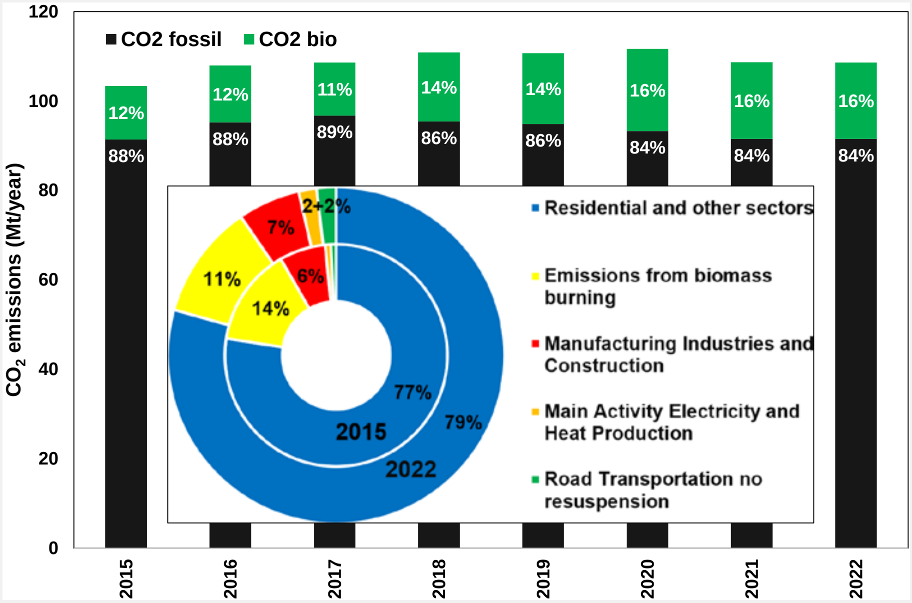
Emissions of biological CO_2 include those from the combustion of primarily solid biomass fuels and liquid biofuels. Large scale biomass burning including forest fires, as well as sources and sinks from land-use, land-use change and forestry (LULUCF) are excluded. Biological CO_2 emissions in 2022 in WB5 region (excluding Kosovo) increased by 85% comparing to 1990 and 43% comparing to 2015. In the recent period, the share of Bosnia and Herzegovina significantly increased (roughly doubled) while those of Serbia and Montenegro decreased (RS and ME are provided in aggregate form in the database for technical reasons).



Source: EDGAR JRC.

Box 4. Origin of biological CO_2 emissions in WB5 region

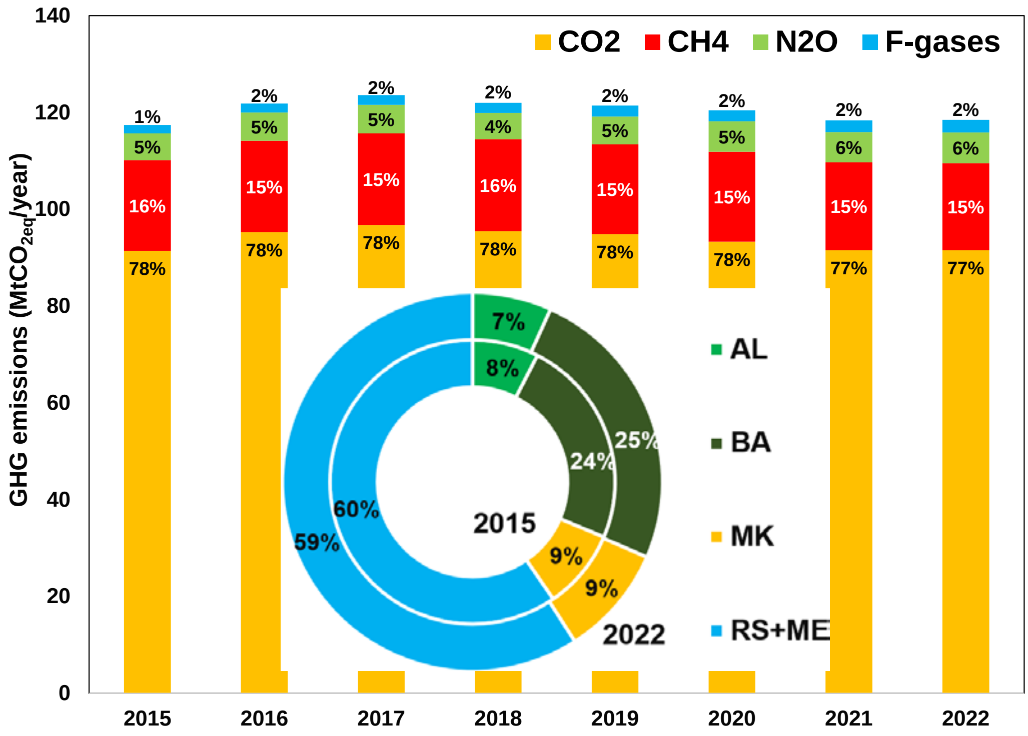
The contribution of biological CO_2 emissions relative to the fossil CO_2 emissions in WB5 region (Kosovo is not available in the source dataset) increased during the period 2015-2022. In 1990, only the residential sector and biomass burning contributed to the biological CO_2 emissions, while in 2022 all sectors are included. The share of the most dominant sector, residential, slightly increased while the emissions from biomass burning decreased.



Source: EDGAR JRC.

Figure 9 depicts the trend of overall GHG emissions in WB5 region during the period between 2015 and 2022 (Crippa *et al.*, 2023). The share of WB economies and considered gases (CO_2, CH_4, N_2O and F-gases) in the overall emissions is also provided. No significant change in the overall GHG emissions 2015-2022 is observed. However, overall GHG emissions were reduced by 18% in 2022 compared with the reference year 1990. CO_2 emissions remain the main contributor with a share of around 77%. The most pronounced decrease in the same period between 1990 and 2022 was recorded in CH_4 emissions, *i.e.* by 33%. The share of biological GHG in the overall emissions is extremely low, whereas it increased from 0.6% in 1990 to 1.3% in 2022.

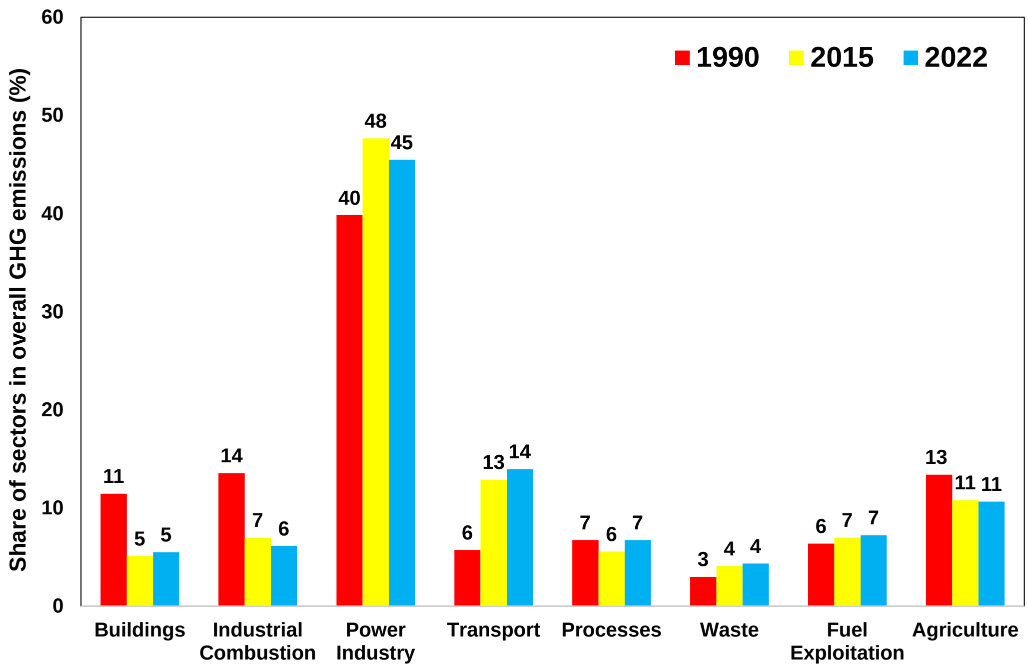
Figure 9. Trend of overall GHG emissions with contribution of economies and individual gases in WB5 region 2015-2022.



Source: EDGAR JRC.

Figure 10 gives the overview of change of contribution of sectors in overall GHG emissions in WB5, considering the reference year of 1990 and starting and end years of the analysed period 2015 and 2022 (Crippa *et al.*, 2023). A significant increase is identified in the sectors of power industry and transport, while a significant decrease in the sectors of buildings and industrial combustion.

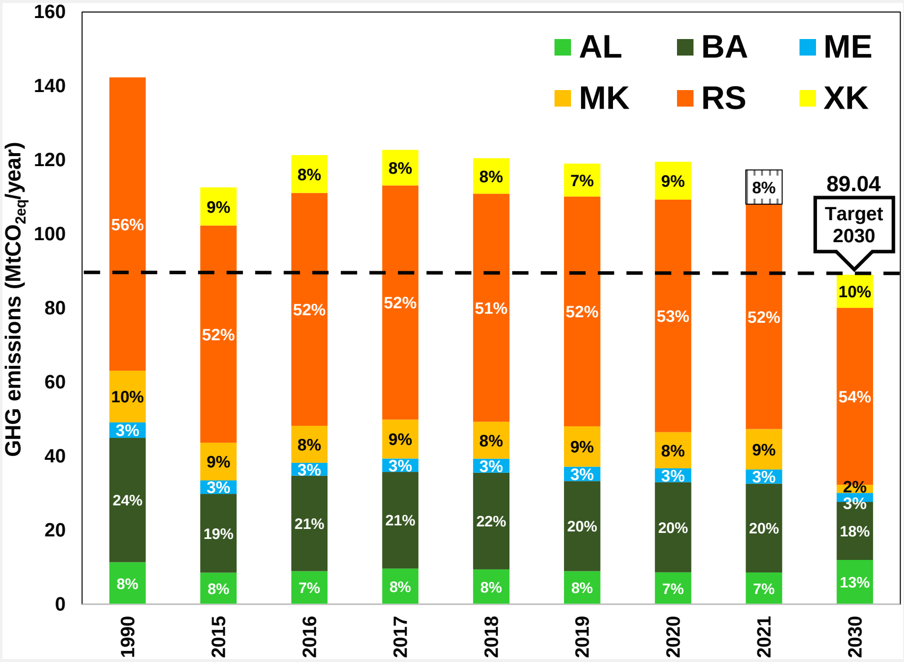
Figure 10. Contribution of sectors in overall GHG emissions region in 1990/2015/2022 in WB5.



Source: EDGAR JRC.

Box 5. Overall GHG emissions reduction target

To accelerate the reduction of GHG emissions and achieve climate neutrality by 2050, the Energy Community adopted in December 2022 climate targets for 2030 (Energy Community, 2022). The targets subsume all domestic net GHG emissions, including LULUCF emissions and removals in all countries except of Montenegro. The target is set compared to 1990, with the exception of Kosovo which is related to 2016 levels. Analysing the trend by World Resource Institute (Climate Watch, 2023) and for Kosovo (Government of Kosovo, 2023), the overall emissions in 2020 should be reduced by 26% until 2030 to meet the defined target. This requires an average annual reduction rate in the period 2020-2030 of around 3.0%.



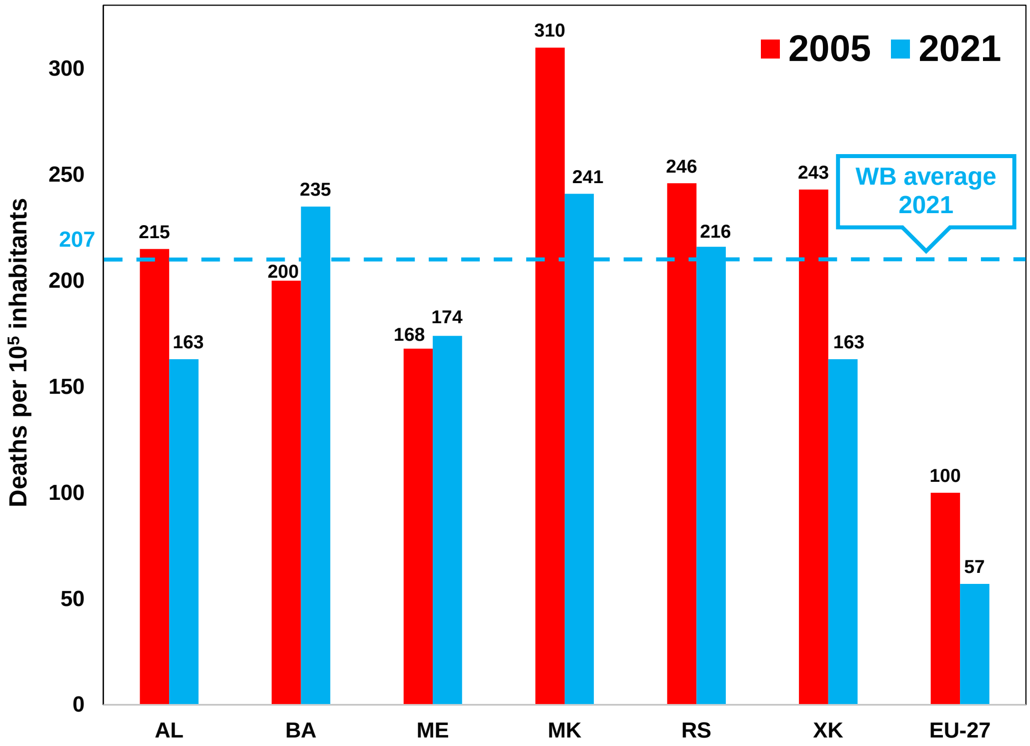
Source: Climate Watch & Energy Community (JRC elaboration).

2.4 Air quality impacts on health

In this chapter the most significant impact of air quality on human health in WB economies are discussed. Such effect is mainly associated with $PM_{2.5}$, O_3 and NO_2, whereby the premature deaths (PD) and years of life lost (YLL) were the basis to quantify further the costs related to impaired health.

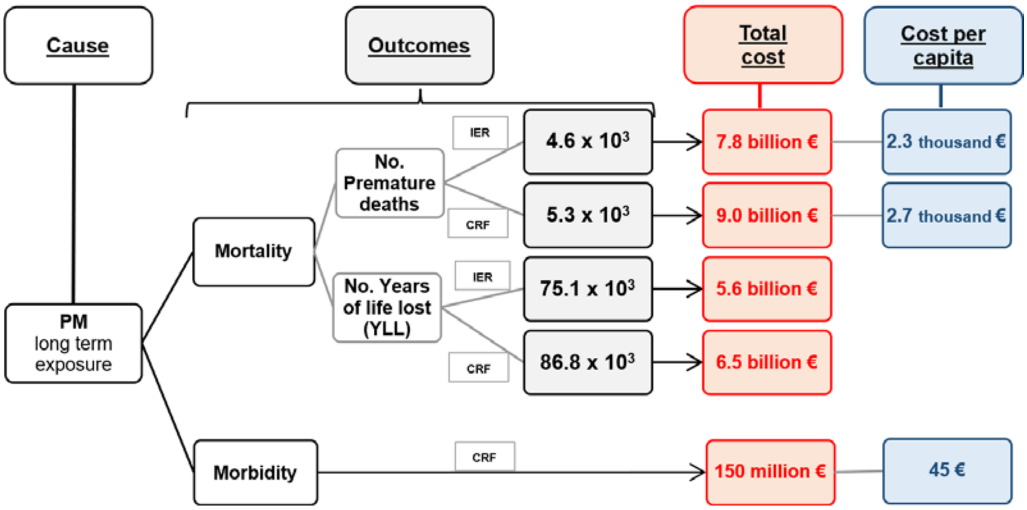
Figure 11 gives an overview of the estimated rate of premature deaths per 100,000 inhabitants attributable to the exposure to $PM_{2.5}$ annual average concentrations above 5 µg/m^3 which is the WHO guideline (EEA, 2023). Comparative analysis of data from WB economies and EU27 over the period 2005 - 2020 shows that the mortality rate decreased in most countries of the WB region. The most significant improvement were achieved in Kosovo (-33%), Albania (-24%) and North Macedonia (-22%) while in Serbia it decreased by 12%. By comparison, the situation worsened in Bosnia and Herzegovina (+18%) and in Montenegro (+4%). In EU27 the mortality rates in 2005 and 2021 are significantly lower. The decrease in average mortality rates in 2021 compared with 2005 is significantly higher in EU27 (-43%) than in the WB economies (-14%). Thus, in 2005 the mortality rate in individual WB economies was between 1.7 to 3.1 and in 2021 between 2.9 to 4.2 times higher than in EU27. The gap between the two regions grew despite the decrease in absolute deaths in WB from 45.9 thousand in 2005 to 36.7 thousand in 2021.

Figure 11. Annual mortality rates in 2005 and 2021 in WB and EU27 attributable to exposure to $PM_{2.5}$.



Source: EEA (JRC elaboration).

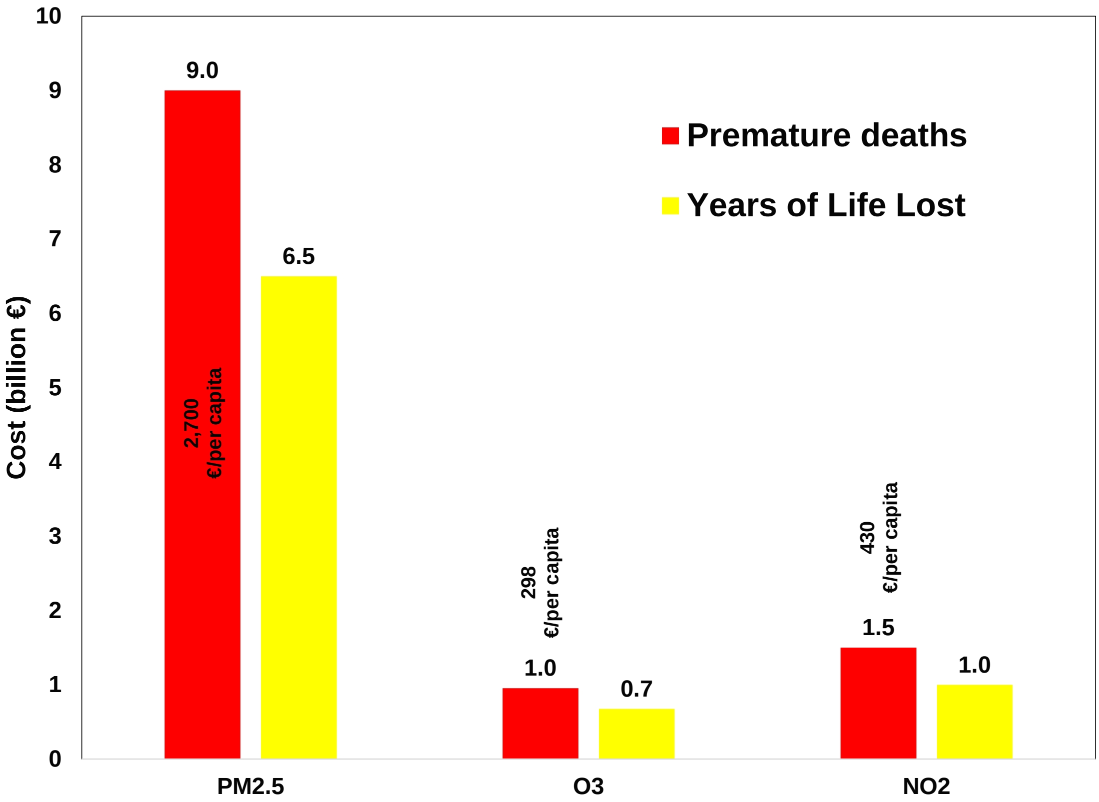
Figure 12. Health impacts and costs attributable to $PM_{2.5}$ (mortality) and PM_{10} (morbidity) in 30 WB cities.



Source: Belis et al., 2023 (JRC elaboration).

The study of health impacts and costs attributable to air pollution in urban areas by Belis *et al.* (2023), states that in 2019 in WB the total premature deaths attributable to $PM_{2.5}$ were between 4.6 and 5.3 thousand, depending on the methodology applied. The defined range is obtained by applying two different methods (IER and CRF). The analysed 30 urban areas represent 21% of the total WB population and 37% of urban population. According to the Western Balkans regular economic report by the World Bank (2024), in 2022 60% of the WB regions population on average was urban. **Figure 12** depicts the information on particulate matter as a cause of mortality and morbidity including attributable costs (total and per capita). The calculated cumulative costs of $PM_{2.5}$-related number of premature deaths were between 7.8 and 9.0 billion € corresponding to 2.3 and 2.7 thousand € per capita.

Figure 13. Costs attributable to $PM_{2.5}$, O_3 and NO_2 related to premature deaths and years of life lost in 2019 in 30 WB cities.



Source: Belis et al., 2023 (JRC elaboration).

The calculated cumulative costs of morbidity caused by PM were 150 million € and 45 € per capita (Belis *et al.*, 2023). The largest share (92.3%) in morbidity outcome costs is related to myocardial infarction (MI), chronic obstructive pulmonary disease (COPD), diabetes mellitus (DMT2) and cerebrovascular disease (CVAD). The remaining share (7.7%) is related to working lost days (WLD), restricted activity days (RAD), hospital admissions due to cardiovascular diseases (HA CVD) and respiratory diseases (HA RD), asthma (AST CHI) and bronchitis in children (BR CHI) and in adults (BR AD), and lung cancer (LC).

The number of premature deaths (PD) and years of life lost (YLL) related to $PM_{2.5}$ exceeds those associated with O_3 and NO_2 by a factor of more than 8 and 5, respectively (according to CRF). The costs associated with these pollutants are shown in **Figure 13**.

3 Impacts of climate change

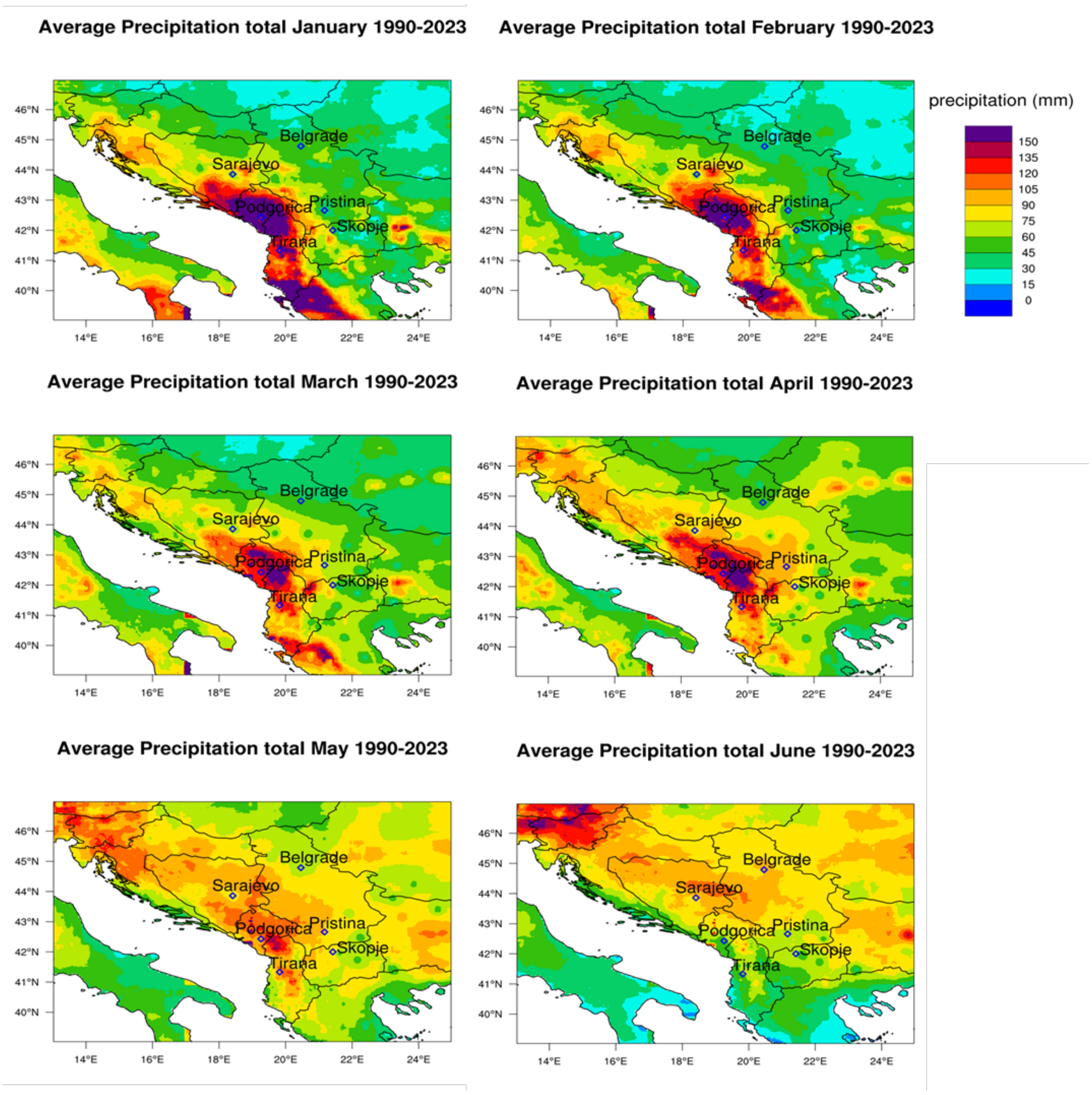
3.1 Precipitations

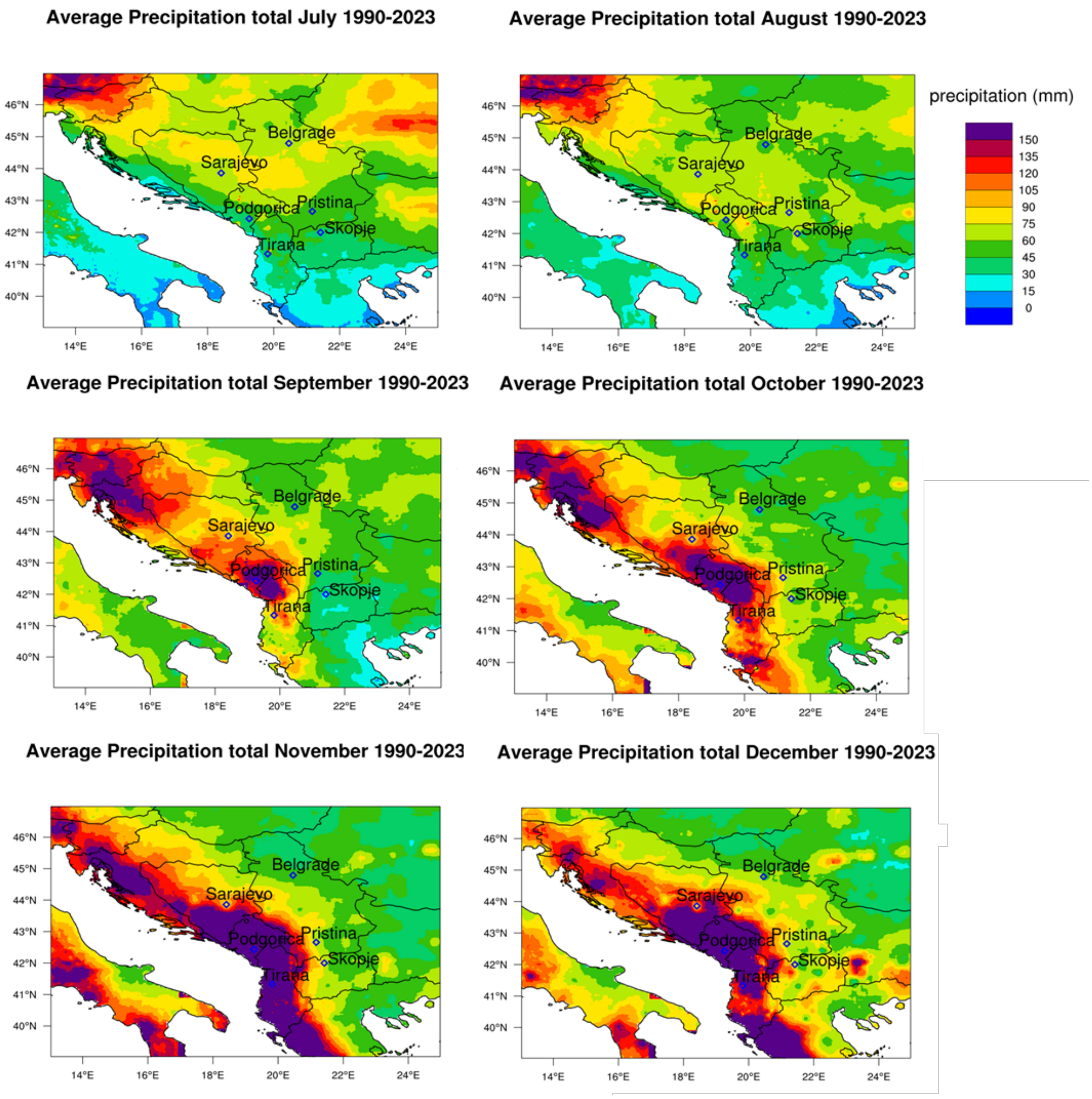
In this section we use precipitation data from the Climate Hazards Center InfraRed Precipitation with Station data (CHIRPS). This data set is a 30+ year quasi-global rainfall data set, spanning 50°S-50°N (and all longitudes) and starting in 1981 to near-present. CHIRPS data incorporates 0.05° resolution satellite imagery with in-situ station data to create gridded rainfall time series for trend analysis and seasonal drought monitoring (Funk *et al.*, 2015). In this work we analyse the precipitation over the Western Balkan region between 1990 and 2023.

3.1.1 Monthly total precipitation climatology

The maps below (**Figure 14**) show the average monthly total precipitation for the Western Balkans between 1990 – 2023. Each map shows for each calendar month the average monthly precipitation

Figure 14. Average monthly total precipitation 1990 – 2023.





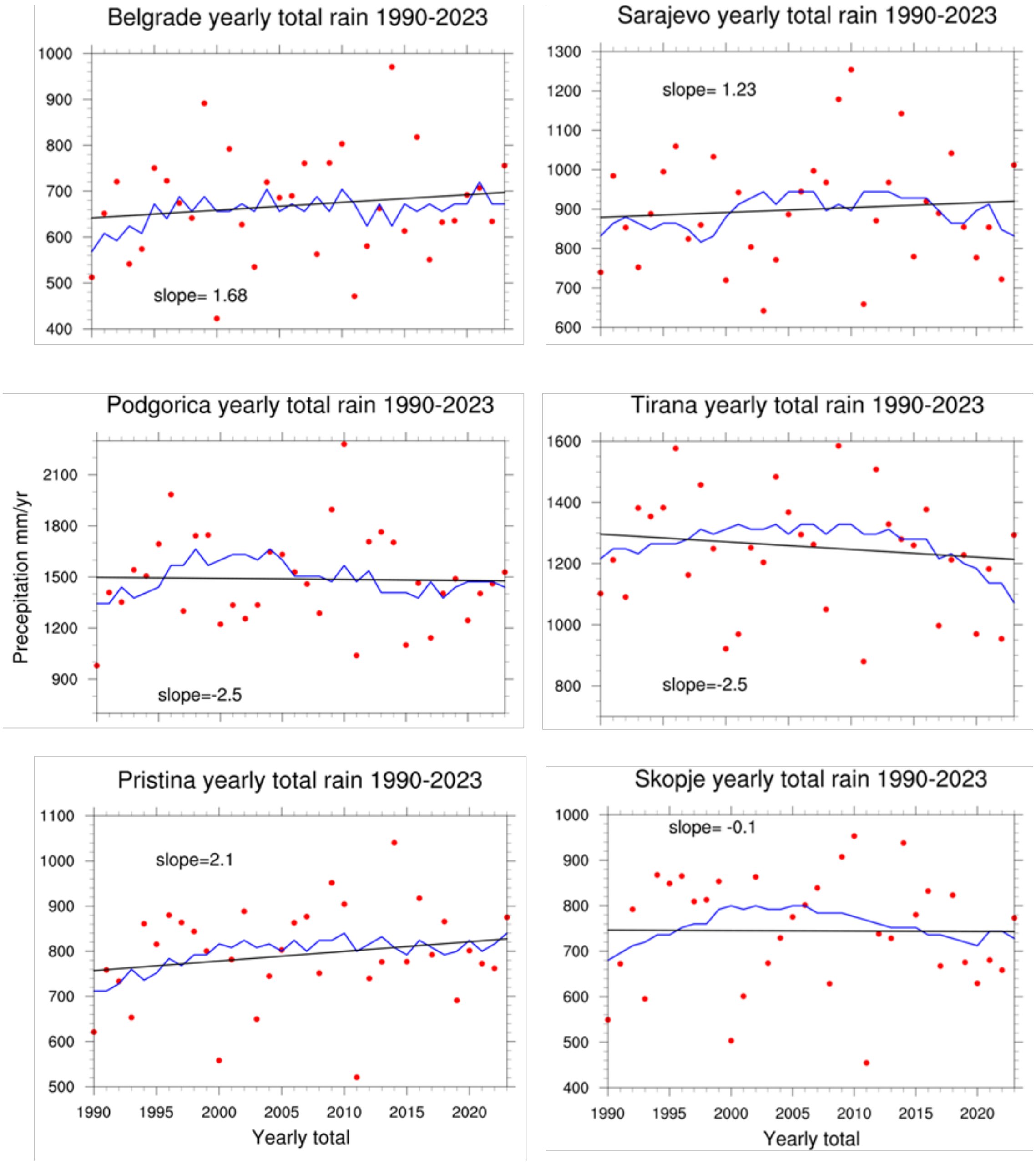
Source: JRC

based on the period 1990 – 2023. The highest precipitation values are found during the boreal winter and spring period and the lowest values during the boreal summer.

3.1.2 Yearly total precipitation climatology

In **Figure**, the average yearly total precipitation between 1990 – 2023 for Belgrade, Sarajevo, Podgorica , Tirana, Pristina and Skopje are shown. An upward trend in the total yearly rain fall is found, except for Tirana (-2.5) and Skopje (slope -0.1). Looking at the maximum precipitation quantities, we see that for Sarajevo and Podgorica the highest total precipitation quantities were found in 2010 and for Belgrade in 2014. For Tirana the highest yearly totals are found for 1996 and 2009, up to 1600 mm rain, however a negative trend is observed between 1990 and 2023 as mentioned earlier.

Figure 15. Yearly total rain 1990 – 2023.



Source: JRC

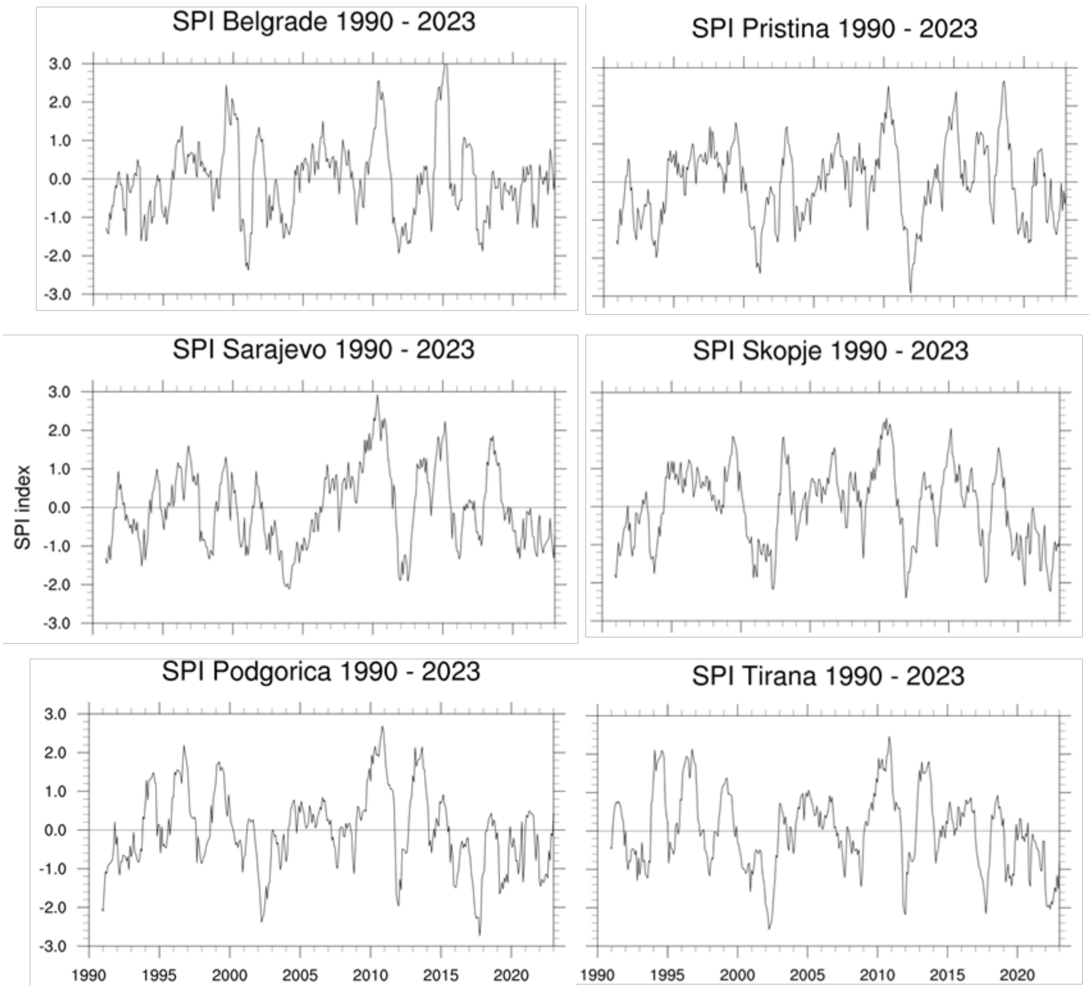
3.2 Droughts

SPI index is relevant for droughts. The World Meteorological Organization (WMO) recommends that all national meteorological and hydrological services should use the standardized precipitation index (SPI) for monitoring of dry spells. The standardisation of the SPI allows the index to determine the rarity of a current drought. However, the SPI are based on precipitation alone and provide a measure only for water supply. They are very useful as a measure of precipitation deficits or meteorological drought, but are limited because they do not deal with evapotranspiration.

Generally, monthly precipitation is not normally distributed, so a transformation is performed such that the derived SPI values follow a normal distribution. The SPI is the number of standard deviations of the observed value with respect to the long-term mean. An interpretation of the SPI values is:

- [+, -] 2.00 and above/below: exceptionally [wet, dry].
- [+, -] 1.60 to 1.99: extremely [wet, dry].
- [+, -] 1.30 to 1.59: severely [wet, dry].
- [+, -] 0.80 to 1.29: moderately [wet, dry].
- [+, -] 0.51 to 0.79: abnormally [wet, dry].
- [+, -] 0.50: near normal.

Figure 16. Standard Precipitation index (SPI) for 1990 – 2023 for Belgrade, Pristina, Sarajevo, Skopje, Podgorica and Tirana.

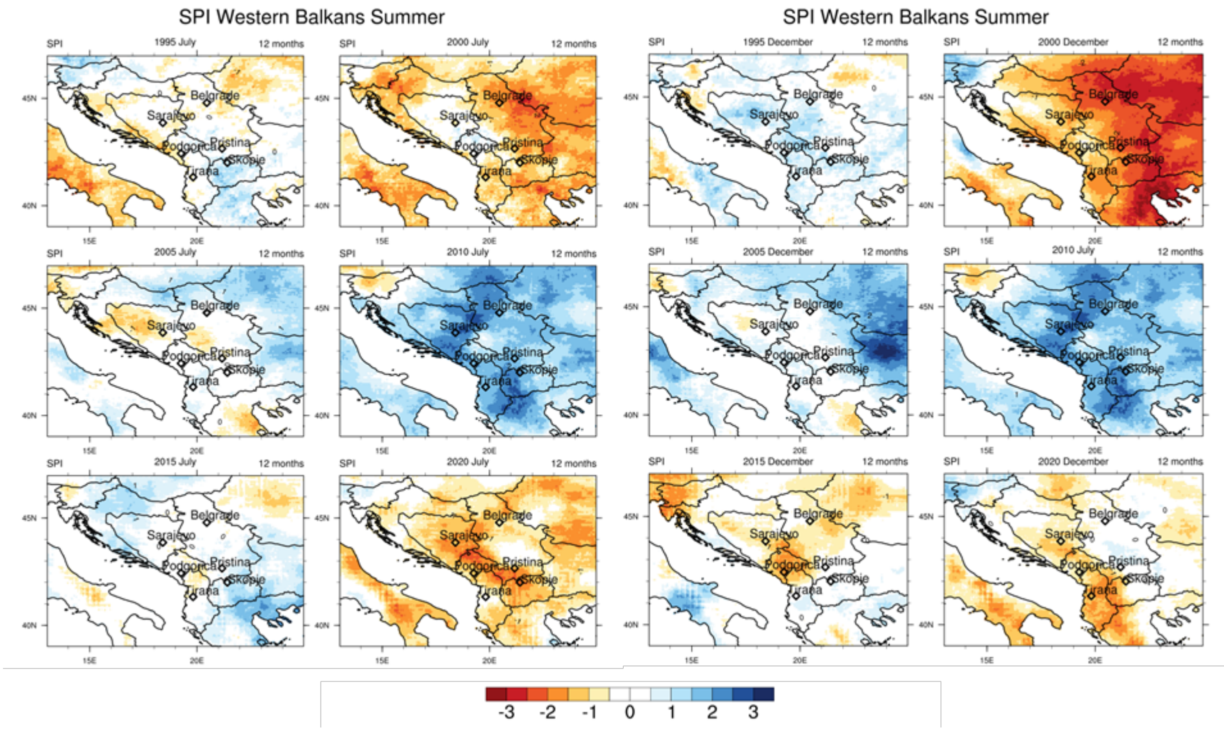


Source: JRC

Analysing the SPI for Belgrade (**Figure 16**), we see that exceptionally intense wet periods were observed during 1999, 2010 and 2015, with exceptionally drought around 2000 and 2011. For Pristina, Skopje and Tirana, exceptionally droughts were found around 2012, and for Podgorica 2017 was extremely dry. Extremely wet conditions were found in the Western Balkan region around the year 2010, where SPI is > 2.0.

In **Figure** an overview of the graphical distribution of the SPI index is presented during the Summer and Winter period. This allows to understand better the general trend in wet or drought periods during the winter and summer periods.

Figure 17. Geographical overview of the Standard Precipitation index (SPI) between 1990 – 2023.



Source: JRC

3.3 Surface and ground waters

In WB climate change is addressed in national water management strategies of the countries, national climate change strategies and action plans and in the case of transboundary rivers by management plans of major basins (Danube River Basin Management Plan 2021; Sava River Basin Management Plan, 2022). Having in mind data shown in the beginning of the chapter, the trend points to more significant drying during the summer in southern and coastal regions of WB, alongside heightened winter precipitation, thereby increasing the risks of both droughts and flooding. Hydrological data indicated the average trend of decreasing annual mean flows in central Serbia is around 30% per 100 years, but it varies spatially (Government of the Republic of Serbia, 2017). The smallest changes are expected in the southwestern part of Serbia, while the largest negative changes are anticipated in the eastern part.

3.3.1 Hydromorphological alterations

Climate change can lead to hydromorphological changes **directly** through the new hydromorphological alterations as a result of impacted hydromorphological processes or **indirectly** by new man-made physical modifications as a result of further needs related to increased water demand for water supply, irrigation and other purposes (ICPDR, 2021). Droughts and floodings are **directly** affecting river ecosystems by causing changes in hydrological and sediment regime. Hydromorphological alterations caused by different purposes for water usage are seen as **indirect** effect of a climate change. Additionally, ecological stress of climate change on dammed and channelized rivers are projected to be greater than on undammed rivers. Specific attention should be focused not only on future infrastructure projects, but also to small size projects that may contribute to hydromorpological degradation, such as small hydropower plants. By ratifying the Energy Community Treaty WB countries also undertaken obligations from the Directive 2009/28/EC, which, among other things, promotes electricity produced from renewable energy sources resulting in a substantial increase in the number of locations where there is an interest in building small hydroelectric power plants (SHPP). The study of Pavlakovič *et al.* (2022) provides an overview on the distribution and development of SHPPs across the countries within the region. As of the latest data, Albania, the capacity of these plants remains at about 12% of the total installed capacity by 2020 data. In Bosnia and Herzegovina, the installed capacity is about 9%. Montenegro has 16 SHPPs, but only 9 of these plants are newly constructed. North Macedonia has a total installed SHPP capacity of 90.6 MW, with a potential estimated at 260 MW. Serbia, on the other hand, has utilized about 19% of its water resource potential for SHPPs.

3.3.2 Climate change effects on water quality

Table 2 summaries the effect of the climate change consequences on the major group of pollutants present in waters in WB region. Considering the issue of untreated wastewater discharge, droughts can greatly impact pollutant concentrations by increasing the proportion of wastewater in surface waters. Climate change also significantly influences the release and movement of **nutrients** such as nitrogen and phosphorus in water sediments. Altered precipitation patterns result in more frequent and intense runoff events, carrying higher loads of these nutrients from agricultural lands into water bodies. This can cause eutrophication, where elevated nutrient levels promote harmful algal blooms. Changes in redox conditions, driven by warmer temperatures and water stratification, can create hypoxic or anoxic conditions in sediments.

This affects the mobility of heavy metals, increasing their presence in the water column. Higher temperatures can increase the decomposition rates of some organic micropollutants, altering their concentrations in sediments. Changes in precipitation patterns can lead to increased runoff, transporting pesticides and pharmaceuticals from land to water bodies, affecting their sediment levels and potentially causing ecological and health concerns.

Groundwater quality can also be impacted by climate change. Increased flooding can lead to the contamination of aquifers with surface pollutants. Evidence is available for the soil-to-groundwater migration of heavy metals in mining area hotspots in Serbia (Vesković and Onija, 2024). Moreover, higher temperatures and altered precipitation patterns can change the chemistry of groundwater, potentially increasing the concentrations of harmful substances such as nitrates and heavy metals.

Table 2. The effects of climate change consequences on the major group of pollutants of interest for WB region

CC consequences	Nutrients	Heavy metals	Organic Micropollutants	Pathogens
Temperature increase	Increase due to higher decomposition rate of organic matter	Release of heavy metals from sediment due to acidification and alteration the redox conditions in sediments	Increase due the higher decomposition rate of micropollutants	Decrease of autochtonous species of pathogens Increase of occurrence of alochtonous pathogens
Floodings	Increase by intense runoff events and sediment disturbance	Increase by sediment disturbance	Increase by intense runoff events and sediment disturbance	Increase by runoff of manure and feces, and re-suspension of pathogens from sediments
Droughts	Increasing the proportion of wastewater in surface water	Increasing the proportion of wastewater in surface water	Increasing the proportion of wastewater in surface water	Increasing the proportion of wastewater in surface water

Source: JRC

3.3.3 Climate change effects on occurrence of pathogens

According to the Hofstra (2011), climate impacts on waterborne pathogen concentrations in surface water are three folded: (a) higher water temperatures can inactivate viruses, bacteria, and parasites; (b) increased precipitation and extreme weather events heighten waterborne pathogen concentrations through sewer overflows, runoff of manure and feces, and re-suspension from sediments; and (c) decreased precipitation and droughts raise the proportion of wastewater in surface water, leading to higher pathogen concentrations. Having in mind the pressure from untreated wastewaters discussed below in the chapter on water quality, impact of climate change described under points (b) and (c) is of great significance in WB case. Although the rise in temperature negatively correlates with the persistence of introduced pathogens in environment, it shows positive correlation with occurrence of pathogens naturally present in environment. There is an evidence suggesting that *Vibrio vulnificus* and *V. parahaemolyticus* infections are increasing, and tend to follow regional climatic trends (Baker-Austin *et al.*, 2010). This might be of significance interest for the areas which are natural habitats for indicated species such as marine ecosystems and lagoons. For instance, the main production of molluscs in **Albania** consists in the cultivation of *Mytilus galloprovincialis*, which takes place in the Butrinti lagoon. The study of (Çoçoli *et al.*, 2013) reported occurrence of *Vibrio* spp. in samples of mussels taken between June-September, which is related to the fact that *Vibrio* species prefer high water temperatures. Out of 234 samples analysed those positive for the presence of Vibrio spp. were as follows: 7 samples positive for *V. vulnificus* (2.9%). 4 for *V. fluvialis* (1.7%). 5 for *V. alginolyticus* (2.13%). *V. vulnificus*. *V. alginolyticus* and *V. fluvialis* are among *Vibrio* species of interest for humans as they can cause food poisoning (Çoçoli *et al.*, 2013). Such environments are also present in other WB countries apart from marine ecosystems. For instance, study of Rhem *et al.* (2023) was the first report on the occurrence of *V. cholerae* non01/non0139 in natural and artificial lakes and ponds in Serbia. Non-toxigenic *V. cholerae* (NTVC) are able to cause a variety of mild-to-severe human infections (via seafood consumption or recreational activities) and in the northern hemisphere, NTVC infections have been reported to increase due to global warming. With the exception of one highly saline lake, all investigated water-bodies harboured NTVC indicating need for seasonal monitoring of ponds/lakes used for recreation in Serbia to predict occurrence of infections promoted by climate change-induced rise in water temperatures.

Box 6. Mitigation measures for climate change impacts

Mitigation of the climate changes impact is addressed within the strategies of water management and climate change strategies of WB countries. Following mitigation measures are addressed by the most of the WB countries:

1. Improvement of Water Supply and Wastewater Management:

Countries aim to enhance the resilience and sustainability of water supply systems to cope with the impacts of climate change, such as increased precipitation and droughts.

2. Investment in Infrastructure:

Significant investments are planned to upgrade and expand water and wastewater infrastructure, which includes developing new facilities and modernizing existing ones to handle extreme weather events and changing climate conditions. This is key step to further improve the water quality management to align with the European policies.

3. Nature-based flood solutions and green areas:

Wise land use planning and protection of river corridors, floodplains and wetlands are main protective measures that bring benefits not only to water ecosystems quality but also to minimisation of negative effects of climate change.

4. Integrated Water Resources Management (IWRM):

Emphasis is placed on adopting an integrated approach to managing water resources, considering the entire water cycle and the various factors affecting it, including climate change.

5. Monitoring and Adaptive Management:

Establishing of comprehensive monitoring systems is crucial to track water quality and quantity, enabling adaptive management practices to respond effectively to climate variability and change, and to align with the European policies.

6. Capacity Building and Public Awareness:

Efforts are directed towards strengthening the capacities of institutions and communities to manage water resources sustainably under changing climatic conditions. This includes training programs and public awareness campaigns about water conservation and climate resilience. Collaboration with European Member States through Horizon projects, conferences, training would gain benefits to embrace the EU policy in the future.

7. Policy and Regulatory Framework:

Updating and enforcing policies and regulations is necessary to support climate-resilient water management practices. This includes setting standards for water use and quality that consider the projected impacts of climate change. The reviewed EU policies on water management to protect the human health and environmental health is a great challenge for the Wester Balkan regions.

3.4 Heat waves intensity

Increase of temperatures due to global warming has adverse effects on the society. One the most pronounced consequences of global warming is the increase in frequency and intensity of heat waves that may strongly impact local population and ecosystems (*e.g.* Vogel *et al.* 2020). People and ecosystems are sensitive to extreme temperatures. In particular, extremely high temperatures persistent for longer periods bring discomfort to people, especially impacting the most sensitive parts of the population like older people and young children. The mortality increases significantly during the several days long periods of heat waves (*e.g.* Basu and Samet 2002; Ballester *et al.,* 2023). In the previous report covering the period until 2019 it was demonstrated that in general heat waves in the Western Balkans have increased in the recent years (Belis *et al.*, 2022). In this report we evaluate the persistence of the trend until 2023, the characteristics of increasing heat waves and the connection between the more frequent heat waves and warming trends.

The Heat Wave Magnitude Index daily (HWMId) is calculated as the major seasonal event with three or more days with maximum temperatures exceeding the 90 percentile threshold, normalized by the difference between the 75 percentile and 25 percentile temperatures at each geographical point (Russo *et al.* 2014). It is calculated during summers (June, July and August) between 1979 and 2023. In order to evaluate the changing characteristics of heat waves, we also calculated the sum of all events of heat waves in the same season, the maximum anomaly during HWMId and the number of days forming each HWMId.

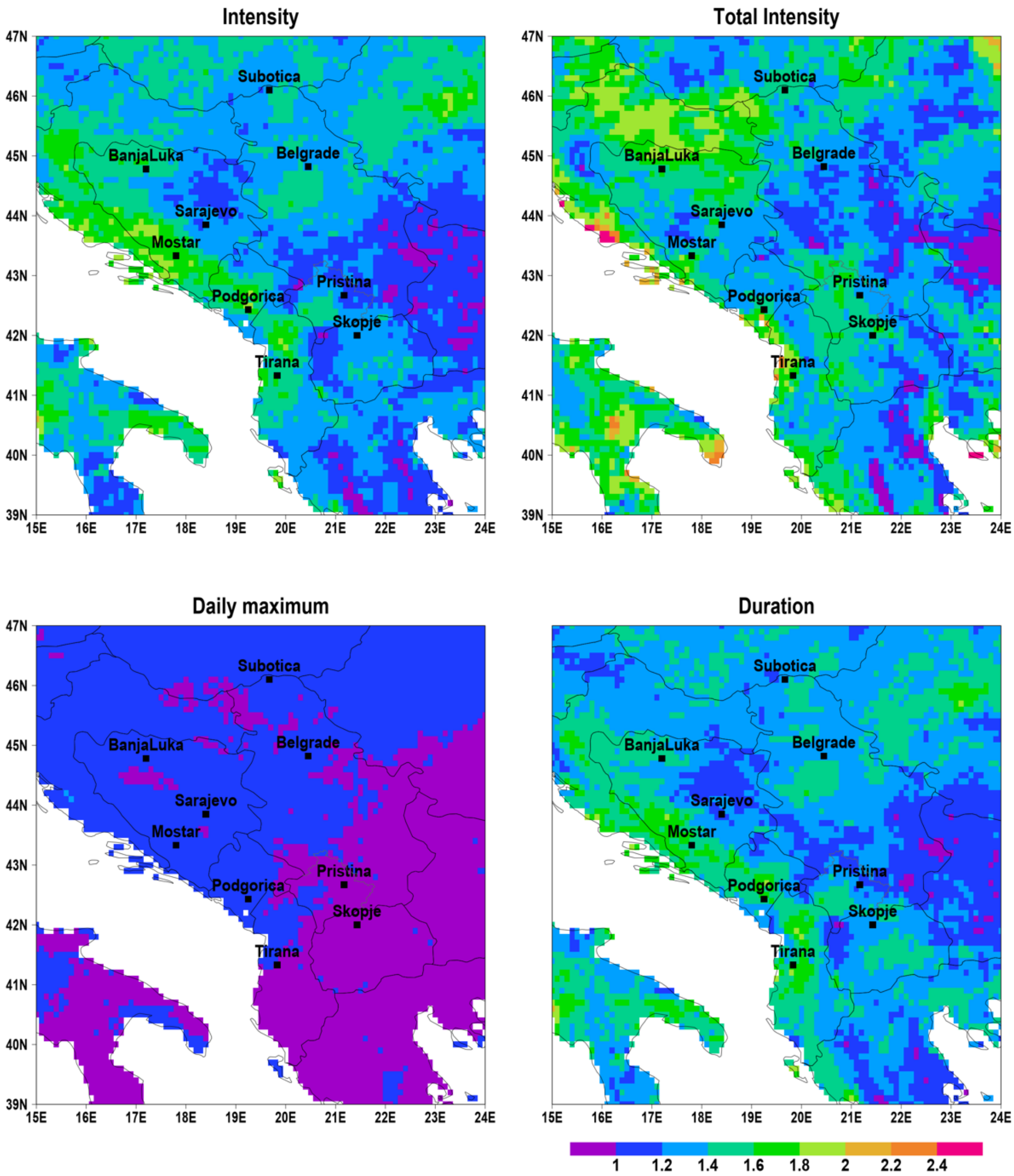
As in Russo *et al.* (2014) and Dobricic *et al.* (2020) the algorithm for calculating HWMId uses a 30 days long running window for augmenting the data set length for the statistics. Such a long running window may introduce a bias in estimating the severity of heat waves (Brunner and Voigt 2024). In order to estimate the impact of the possible bias the analysis presented here was repeated with the detrended data as proposed by Brunner and Voigt (2024), but there was no significant quantive change in the findings (not shown). The practical insensitivity of the results to detrending may be due to the choice of only summer season for estimating HWMId and a relatively short temporal span of the study over four decades (1979-2023). The choice to keep the original data set for the calculation may be also justified by the use of HWMId to estimate their impact on individuals during their life, that is, as periods of extremely high temperatures in each summer independently of the exact part of the summer when they appear.

Average intensity of HWMId increased in period 2003-2023 with respect to previous period 1982-2002 (**Figure 18**, up and left). The area with the most intensive increase of 40 – 60 % is in the vicinity of the Adriatic coast and extends from central Albania in the south-east to the Croatian Adriatic coast extending to north-western Bosnia and Herzegovina in the north-west. Other areas with similar increase are in Kosovo and central and northern Serbia.

The total intensity of heat waves calculated as the sum of all heat waves in a season increased with a different pattern than HWMId, with areas with the most pronounced increase over central and north-western parts of Western Balkans (**Figure 18**, up and right). The increase of the total intensity of heat waves during summer generally does not coincide with the increase of HWMId, except in the vicinity of the Adriatic Sea coast including three larger cities Mostar, Podgorica and Tirana. The increase in the average intensity of HWMId in period 2003-2023 is mainly due to the longer heat waves and less due to higher maximum temperatures during heat waves. This finding is demonstrated by **Figure 18** (down and left). The increase of maximum daily temperatures is relatively small with a weak east-west increasing gradient, while the increase of number of days during HWMId in period

2003–2023 reassembles closely the pattern of increasing HWMId shown in **Figure 18** (down and right).

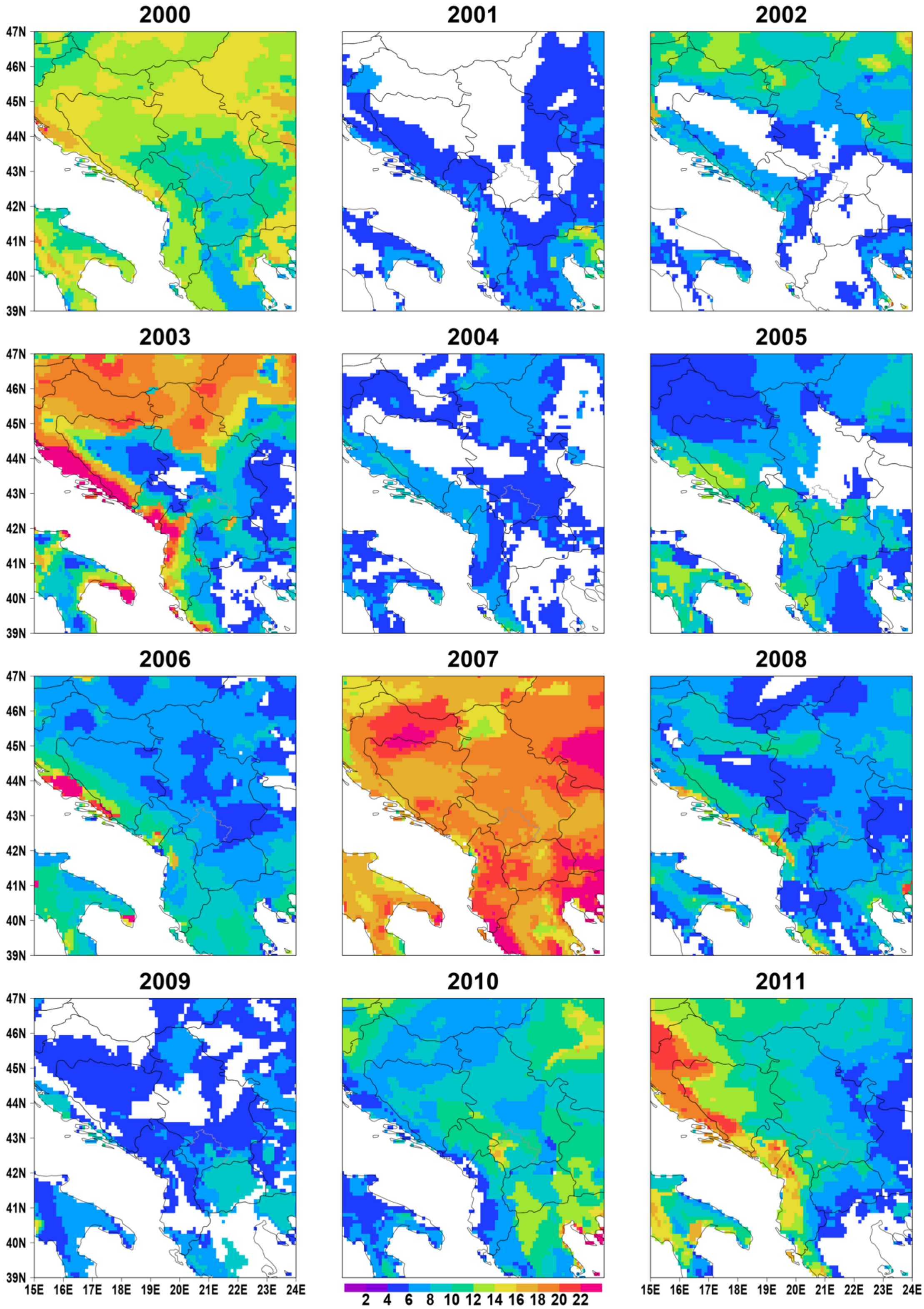
Figure 18. Ratio between the average values in periods 2003-2025 and 1982-2002: a) HWMID, b) the seasonal sum of all HWMIs, c) the maximum daily temperature anomalies during the most intense heat wave in a season and d) the duration in days of the most intense heat wave in a season.



Source: JRC.

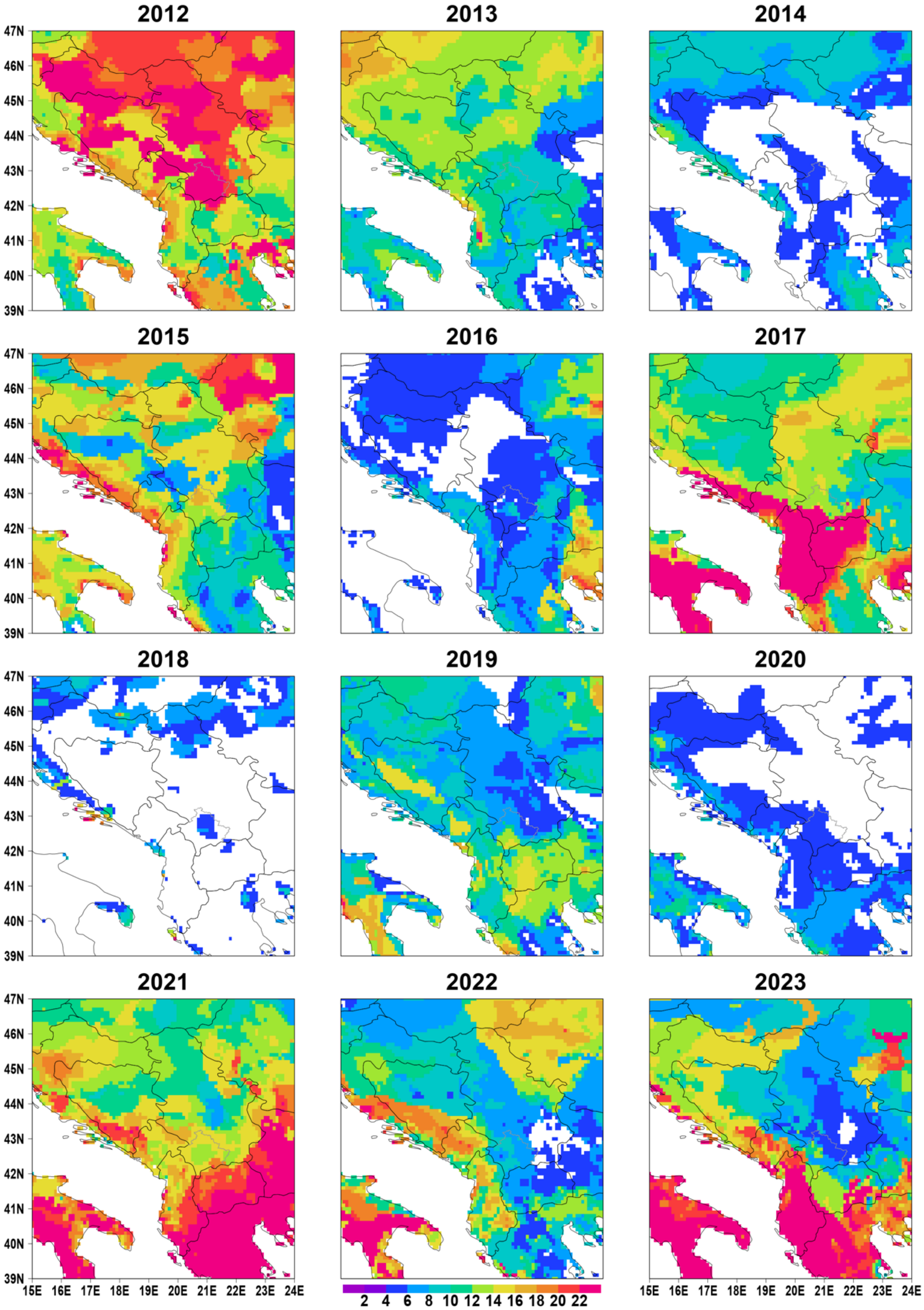
Figures 19 and **20** show the timeseries of HWMId during period 2003-2023. The temporal evolution shows a strong interannual variability between years with strong and weak HWMId. Furthermore, strong or weak HWMIds are strongly spatially correlated within the same year. Sometimes strong HWMIds are correlated interannually like for example in periods 2011-2013 and 2021-2023. In particular the last period between 2021 and 2023 is characterized by strong HWMId over the near-coastal areas in the Southern Adriatic Sea and the southern parts the Western Balkans area.

Figure 19. Intensity of HWMID in each summer season during period 2000 – 2011.



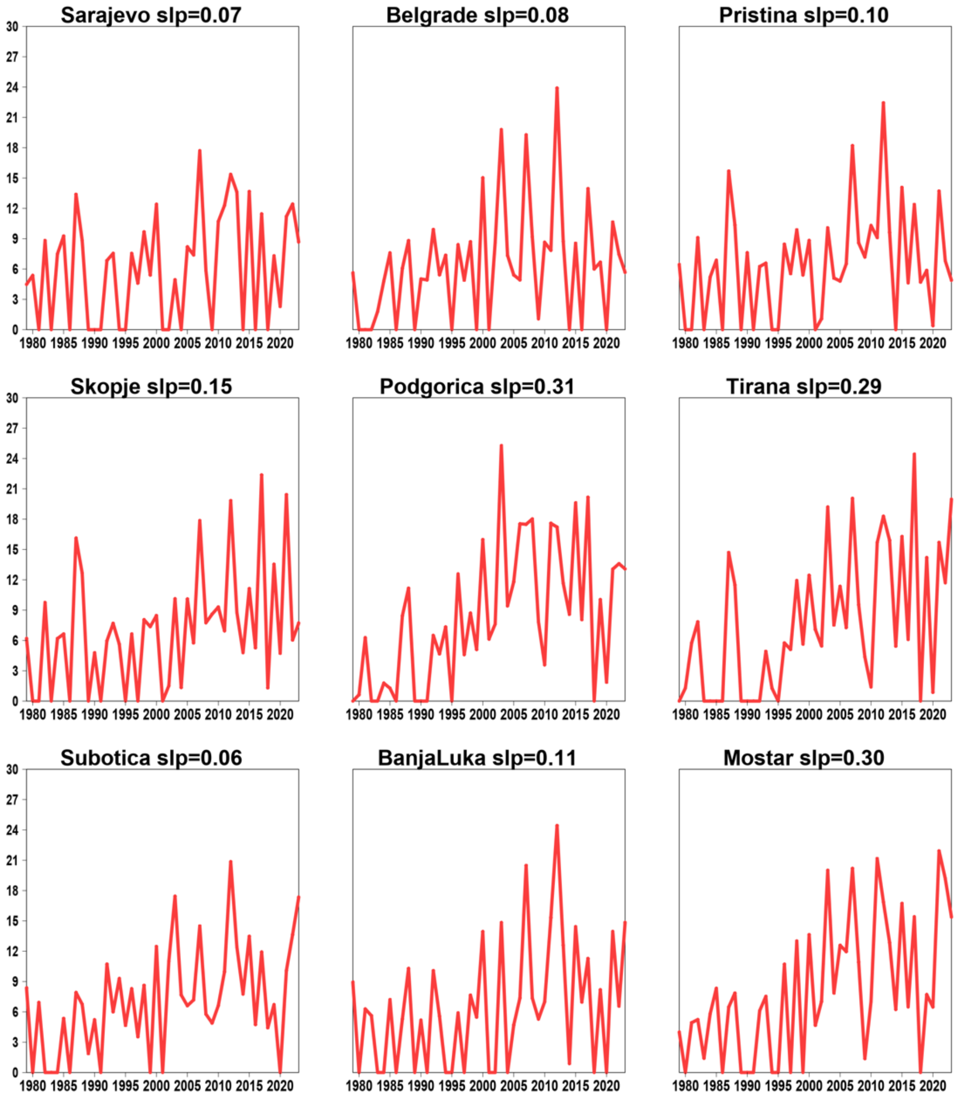
Source: JRC.

Figure 20. Intensity of HWMID in each summer season during period 2012 – 2023.



Source: JRC.

Figure 21. HWMID in the selected cities: a) Sarajevo, b) Belgrade, c) Pristina, e) Podgorica, f) Tirana, g) Skopje, h) Subotica, i) Banja Luka and g) Mostar. Linear slopes are shown in the top of each panel. All slopes are statistically significant.



Source: JRC.

The change of HWMId in the most populated areas over the Western Balkans is evaluated at the nine selected cities (Sarajevo, Belgrade, Pristina, Podgorica, Tirana and Skopje, Subotica, Banja Luka and Mostar) and trends are estimated by the Sen-Kendall method (Sen, 1968) and the statistical significance of 0.05 is set by the two-sided Mann-Kendall test (Mann, 1945). The frequency and intensity of HWDMId increase in all selected cities (**Figure 21**). The increase is, however, about three times more pronounced in the southern part of the Western Balkans (*e.g.* Podgorica, Tirana) with respect to the Northern part (*e.g.* Sarajevo, Belgrade). The more intense increase of HWMId over the southern part of Western Balkans might be attributed to the stronger influence of Mediterranean climatic conditions during summer, while the northern part may be more influenced by continental summer conditions with higher weather variability during summer. This hypothesis should be confirmed in a more detailed study.

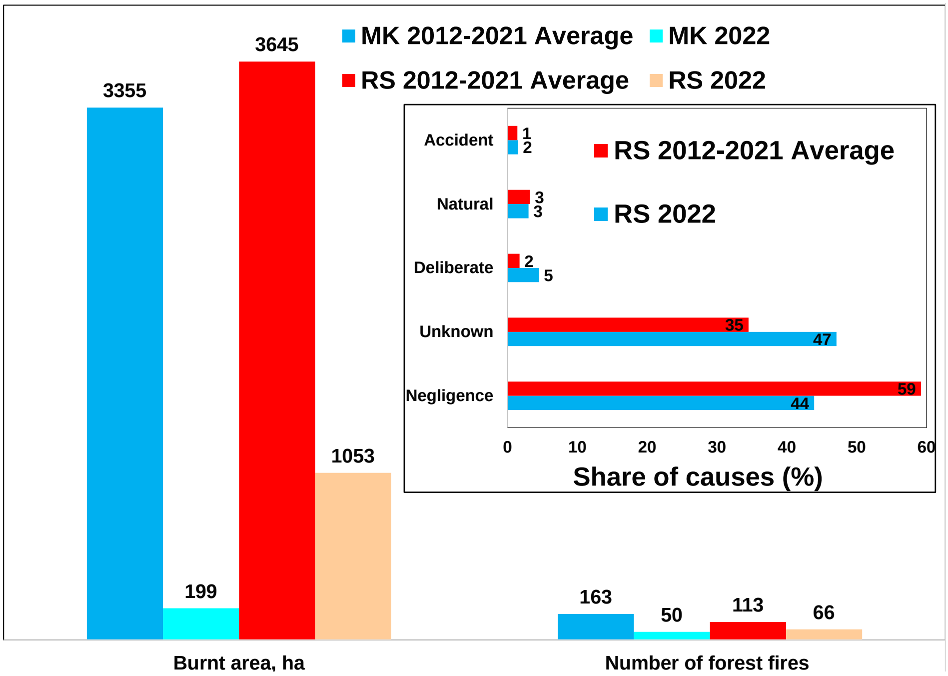
3.5 Forest fires

Climate change can lead to droughts and therefore to the potential increase of the risk for forest fires. Between 2009 and 2023 the number of forest fires in Serbia appear to decline, with the highest number of forest fires of 318 in 2012, followed by 2017 and 2018. During 2012 more than 12k ha was burned and in 2019 9000 ha. In Albania, between 2011 and 2021 226k ha was burned, with the most severe fires occurred in 2007 and 2012. In Kosovo, the highest number of fires is found for 2022 (i.e. 476), but the total burnt area was lower than found in 2007, 1.6k ha vs 11k ha respectively. The total burnt area for the period from 2000 to 2022 is almost 35k ha and the total number of forest fires is more than 2300. In Montenegro the highest number of forest fires is found for year 2020, with around 220 fires, with a total burnt area of almost 500 ha (Funk *et al.*, 2015).

Forest fires in this chapter are elaborated using the data from the report Forest fires in Europe, Middle East and North Africa 2022, provided by European Commission– Joint Research Centre (JRC, 2023). According to the data available from the national fire services country reports, in 2022 there were only 66 forest fires out of 235 total fires in Serbia and only 50 forest fires out of 441 total fires (agricultural and other) in North Macedonia.

There is a clear significant decrease in the number of forest fires as well as in the burnt area in these two countries, by comparing 2022 and the previous decade (2012-2021). In Serbia, the average burnt area size consequently decreased from 32% to 16%. Negligence was identified in the previous decade in Serbia as the main cause of forest fires with contribution of 59%, while in 2022 unidentified causes (unknown reason) was reported as the major cause with the share of 49% and the negligence decreased to 44%. Number of forest fires in the period between 2012 and 2021 in Serbia was more evenly distributed over all months of the year, with the two peaks in March with around 30% and in August with 30%. The distribution changed in 2022, with an increase in March to around 40% and decrease in August to around 20%.

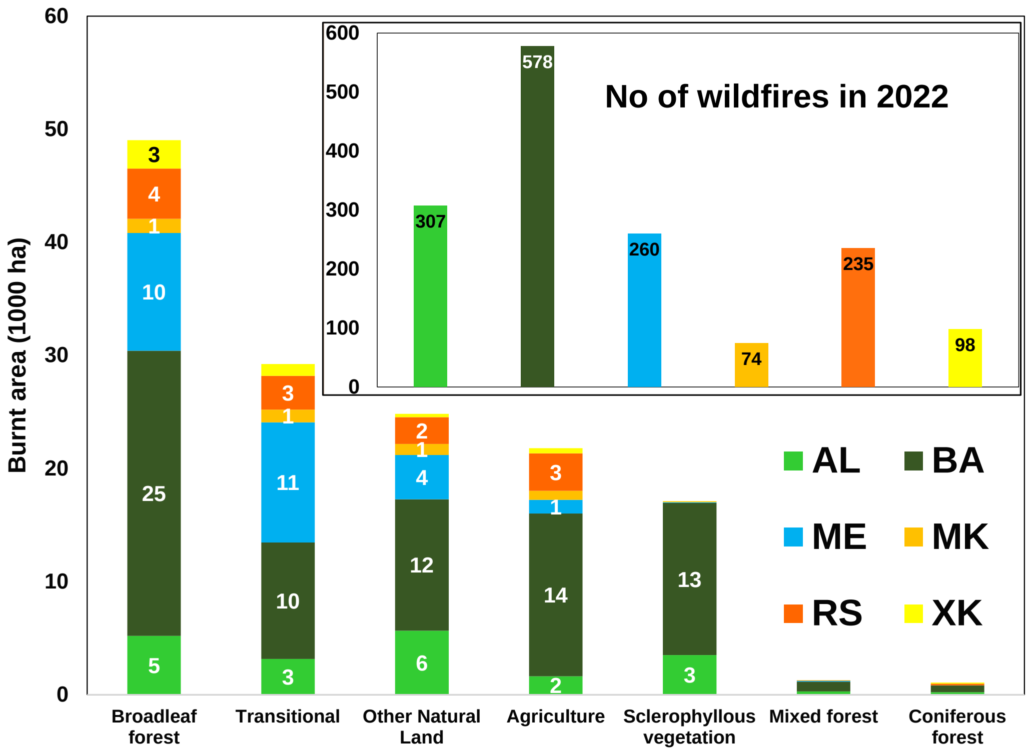
Figure 22. Magnitude and number of forest fires in North Macedonia and Serbia in 2022.



Source: JRC.

In the following presented are data also elaborated from the JRC report (JRC, 2023), which are excerpted from the European Forest Fire Information System (JRC, 2024), that has been established jointly by the European Commission services (DG ENV and JRC) and the relevant forest services and civil protection services. In the year of 2022, according to the areas estimated from the satellite imagery in EFFIS, Bosnia and Herzegovina has significantly higher absolute number of wildfires, all types including forest fires, and around double than in Albania and more than double than in Montenegro and Serbia (**Figure 23**). Also, in the same year 53% of the total burnt area within WB economies was in Bosnia and Herzegovina, while 18% in Montenegro and 14% in Albania. Forests land affected by fires was around 36% of the total 144 thousand hectares, whereby more than 95% of this forest surface is broadleaf forest. Compared to the EU27 average burnt area in 2022 (107 ha per forest fire), in WB economies average burnt area was lower (93 ha per forest fire).

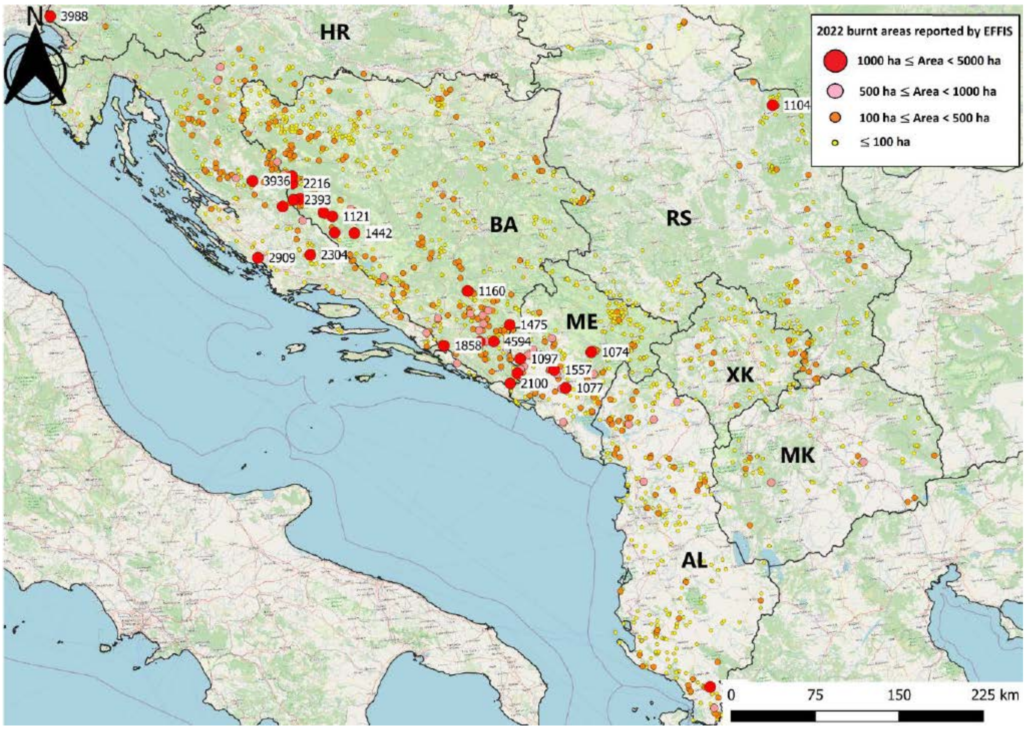
Figure 23. Distribution of overall burnt area in WB6 economies by land cover types and number of wildfires in WB6 economies in 2022.



Source: JRC.

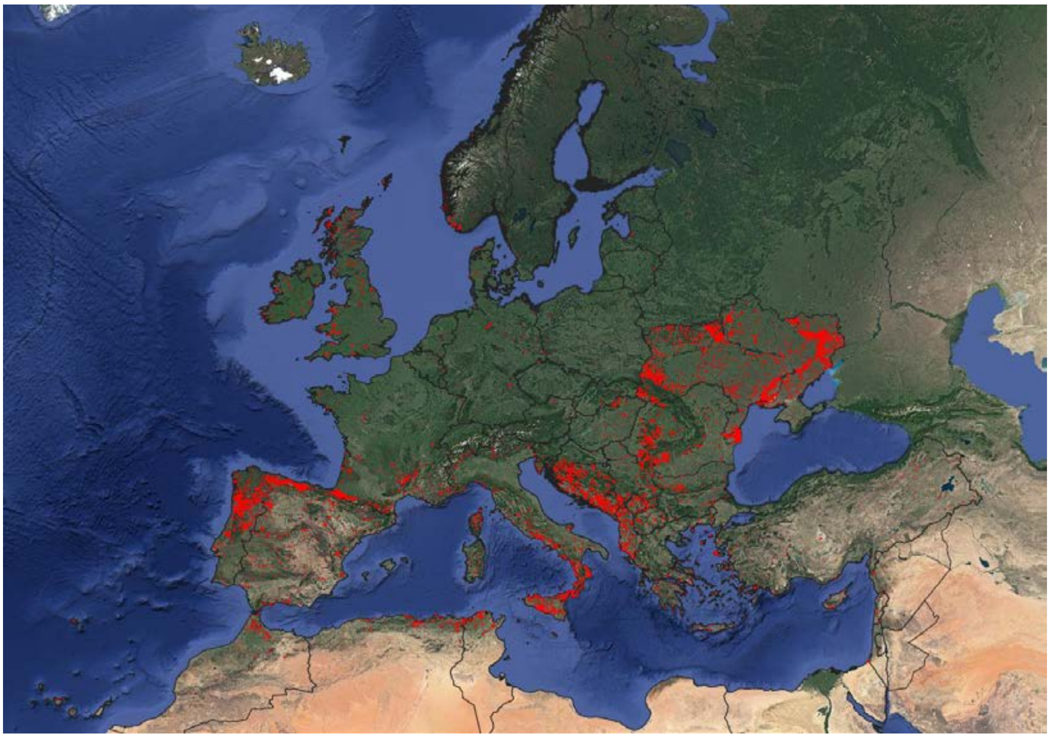
Figure 24 shows the locations of mapped fires in 2022 in the Balkans, where the magnitude of fires in WB economies could be compared along the broader region. Thereby, **Figure 25** shows burnt scars produced solely by forest fires in the same year in the entire Europe.

Figure 24. Locations of mapped fires in the Balkans in 2022.



Source: JRC.

Figure 25. Burnt scars produced by forest fires in 2022 in Europe.



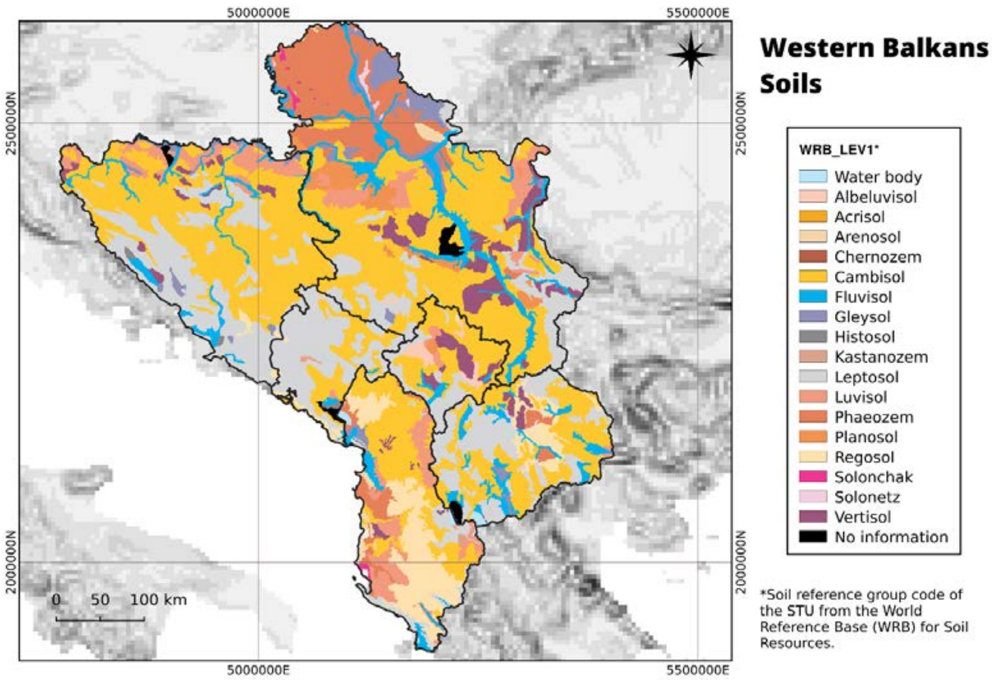
Source: JRC.

4 Status of soil

4.1 Dominant soil types and distribution

The Western Balkans region has a wide diversity of soil types, influenced by its biogeographical and climatic conditions. The large diversity is represented by Cambisols, Luvisols, Chernozems, Kastanozems, Phaeozems, Umbrisols, Fluvisols, Gleysols, Histosols, Arenosols, Calcisols, Leptosols, Regosols, Vertisols, Solonchacks, Solonetz and Anthrosols (**Figure 26**).

Figure 26. Soil map of the Western Balkans based pm the World Reference Base (WRB) for soil Resources.



Source: European Commission (2005).

Cambisols, Luvisols, Chernozems, Kastanozems, Phaeozems, Umbrisols, and Fluvisols are very fertile soils, typical for flatlands as well as uplands and are used mostly for cereals, horticulture, fruit trees, olives, vines, and forage crops providing higher yields even with minimum inputs. Leptosols, Cambisols and Regosols are mostly located in the uplands and the mountain regions. They are often covered with forests, shrublands and natural pastures. Histosols cover relatively small areas, Arenosols usually follow the coastal sand dunes, Solonchacks and Solonetz most widely found in Albania, North Macedonia, and Serbia, while Vertisols are also evident throughout the region. Gleysols have limited extent typically found in former drained wetlands and in depressions while Calcisols usually are found in the hilly areas of Albania, Montenegro and at limited extent all over the region. Large parts of them are used for the cultivation of olive groves and vines. Finally, Anthrosols cover limited areas compared to other soils but are widely distributed in the vicinity of large urban areas as the best testimony of the urban sprawl (Arias-Navarro *et al.*, 2024a).

4.2 Status and trends of Soil health in the Western Balkans

The assessment draws on the findings from the Joint Research Centre's (JRC) 2024 State of Soils in Europe Report (Arias-Navarro *et al.*, 2024). **Table 3** provides an overview of soil degradation indicators in the region, highlighting the affected areas and specific details of each indicator as identified in the assessment.

Table 3. Summary of soil degradation indicators and affected areas in Western Balkan countries

Soil degradation indicator	Affected Area	Details
Soil erosion	30% of agricultural land, 45% of total land	- average loss: 4.1 t/ha/year
Soil compaction	NA	- not sufficient research and data in the countries to estimate the area affected by soil compaction
Soil sealing	>2.8 % of total land	- Artificial areas, which includes built-up areas and unbuilt surfaced areas such as transport networks and associated areas.
Soil biodiversity change	NA	- Poorly understood and under-researched, but likely affected by land use changes and pollution
Soil carbon decline	< 5% of the total land area, about 10% for agriculture land	- Albania: Soils are relatively poor in soil organic carbon content. - Bosnia and Herzegovina: Soil organic carbon content is mostly at a middle level. - Kosovo: Soil organic carbon content ranges from 0.02% to 2.79%, varying by soil type, depth, land use, slope, and cover. - Montenegro: No data available on soil organic carbon changes. - Serbia: Most agricultural soils have 1–2% organic carbon, with a significant degradation caused by the loss of organic matter.
Nutrient Mismanagement	5.2% of agricultural land has large N surpluses due to high fertilizer use.	- Imbalance of direct nutrient inputs in agricultural systems - Fertilizer application in these countries is generally below EU averages, leading to negative N and P budgets, nutrient mining, and decreased soil fertility.
Soil pollution	Over 100 identified contaminated or potentially contaminated sites due to mining and industrial activities	- True extent unknown

Source: Arias-Navarro et al. (2024)

Around 30% of agricultural land and 45% of total land in the Western Balkans are affected by **soil erosion**, though there is limited official data and no comprehensive monitoring system in place (Zdruli *et al.*, 2022). **Soil compaction**, though not widespread across the region, is a concern in areas where heavy agricultural machinery is used, particularly on cultivated land (Vidojevic *et al.*, 2022). Data on the extent of soil compaction is scarce, but it remains a significant threat to agricultural productivity. Additionally, rapid urbanisation and infrastructure development have led to extensive **soil sealing** in the Western Balkans. Between 1990 and 2020, Albania lost approximately 50,000 ha of agricultural land to urbanisation. In Skopje, North Macedonia, soil sealing is driven by population growth, with an annual sealing rate of 0.14%. Corine Land Cover data highlights the impact of urban expansion, particularly on pastures and agricultural lands (Vidojevic *et al.*, 2022). **Soil biodiversity** in the Western Balkans remains poorly understood, with limited data on soil organisms and their contribution to soil health. Changes in land use, pollution, and degradation are likely having a negative impact on soil biodiversity across the region. Furthermore, **soil carbon stocks** are declining, particularly in agricultural lands due to poor land management practices (Vidojevic *et al.*, 2022; Zdruli *et al.*, 2022). **Nutrient mismanagement** is another growing issue, with an estimated 5.15% of agricultural land affected by an imbalance of direct nutrient inputs in agricultural systems, excluding air pollution impacts (Zdruli *et al.*, 2022).

The Western Balkans has a long history of industrial activity, and **soil pollution** remains a major issue. Key pollutants include **potentially toxic elements** such as arsenic (As), cadmium (Cd), lead (Pb), nickel (Ni), and zinc (Zn), as well as **organic contaminants** like PCBs, PAHs, and mineral oils (Arias-Navarro *et al.*, 2024b). The region has over 100 identified contaminated sites, but many more are likely polluted, with mining and industrial activities being the primary sources. Countries like Serbia have made preliminary estimates of contamination, but aggregated regional data is still lacking. Agricultural soils in the region are threatened by contamination from fertilizers and pesticides. Trace elements like cadmium and copper, often derived from fertilizers and fungicides, accumulate in the soil, posing long-term risks to soil health and food safety. Emerging contaminants such as **microplastics**, **pharmaceuticals**, and **PFASs** are under-researched but require urgent attention (Arias-Navarro *et al.*, 2024c). Based on the findings of the JRC's 2024 State of Soils in Europe Report (Arias-Navarro *et al.*, 2024), an assessment of the status and trends of the main soil threats in Western Balkan countries is summarized in **Table 4**.

Table 4. Summary of soil degradation in the Western Balkans

Soil Degradation Indicator	**AL**	**BA**		**XK**	**ME**	**MK**	**RS**
		FBiH	Rs				
Land take and soil sealing	⇅	⇅	↘	↘	↘	↘	↘
Soil pollution	⇅	⇅	↘	↘	=	↘	=
Organic carbon change	=	=	↘	↘	↘	↘	↘
Soil erosion	↘	↘	↘	↘	↘	↘	↘

Legend: Stable = Variable ⇅, Improving ↗, Deteriorating ↘.

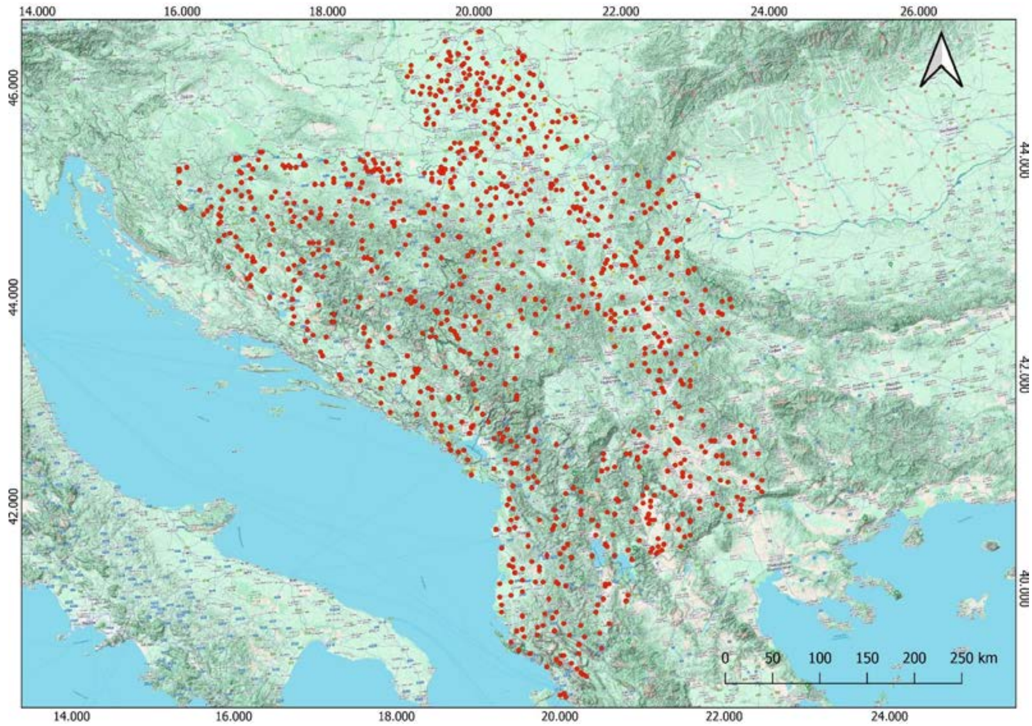
Source: JRC

4.3 Soil health monitoring and data gaps

The Western Balkans faces significant challenges in monitoring and assessing soil health due to outdated soil data and limited resources for soil monitoring systems. The lack of reliable and harmonized data complicates the development of soil protection policies and sustainable land management practices. In 2015, the European Commission, under the JRC's Enlargement and

Integration Programme, launched the first soil sampling in the Western Balkans (Albania, Bosnia and Herzegovina, North Macedonia, Montenegro, and Serbia) as part of the LUCAS survey, collecting 1,015 soil samples (**Figure 27**).

Figure 27. Distribution of LUCAS 2015 soil points in Western Balkan.



Source: Arias-Navarro et al. (2024a).

JRC is in the process of publish a new soil database derived from the LUCAS Survey together with detailed statistical and geospatial analysis of soil properties to create comprehensive maps to develop a Soil Health Dashboard for the region that integrates soil assessments and provides an overview of soil health. Soil surveys conducted under the **LUCAS Soil Module** are a step toward addressing data gaps, but the region requires comprehensive soil monitoring systems that align with EU standards.

4.4 Aligning with EU Legislation for soil protection and sustainable development in the Western Balkans

To ensure the same level of protection to soil that exists for water, the marine environment and air in the EU, the Commission has put forward a proposal for a **Soil monitoring and Resilience Directive** on 5 July 2023 (EC, 2023). The ultimate aspirational objective of the proposed directive is to have all soils in a healthy condition by 2050, in line with the EU Zero Pollution ambition. Member states, supported by the Commission, should first monitor and then assess the health of all soils in their territory, so that sustainable soil management practices and other appropriate measures can be taken by authorities and landowners. Member states will determine sampling points for monitoring, based on a common EU methodology. According to the proposed directive, member states will identify all potentially contaminated sites, and then map them in a public register. Once a contaminated site has been identified, it will be investigated, and any unacceptable risks for human health and the environment will be addressed.

The alignment of EU legislation in the Western Balkans is a pivotal step towards regional integration and sustainable development. The EU has established a Waste Framework Directive that lays down some basic waste management principles. It requires that waste be managed without endangering human health and harming the environment (i.e. water, air, soil, plants or animals) and establishes a five-step "waste hierarchy" that establishes an order of preference for managing and disposing of waste. In this framework, preventing waste and recycling are the preferred options while sending waste to landfill should be the last resort. Several key pieces of legislation specifically address soil pollution, namely the Industrial Emissions Directive for industrial activities and the Landfill Directive aims to prevent soil pollution from waste disposal.

These directives work together to prevent soil pollution, promote sustainable land use, and protect human health and the environment. By aligning with these EU directives, Western Balkans countries can strengthen their own soil protection policies and reduce the risks associated with soil contamination.

Efforts to improve soil management and protect soil health are underway, particularly in the context of the **Green Agenda for the Western Balkans**. However, robust legal frameworks, financial support, and cross-border collaboration are needed to effectively address the multiple threats to soil health. The implementation of national soil monitoring programs and harmonized soil indicators across the region is critical for achieving these goals.

Increase awareness and collaboration: Governments, researchers, and local communities must collaborate to promote soil health. Educational programs and public awareness campaigns can foster sustainable land management practices, encouraging broader participation in soil conservation efforts.

In conclusion, the soils of the Western Balkans face significant challenges that require urgent attention. By implementing these measures, the region can mitigate soil degradation, promote sustainable land management, and ensure long-term soil health for future generations.

5 Status of water

5.1 European policy review under the EU zero pollution action plan.

In October 2022, the Commission tabled a proposal to revise the Water Framework Directive, its daughter directive the Groundwater Directive and the Environmental Quality Standard[7] together with the urban wastewater treatment directive (UWWTD)[8], aligning them with the EU's policy objectives on climate action, circular economy and pollution reduction, one of the key initiatives under EU’s zero pollution action plan[9] for air, water and soil.

5.1.1 Water Framework Directive (WFD)

The European Water Framework Directive (WFD), the Environmental Quality Standards Directive (EQSD) for surface waters, and the Groundwater Directive (GWD) for groundwater, are the main legislations for the sustainable management of European inland, transitional and coastal surface waters and groundwaters[10]. The WFD aims to protect and restore, when necessary, water bodies to prevent deterioration and reach good ecological and chemical status.

According to the WFD (2000/60/EC amended by Directive 2013/39/EU)[11], the Commission shall review, at intervals of at least six years, the list of Priority Substances (PS) that pose a risk to the aquatic environment and human health. This process, named prioritisation exercise, identifies and ranks chemical substances or groups of substances based on their potential risks, which ultimately could be candidate PS to be included in the WFD. The European Commission's Joint Research Centre (JRC) has been in charge of leading the prioritisation exercises and drafting EQS dossiers for several candidate substances in collaboration with the experts nominated by each Member State (MS) and by the stakeholders.

On 26 October 2022, the European Commission adopted a proposal to revise the list of pollutants in surface water and groundwater, and some other amendments were also proposed (EC, 2022).

The 24 new candidate PS or group of substances proposed for surface waters were selected from three processes: i) prioritisation exercises; ii) Watch List (WL) program and iii) directly included because emerging substances of very high concern i.e. the per- and polyfluoroalkyl substances (PFAS). Five substances (one industrial, two pharmaceuticals, a biocide and an herbicide) were selected from those short-listed in the first prioritisation exercise but not finally proposed as PS but for which new data were available (Scoping Report, 2014). From the first WL (Carvalho *et al.*, 2015), were selected twelve substances (one pharmaceutical, three hormones, three antibiotics, and five neonicotinoids

[7] https://environment.ec.europa.eu/publications/proposal-amending-water-directives_en

[8] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52022PC0541&qid=1668778087100

[9] https://environment.ec.europa.eu/strategy/zero-pollution-action-plan_en

[10] European Commission website, Water Framework Directive: Setting out rules to halt deterioration in the status of EU water bodies and achieve good status for Europe’s rivers, lakes and groundwater. Available on-line at: https://environment.ec.europa.eu/topics/water/water-framework-directive_en

[11] Article 16(4) ‘The Commission shall review the adopted list of priority substances at the latest four years after the date of entry into force of this Directive and at least every six years thereafter, and come forward with proposals as appropriate.’ Directive 2013/39/EU of the European Parliament and of the Council of 12 August 2013 amending Directives 2000/60/EC and 2008/105/EC as regards priority substances in the field of water policy. ELI: http://data.europa.eu/eli/dir/2013/39/oj

insecticides). From the second prioritisation exercise (Carvalho *et al.*, 2016; Lettieri *et al.*, 2016), were included six substances (four pyrethroid pesticides, an herbicide and a metal). On the other hand, the selection of the 24 PFAS were included because of the increasing public concern about these substances, leading to consider them as a group (SWD, 2020). Additionally, the EQS for 16 of the existing PS were revised in order to update the EQS value based on the latest scientific and technical knowledge concerning risks to, or *via*, the aquatic environment, and in this manner, to ensure an appropriate level of protection (EC, 2022).

For groundwater, seven new candidate PS or group of substances were included in the Annex I of the proposal directive, including two pharmaceuticals and the sum of them, the group of 24 PFAS and the Non-relevant metabolites of pesticides (nrMs) (EC, 2022). This proposal is still under discussion by the European Parliament and the Council.

5.2 Urban Wastewater Treatment Directive (UWWTD)

The ongoing review of the UWWTD aims to improving the EU's water management and urban wastewater treatment standards to better protect public health and the environment. Based on the current proposal[12], by 2035, urban wastewater should undergo secondary treatment (*i.e.*, the removal of biodegradable organic matter) before it is discharged into the environment, in all agglomerations of the size of 1,000 population equivalent (p.e., standard measuring unit describing the average pollution released by one person per day) or more.

By 2039, tertiary treatment (i.e. the removal of nitrogen and phosphorus) should be applied in all wastewater treatment plants covering 150,000 p.e. and above, and by 2045 in those covering 10,000 p.e. and above. An additional treatment removing a broad spectrum of micro-pollutants ('quaternary treatment') will be mandatory for all plants over 150,000 p.e. (and over 10,000 p.e. based on a risk assessment) by 2045.

Microbiological parameters (*e.g.* viruses and emerging pathogens), chemical pollutants, including so-called "forever chemicals" (per- and polyfluoroalkyl substances, PFAS), microplastics and antimicrobial resistance will be strictly monitored by the Member States.

Furthermore, the law introduces the extended producer responsibility (EPR) for medicinal products for human use and cosmetic products, to cover the costs of quaternary treatment (to remove micro-pollutants from urban wastewater). At least 80% of the costs should be covered by producers, complemented by national financing. EU countries will be required to promote the reuse of treated wastewater from all urban wastewater treatment plants where appropriate, especially in water-stressed areas. Such integrated management plans should be reviewed at least every six years, in line with the Water Framework Directive.

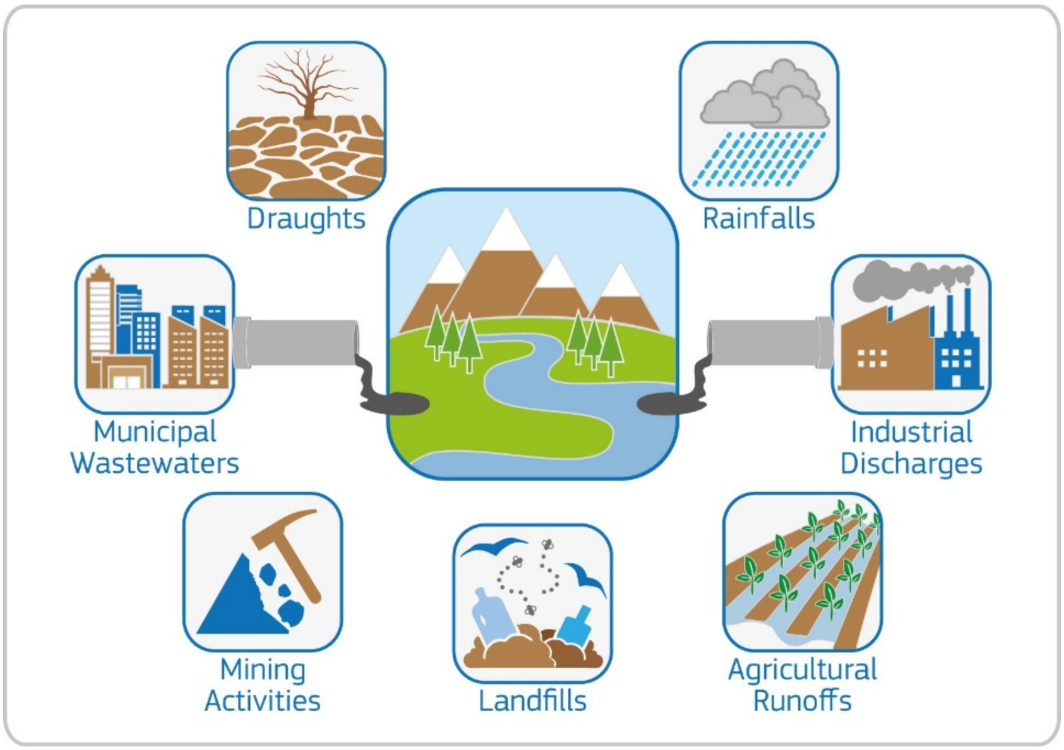
[12] The review UWWTD has been approved by the EU parliament and Council on 10 April 2024. Before becoming EU law, the proposal will need to go through the European Parliament and be approved by Member States in the Council. It will then be published in the EU Official Journal and come into force 20 days later. Member States will have 30 months to transpose the recast Directive into their national legislation.

5.3 The major pressures on surface and groundwaters in WB region

Surface and groundwaters in WB economies are under the impact of multiple pressures, mainly of anthropogenic origin. Common pressures outlined in water management strategies of countries in the region are municipal wastewaters, industrial discharges, agricultural runoff, mining activities and landfills (**Figure 28**).

Particular attention should be attributed to combined (cumulative) effect of changes in climate and hydromorphological degradation. Generally unequal precipitation over the year, with distinguished periods with water scarcity combined with different waterworks, largely contribute to changes (mainly over fouling and succession) of aquatic ecosystems.

Figure 28. The major pressures on surface and groundwaters in WB countries (figure has been designed using resources from Flaticon.com).



Source: JRC.

5.3.1 Impact of untreated wastewaters on surface and groundwaters

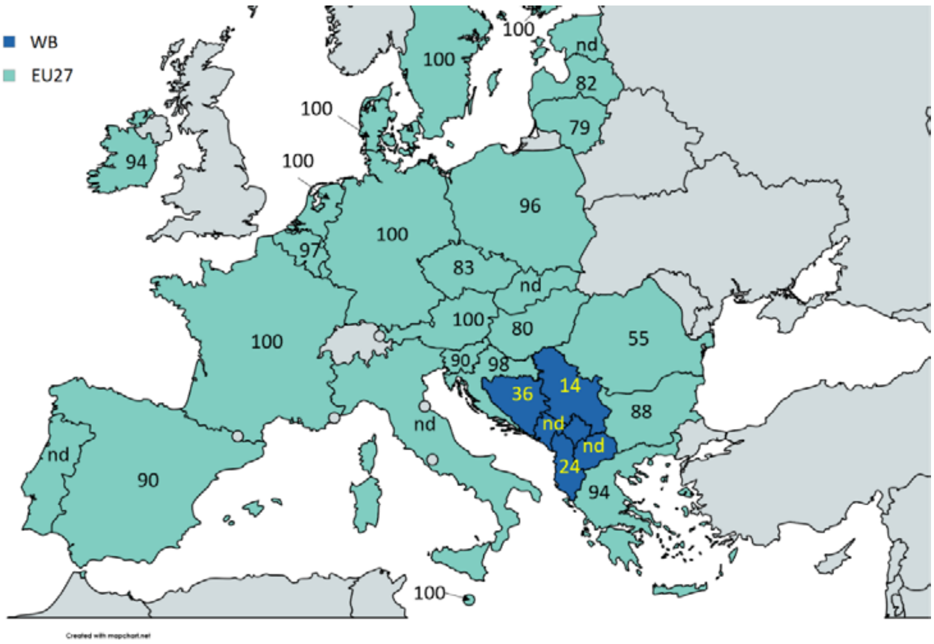
The current wastewater treatment situation in the WB countries is characterised by infrastructural challenges and underdevelopment. The national water management strategies of all WB countries are focused on substantial reforms and investments to meet the standards of the EU's Urban Wastewater Treatment Directive UWWTD (EC 91/271/EEC). This involves improving the operational capacity of existing wastewater treatment plants (WWTPs), ensuring their maintenance, and improving the monitoring of water quality. **Table 5** provides an overview of the data on wastewater treatment in the WB countries, while **Figure 29** provides an overview of the percentage of the population connected to wastewater treatment in the WB countries.

Table 5. Overview of the data on wastewater (WW) treatment in WB countries

	Percentage of WW treated	Year	Source
Albania	12% of total WW generated	2017	Government of Albania (2020)
North Macedonia	27.8% of total WW discharged	2023	Republic of North Macedonia State Statistical Office (2023)[13]
Bosnia and Herzegovina	41.6% of total discharged WW	2022	Institute for Statistics of Federation of Bosnia and Herzegovina (2022)[14] Institute of Statistics of Republic of Srpska (2022)[15]***
Montenegro	16.4 of total generated WW	2013	Government of Montenegro (2017)
Serbia	10.8 of total discharged WW	2023	Statistical Office of Republic of Serbia (2023)[16]
Kosovo	<1% of generated WW	2020	The World Bank (2018)

Source: see the end right table column.

Figure 29. Percentage of population connected to wastewater treatment in WB and EU-27 countries.



Source: United Nations Statistics Division[17] (2019).

[13] https://www.stat.gov.mk/Default_en.aspx

[14] https://fzs.ba/

[15] https://www.rzs.rs.ba/

[16] https://www.stat.gov.rs/en-US/

[17] https://unstats.un.org/unsd/envstats/Questionnaires/2022/Tables/Population%20connected%20to%20wastewater%20treatment.xlsx

Box 7. Mitigation measures

The mitigation of pollution caused by wastewater is addressed in the water management strategies of the WB countries. The following mitigation measures are addressed by most of the WB countries:

Investment in Wastewater Infrastructure: countries are planning significant investments in wastewater infrastructure, including sewerage systems and WWTPs. The projected investment dynamics indicate a steady increase over the years to enhance wastewater systems and treatment facilities.

Regulatory Framework: the strategies include compliance with EU directives on water quality and wastewater management.

Pollution Control: the strategies highlight measures to prevent and control water pollution from industrial sources. These include the maintenance of a national register of pollution sources and the implementation of appropriate pre-treatment processes for industrial wastewater prior to discharge.

Funding and Financial Strategies: countries intend to utilise EU funding and other sources to support the construction and improvement of wastewater infrastructure. These funds will be used specifically for environmental protection projects, including the development of wastewater and water supply networks in settlements.

5.3.2 Contaminants of emerging concern in WB waters

Monitoring of chemical pollution in WB countries still represents a significant challenge. There is a significant information gap related to the lack of monitoring data, and data related to emissions of priority and priority hazardous substances. While in some countries the EU WFD compliant programs for monitoring chemical pollution are limited to physicochemical water quality (such as Albania), other countries monitor priority substances as well (Serbia, Montenegro, Bosnia and Herzegovina) (Belis *et al.*, 2022). Monitoring of the contaminants of emerging concerns (CECs), such as pharmaceuticals, antibiotics, pesticides, endocrine disruptors (including pathogens and antimicrobial resistance genes), is not included in routine monitoring practices in WB countries. However, data on these contaminants are available from scientific literature or special datasets from national and international projects. Considering the frequency of data collection, spatial coverage of analysed sites, and the period when the samples were collected, it must be indicated that data on CECs for WB are scarce and that updating the information on the presence of CECs in WB surface and groundwater is more than urgent.

The Joint Danube Surveys (JDSs) provide data on the majority of contaminants addressed in previous chapter. However, the limitation of the JDS dataset in context of WB is that it covers only the Danube River and its major tributaries in the region. JDS4 dataset (from 2019) is now 5 years old. JDS5 will take place next year (2025) and will provide more reliable information on this matter. IPA projects, such as the project "**Strengthening the Capacities for Implementation of the Water Framework Directive in Montenegro"** significantly contribute to filling of the data gaps. The results generated within international research projects (such as the FP7 project "Solutions" (2013-2018) also provide significant data on CECs. In some cases, these projects represent the only available data on this matter for certain tributaries, such as the Bosna River in Bosnia and Herzegovina (Toušová *et al.*, 2019). However, it should be noted that for some countries, these data are outdated (i.e. for Bosnia and Herzegovina the latest data are from 2012). On the other hand, for some countries, data on chemical CECs are completely missing, as is the case for Albania.

A valuable source of information is the IPCHEM - the Information Platform for Chemical Monitoring is the European Commission's reference access point for searching, accessing and retrieving chemical occurrence data collected and managed in Europe. Most of the data relevant for WB is addressed through the NORMAN Database System, developed by the NORMAN network (Network of Reference Laboratories, Research Centres, and Related Organisations for Monitoring of Emerging Environmental Substances).

Groundwaters - as indicated in the previous report (Belis *et al.*, 2022), the development of WFD-compliant monitoring of groundwater in the WB is an ongoing process. Data from scientific studies are scarce and mostly limited to the assessment of heavy metal concentrations. Within JDS4, only one groundwater site in Serbia was assessed in parallel with an adjacent site at the Danube River (Novi Sad). Results indicated that diclofenac and carbamazepine were present in groundwater, while the concentration of the metabolite carbamazepine-10,11-dihydro-10,11-dihydroxy was the highest among the investigated sites, at a concentration of 0.025 µg/L. None of the detected pesticide concentrations in groundwater, neither for individual substances nor for their sum, exceeded the quality standards set under the EU Groundwater and EU Drinking Water directives (EC 2014/80/EU, EC 2020/2184).

5.4 Chemical contaminants

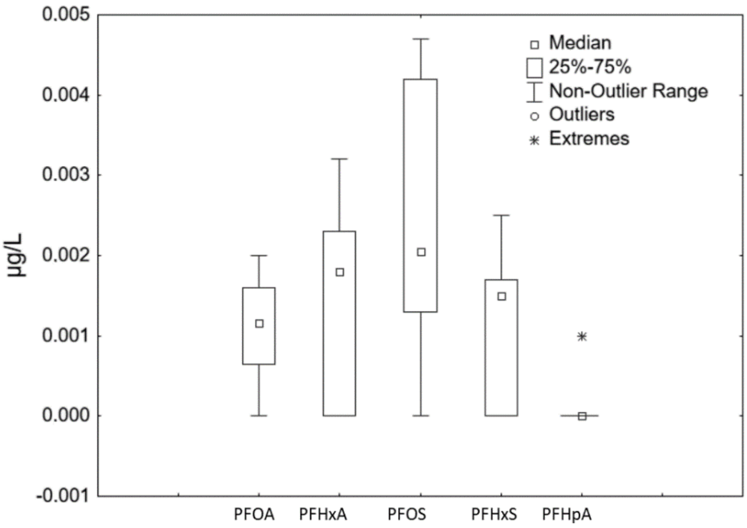
5.4.1 Per- and polyfluoroalkyl substances (PFAS)

PFAS are a group of more than 4,700 substances, they are widely used (they are stable under intense heat, used as surfactants, water and grease repellents etc.) and they are highly persistent in the environment, longer than any other man-made substance (ICPDR, 2019, Niegowska *et al.*, 2021a). Having in mind that PFAS are considered high-priority hazardous substances due to their environmental persistence, bioconcentration, bioaccumulation and biomagnification in aquatic and terrestrial food chains, they are regulated under several frameworks aimed at protecting environmental and human health.

The Serbian national regulation lays down the Environmental Quality Standards (EQS) for priority and hazardous priority substances including perfluorooctane sulfonate (**PFOS)** (Official Gazzete of the Republic of Serbia 24/2014). Still, PFOS are not analysed within national monitoring program. Data on PFAS for Serbia are available from special research programs such as JDS4. Five perfluoroalkyl substances (perfluorooctanoic acid (PFOA), perfluorohexanoic acid (PFHxA), PFOS, perfluorohexanesulfonate (PFHxS) and perfluoroheptanoic acid (PFHpA)) were detected in surface waters (**Figure 30**). PFOS were detected in the highest concentrations of 0.0047 µg/L. PFHpA were detected only at two sampling sites in the area of Belgrade. PFOA, PFHxA, PFOS were detectable in groundwaters in concentrations 0.0014, 0.0027 and 0.0016 µg/L respectively. Only PFHxA was detactable in wastewaters (0.0023 µg/L).

The study of Saxena *et al.* (2023) employs the NORMAN database to evaluate the occurrence of PFAS in various countries along the Danube River Basin. For Serbia, the study summarizes the data available for surface waters in period 2010 to 2020 and indicates that there is no significant temporal variation in PFAS concentrations in indicated period. The predominant PFAS congener found in surface water was PFHxA, unlike other Danubian countries where PFOA was more common. There is no significant detection of PFAS in Serbian sediments, and the data for biota is insufficient to predict temporal trends. There is no available data for other WB countries.

Figure 30: Concentrations of PFAS measured in groundwater (one site), surface waters (Danube and the major tributaries – 8 sites) and WW (one site) in Serbia within the JDS4 (2019).



Source: NORMAN EMPODAT Database - National and Kapodistrian University of Athens.

5.4.2 Pharmaceuticals

Data from a recent study (Grujić-Letić *et al.*, 2023) showed that traces of **ibuprofen** were detected in most samples collected in 2020 from 10 locations along the Danube in Novi Sad (**Serbia**) but in concentrations that represents low risk for aquatic biota (based on risk assessment proposed in Fernandez *et al.* (2010). This aligns with the results of JDS4 from 2019 where **ibuprofen, diclofenac and carbamazepine** were detectable in Serbian wastewaters but also in surface waters of the Danube and its main tributaries in maximum concentrations 0.086, 0.023 and 0.029 µg/L respectively (**Table 6**).

Antibiotic **azithromycin** was detected in maximum concentration 0.0032 µg/L, Maximum concentration of **erythromycin** and **clarithromycin** in surface waters was 0.007 µg/L while their concentrations in effluents of WW reached 0.76 and 1 µg/L respectively. In **Montenegro** (2018 data), **carbamazepine** was detectable in the river Breznica, wastewaters, Skadar Lake and coastal waters (up to 0.0054 µg/L). The study of Stipaničev *et al.* (2017) provides comprehensive data on 463 organic contaminants in rivers of **North Macedonia**. The highest total concentrations of drugs were measured in the Vardar downstream from Skopje and in the Kriva River (1.54 µg/L and 1.06 µg/L respectively). Antibiotics were mainly represented by **sulfamethoxazole** and c**iprofloxacin**, analgesic by **ibuprofen**, and cardiovascular medicals by verapamil and strophanthidin. **Carbamazepine** was detectable in the Kriva, Bregalnica and Vardar rivers. The study of Toušová *et al.* (2017) was performed at 10 locations in **Bosnia and Herzegovina** along the Bosna River in 2012. **Sulfamethoxazole, trimethoprim and clarithromycin** reached the greatest concentrations ranging from a few to hundreds of ng/L. **Diclofenac** was detected at 8 sampling sites at concentrations ranging from 10 to 82 ng/ L.

Table 6. Data on concentrations of pharmaceuticals measured in surface waters in Serbia, Montenegro, North Macedonia and Bosnia and Herzegovina

WB economy	Pharmaceutical	Maximum concentration (µg/L)	Site	Source
Serbia	ibuprofen	0.086	Varvarin, Velika Morava	NORMAN database
	diclofenac	0.023	Tisa mouth, Tisa	
	carbamazepine	0.029	Tisa mouth, Tisa	
	azithromycin	0.003	Downstream Pančevo, Danube	
	erythromycin	0.007	Velika Morava mouth	
	clarithromycin	0.007	Varvarin, Velika Morava	
Montenegro	carbamazepine	0.004	Downstream Pljevlja, Breznica	NORMAN database
North Macedonia	sulfamethoxazole	0.014	Kežovica, Bregalnica	Stipaničev *et al.* (2017)
	ciproflaxacin	0.233	Vardar	
	ibuprofen	0.201	Vardar	
	carbamazepine	0.007	Kriva Reka	
Bosnia and Herzegovina	carbamazepine	0.042	Bosna River	Toušová *et al.* (2017)

Source: see end right table column.

5.4.3 Endocrine disrupting chemicals

In the study by Ćelić *et al.* (2020), a survey on the occurrence of selected Endocrine Disrupting Chemicals (EDCs) was conducted, covering industrial chemicals (**bisphenol A - BPA),** natural estrogens **(estrone - E1, 17β-estradiol - E2)**, synthetic estrogens **(17α-ethynylestradiol - EE2)**, and their conjugates at 30 sites along the Danube River and its tributaries in the north of **Serbia**. Out of the 13 EDCs analysed, E1 was the most ubiquitous in wastewaters and the corresponding surface water impacted sites, while BPA was the most frequently detected substance in industrial wastewaters and freshwater sites. The calculated risk quotients for each of the compounds detected in wastewater samples showed high risk for the estrogens E2 and E1, while BPA presented high risks in only one sampling site. Within the JDS4, E2 was detected only at the site Jamena (Sava River), while E1 and BPA were detectable in both the Danube and its tributaries (0.0012 µg/L and 0.12. µg/L respectively – **Table 7**).

Table 7. Concentrations of BPA and E1 measured in Danube and its tributaries in Serbia within the JDS4

River	Danube	Tisa	Sava	Velika Morava
BPA (µg/L)	0-0.025	0.012	0.014-0.12	0.0068-0.0073
E1 (µg/L)	0-0.0003	0.0002	0-0.0004	0.0001-0.0012

Source: NORMAN database.

In **Montenegro** (2018 data)**, BPA** was detectable in Breznica (3.76 µg/L), Skadar Lake (7.98 µg/L), and coastal waters (0.51 µg/L). The study by Stipaničev *et al.* (2017) showed that xenoestrogens such as p-nonylphenol, 4-octylphenol, and BPA were much more abundant in all studied rivers in **North Macedonia** than natural hormones such as estrone, progesterone, and testosterone. The study by Toušová *et al.* (2017) showed that **E1, E2,** and **E3** were detected at all sites on the **Bosna River** in a range of 0.02 to 5.8 ng/L. Concentrations of E3 at some sites were 10-fold greater than those measured in the Danube and Sava.

5.4.4 Pesticides

According to JDS4 data, among the group of pesticides following were detectable in both the Danube and its tributaries: **acetamiprid** (up to 0.0017 µg/L), **imidacloprid** (up to 0.019 µg/L)**, nicosulfuron** (up to 0.32 µg/L), and **thiamethoxam** (up to 0.005 µg/L). **Imidacloprid** surpassed the proposed Predicted No-Effect Concentration (PNEC) value in the tributary Tisa (0.019 µg/L). **Bifenthrin, esfenvalerate**, and **permethrin** were below the limit of detection (LOD), while **clothianidin** was detected only at one site (0.001 µg/L). In **Montenegro**, only thiamethoxam was detectable, and it was found only in wastewaters (0.0021 µg/L).

5.4.5 Contaminants from mining industry

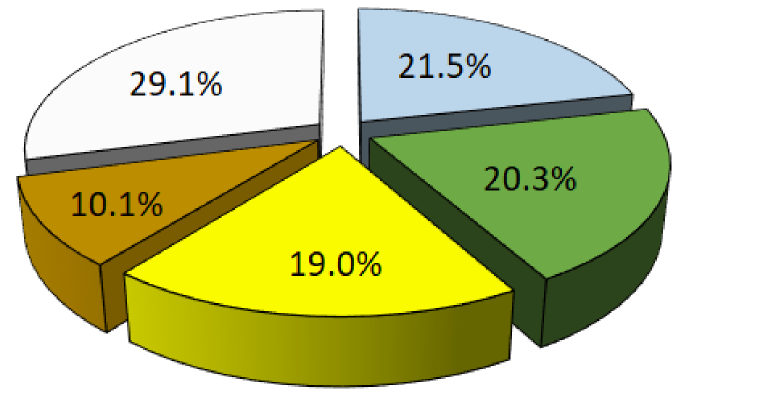
An emerging threat to the environment in the WB region is the waste generated by mining activities. In total, there are 1,650 waste disposal sites in the WB region of which 1,540 (93%) belong to mining waste landfills, 67 (4%) to processing waste landfills, and 43 (2%) to metallurgical waste landfills (Šajn *et al.*, 2022). The study by Osenyeng *et al.* (2023) was conducted in the Bor copper mining region of **Eastern Serbia**, where wastewaters from the Bor metallurgical/smelting facilities have caused serious copper (Cu) and arsenic (As) contamination of the Timok River system. The industrial activity of the Artana mine (**Kosovo**) has been identified as the main cause of pollution in the Marec River waters and the surrounding habitat (Sadiku *et al.*, 2021). In recent years, there has been increasing interest in the exploitation of the Jadar Valley lithium/borate deposit in **West Serbia**. The investigation phase of this project has had a harmful impact due to the leakage of toxic mine water containing high levels of boron, arsenic, and lithium, resulting in soil and water pollution in agricultural areas (Đorđević *et al.*, 2024).

5.5 Faecal contamination of surface and groundwaters

Given the low percentage of wastewater treatment in WB countries, additional attention should be given to faecal contamination of surface and groundwater not only due to the i**ntroduction of pathogens into the environment** but also because of the potential spread of **antimicrobial resistance**. In WB region, only **Serbia and Bosnia and Herzegovina** use faecal indicator bacteria (*Escherichia coli* and intestinal enterococci) in the assessment of ecological status/potential. Based on the data of Serbian Environmental Protection Agency (**Figure 31**), at 29% of investigated profiles in 2022, water quality assessed by *E. coli* numbers reached class III or higher (using classification system from **Table 8**) which equivalents to critical pollution according to Kirschner *et al.* (2009).

JDS data confirmed that **Serbian stretch of the Danube** is the most affected by pollution related to wastewaters with evident impact of the major settlements situated at the river banks (Kirschner *et al.*, 2017, 2024). The tributaries in this section differed in water quality, while Drava and Velika Morava were critically polluted, Sava and Tisa were moderately polluted.

Figure 31. Water quality at national monitoring sites in Serbia in 2022 based on the concentrations of faecal coliforms.



Source: Serbian Environmental Protection Agency.

The situation is not much different in other parts of the region. The data from 2019 indicated that most of the sites assessed in frame of national surveillance monitoring in **Bosnia and Herzegovina** were under the pressure of faecal pollution (**Public Institution "Waters of Srpska" Bijeljina, 2019).** According to the **Kosovo** Water Security Outlook report (World Bank, 2018) the main rivers downstream of big municipalities and industry, especially Sitnica downstream of Priština are so polluted that the water cannot be used as a source of water supply, and in some places, not even for irrigation. This is also indicated in the study of Gashi *et al.* (2015) for the river Sitnica. The study of Krueziu *et al.* (2024) indicated the presence of faecal indicator bacteria in four artisanal wells out of 10 tested at the territory of Prizren confirming pollution pressure on underground waters as well.

Table 8. Microbiological indicators of water quality used for the assessment of ecological status

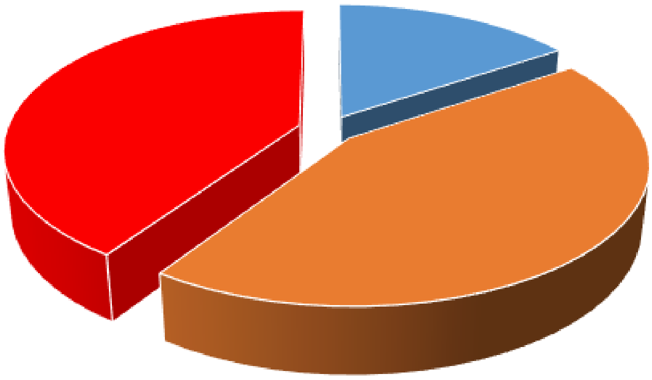
Indicator group	Values marks border between the classes			
	I-II	II-III	III-IV	IV-V
Total coliforms/100 mL	5000	10,000	100,000	1,000,000
Faecal coliforms (*Escherichia. coli*)/100 mL	100	1,000	10,000	100,000
Intestinal enterococci /100 mL	40	400	4,000	40,000

Source: Official Gazette of the Republic of Serbia 74/2011.

Our previous study (Kolarević *et al.*, 2020) indicated that based on monitoring data available for the period 2009-2018 for 37 sites (total of 1,599 samples processed) overall quality of surface water in **Montenegro** is quite good considering that above 80% of all samples had bathing water quality based on the Montenegrin and EU legislation. However, there are evidences on the faecal contamination on groundwaters. Based on the annual report for 2023 (Institute of Hydrometeorology and Seismology of Montenegro, 2023), microbiological parameters of groundwater revealed significant contamination levels in high portion of the samples. Out of 32 investigated sites, faecal indicator bacteria were present at 13 in concentrations above 100/100 mL (**Figure 32**). Data from 2024 indicates that coastal bathing areas in Montenegro are generally of good quality. The results of the sea water quality analysis for 114 locations, conducted by the Institute of Marine Biology from July 1st to July 8th this year, showed that the sea water was of excellent quality at 80.6% of the locations, good quality at 13.2% of the locations, satisfactory quality at 4.4% of the locations, while at 1.8% of the locations the water was of poor quality (data source https://www.morskodobro.me/).

For **Albania**, only scientific data are available, indicating presence of faecal contamination of both surface and ground waters. The data of study Bakalli *et al.* (2019) performed on 30 wells in area of Tirana showed that 100% of water wells were contaminated by the presence of *E. coli*. The study of Hamzaraj *et al.* (2012; 2023) indicated presence of faecal contamination in inhabited areas in the river catchment of Mat River and Vjosa River.

Figure 32. Classification of the groundwater sites according to samples taken in Montenegro in 2023 based on the presence/concentration of faecal coliforms



Source: Annual report for 2023 of the Institute of Hydrometeorology and Seismology of Montenegro.

In 2023, Albania monitored 119 bathing waters of which 41.2% were rated as excellent, 37% as good, 6.7% as sufficient, and 15.1% as poor (EEA, 2024). To best of our knowledge there was no available microbiological data for **North Macedonia.**

5.6 Antimicrobial resistance

Antimicrobial resistance (AMR) defines the ability of microorganisms to withstand the effects of antibiotics and other compounds (Sanseverino *et al.*, 2018). AMR results of the overuse or the misuse of antimicrobials, in particular antibiotics in human or veterinary medicine. It spreads in the environment mainly through agricultural practice and release from Wastewater Treatment Plants (WWTPs). Antibiotics exert a selective pressure on bacteria even at low concentrations. Antibiotic residues (from pharmaceutical industry, households, hospitals and farms), antibiotic-resistant bacteria (ARB) but also free antibiotic resistance genes (ARGs) released by dead cells are collected at WWTPs where they are degraded and removed. Although wastewater treatment process decreases up to 99% counts of bacteria, some ARB could be released with ARGs and antibiotic residues in effluents that further discharge into receiving waters (mainly rivers and lakes). ARB and ARGs spread among environmental bacteria generates a potential threat to human and animal health with the increase of antibiotic resistance. Aquatic environments are thus considered important reservoirs of ARB and ARGs and potentially promote AMR.

In 2019, the World Health Organization (WHO) declared AMR as one of the top ten global public health threats (Antimicrobial Resistance Collaborators, 2022). In 2022, the European Commission identified AMR as one of the top three priority health threats and the Council also made recommendations to fight against AMR in a «One Health» approach (Council of the European Union, 2023). Food and Agriculture Organization (FAO) of the United Nations and World Organization for Animal Health (WOAH) highlighted the environmental contribution to AMR, particularly the role of polluted waterbodies (FAO, 2024; WOAH, 2024).

In Europe, protection and management of freshwater and coastal areas are driven by the European Water Framework Directive (WFD) (EC, 2000). The Watch List (WL) monitoring program, which is part of the WFD, aims at implementing monitoring data on potential pollutants for which few data or data of insufficient quality are available and therefore a risk assessment cannot be performed (Article 8b of EU, 2013/39). Other antimicrobial substances such as fungicides, antibacterial agents *e.g.* biocides can contribute to the spread of AMR (Sanseverino *et al.*, 2018; Niegowska *et al.*, 2021b), Together with antibiotics, antifungal substances (such as azole compounds used as pharmaceuticals and pesticides) were included in the fourth WL (Gomez Cortes *et al.*, 2022; EU, 2022/1307). Antibiotics, ARB and ARGs concentration monitoring in aquatic environments, and the development of risk assessment methodologies (to evaluate their possible toxicity) (EC, 2017; EC, 2019) will contribute to better understand AMR spread.

5.6.1 Antimicrobial resistance in surface waters in WB

As reported in the 1st report by Belis *et al.* (2022), studies on antimicrobial resistance (AMR) were focused mainly on large rivers (surface waters) (Kolarević *et al.*, 2020). Serbia was the only country among the six WB countries, involved in the Joint Danube Survey (JDS). A few point studies also focused on smaller rivers, lakes, springs in Serbia, Montenegro and Bosnia and Herzegovina. Antibiotic resistance was studied in selected ARB species or in bacterial community. JDS5 (planned in 2025) will provide new data, 6 years after the last campaign.

***Escherichia coli and coliforms* (*Klebsiella* spp., *Enterobacter* spp. and other species)**

Serbia took part in the last Joint Danube Surveys (JDS3 and JDS4) in 2013 and 2019. Some studies of AMR relied on the detection or quantification of antibiotic-resistant *Escherichia coli* isolates, or coliforms (used as indicators of faecal pollution) in surface waters (data on groundwaters were too scarce). Overall, multiresistance (resistance to three or more classes of antibiotics) in *Escherichia coli* isolates significantly increased between 2013 and 2019 (from 9.70% to 13.8%, making a 42% increase) (Zarfel *et al.*, 2015; Kittinger *et al.*, 2016a; Dielacher *et al.*, 2021) but it is not clear if it increased along the Danube course. Resistance to ampicillin and tetracycline were the most common but only ampicillin resistance was investigated (since of clinical importance). β-Lactam resistance can be explained by β-lactamase production (extended-spectrum β-lactamases -ESBLs- and carbapenemases for ampicillin and imipenem, meropenem resistance). About 2-3% of total *E. coli* isolates displayed one or more ARGs among a selection, all encoding for ESBLs but no gene encoding for carbapenemases (Kittinger *et al.*, 2016a; Dielacher *et al.*, 2021). Other acquired resistance mechanisms remain to be elucidated.

Kittinger *et al.* (2016a) also showed some *Klebsiella* spp. isolates were resistant to one or more tested antibiotics during JDS3 campaign (no indication during JDS4 campaign). The most common resistance was ampicillin (*Klebsiella* spp. are naturally resistant) and tetracycline (8.46%). Multiresistance was observed in 2.19% of the *Klebsiella* spp. total isolates. The low number of multiresistant *Klebsiella* spp. did not enable to conclude about a resistance trend over the Danube course (Kittinger *et al.*, 2016a). No *K. oxytoca* but 13 of 238 *K. pneumoniae* (5.5%) isolates harboured one ESBL gene or more. Two of them also harboured an additional carbapenamase gene (for imipenem, meropenem resistance).

Kittinger *et al.* (2016a) also identified *Enterobacter* spp. ampicillin-resistant isolates (*Enterobacter cloacae*, *E. asburiae* and *E. cancerogenus*) due to the presence of ESBLs. Some carbapenemase markers could be detected in association with ESBL markers.

Escherichia coli and other coliforms (*Citrobacter brakki*, *Acinetobacter* spp., *Aeromonas* spp., *Raoultella ornithinolytica*, *E. cloacae* species) were isolated from three water samples collected in 2021 in a mountain spring in central Serbia, a close municipal reservoir in a rural area -without any treatment for drinking water-, and tap water in a household. All isolates were resistant to amoxicillin. All *Aeromonas* spp*., E. coli, C. brakki* and *R. ornithinolytica* isolates were resistant to streptomycin (Grujović *et al.*, 2022). The resistance genes were not investigated. As virulence genes could be detected in some isolates, this study suggests that resistant potential pathogenic bacteria can enter springs or municipal reservoirs and stresses the importance of improving access to water treatment, for rural areas (Grujović *et al.*, 2022).

***Pseudomonas* spp.**

During JDS3, 128 isolates of *Pseudomonas* spp. (*P. putida, P. fluorescens, P. oleovorans* and *P. stutzeri*) were isolated in surface water. Fifty eight (45.3%) *Pseudomonas* spp. isolates were resistant to at least one or more antibiotics. Overall, resistance to meropenem was met in 36.7% isolates, followed by doripenem (15.6%) and ciprofloxacin (10.2%). Most of them were naturally resistant to the association trimethoprime/sulfamethoxazole (Zarfel *et al.*, 2015). In another study of 520 *Pseudomonas* spp. isolates (*P. aeruginosa*, *P. putida*, and *P. fluorescens*) during JDS3 campaign, 37% of isolates displayed resistance to at least one antibiotic. The most common resistance was against meropenem (30.4%) and the association piperacillin/tazobactam (10.6%). Multiresistance was observed in 3.1% isolates. If resistance to carbapenems in *Pseudomonas* spp. is mostly mediated by efflux pumps (intrinsec resistance), other mechanisms of resistance remain to be investigated (Kittinger *et al.*, 2016b).

Vibrio cholerae / Vibrio paracholerae

NonO1/nonO139 *Vibrio cholerae* (non-toxigenic *V. cholerae* -NTVC-) and *V. paracholerae*, isolates were detected in all samples from inland waters in natural or artificial lakes and ponds in Serbia, except one (a saline lake) (Rehm *et al.*, 2023). In a Whole Genome Sequencing (WGS) approach, the authors observed the presence of genes potentially involved in pathogenicity. They did not investigate antibiotic resistance but suggested to lead a seasonal sampling campaign in recreational waters as infections increase probably with climate change.

Bacterial community

During JDS4, Sanseverino *et al.* (2021) investigated by 16S rDNA sequencing, changes in the microbial diversity composition along the Danube River (of eight sites, three sites were located in Serbia, associated with different levels of pollution). Overall, Proteobacteria was the most abundant phylum in six samples analysed while Actinobacteria dominated in two samples collected in Serbia. They showed bla_{TEM}, *sul1*, and *qnrS* ARGs, conferring resistance to β-lactams, sulfonamides and quinolones respectively (the most used antibiotics in human and veterinary medicine), were present in at least one sampling point (Sanseverino *et al.*, 2021). In another longitudinal study during JDS4, *E. coli* was shown the main predictor for the presence of a selection of AMR markers, followed by 16S rRNA and

BacHum (associated with faecal pollution of human origin) and a newly home-made developed «water impact index» (WII) but interestingly it did not correlate with antibiotic concentration (Schachner-Groehs *et al.*, 2024). In a parallel temporal study, *E. coli* was also shown the main predictor, but followed by three pesticides (the insecticide antagonist piperonyl butoxide, the herbicide metolachlor or the fungicide carbendazim) (Schachner-Groehs *et al.*, 2024).

5.6.2 Studies of AMR in sediments

The bacterial community diversity was explored in sediments from three glacial lakes with different anthropogenic pressure, in Bosnia and Herzegovina and in Montenegro**.** Predominant phyla were determined (Malesevic *et al.*, 2019). In a Shotgun analysis, Filipic *et al.* (2020) showed that the three communities had a high number of sequences similar with genes encoding Resistance Nodulation Division (RND) efflux pumps, involved in resistance to fluoroquinolones and other genes associated to resistance with other classes of antibiotics. One community harboured a metallo-β-lactamase-encoding gene inserted at an *attC* site. Different integrase gene classes and plasmid sequences were also identified suggesting acquired resistance by horizontal gene transfer (HGT) (Filipic *et al.*, 2020). Further investigations are needed to assign resistance phenotype to the genes identified in the metagenomes.

5.6.3 Studies of AMR in wastewater

Alygizakis *et al.* (2019) did not focus on ARB but on antibiotics and ARGs. They measured the concentration of 280 chemicals among which 32 antibiotics in wastewater effluents in 9 countries

Box 8. Current Status in antibiotic resistance monitoring in water in Western Balkan countries

AMR was identified as one of the top three priority health threat by the European Commission and actions to fight against AMR have to been undertaken.

Aquatic environments (surface waters, wastewaters) are reservoirs of antibiotics and residues, ARB and ARGs, thus there is a need to know in what extent they participate to the spread of AMR. Studies of AMR in the 6 WB countries are scarce (publications selected from 2015 up to now). Of the 6 countries, some aquatic environments from 3 countries were studied: Serbia (mainly), Montenegro and Bosnia and Herzegovina.

Recommendations, future needs:

New data on AMR in water in WB are of utmost importance. A temporal study of removal efficiency could be undertaken for treatment plants (as of primary, secondary or tertiary technologies in these countries). Antibiotic and ARB concentrations, ARGs quantification, and correlation studies with physical and chemical parameters (temperature, antimicrobial substances) in wastewater effluents (before discharge into surface water) could be explored.

Other rivers and lakes could be studied especially when wastewater-influenced surface waters, when used as source for drinking water or as recreational waters. Longitudinal and temporal studies of surface waters could provide many information (as increase or decrease of AMR along rivers, seasonality).

Collaboration could be strengthened between research communities and European countries (national or transnational studies). An exchange of training, knowledge and expertise on promising experimental methods and analysis is needed to improve water monitoring in WB.

along the River Danube and tributaries. One tertiary WWTP was located at Šabac, a big town in the center West of Serbia (Alygizakis *et al.*, 2019). They showed, among 14 ARGs markers*, intl1* and *sul1* were the most abundant genes in all effluents. The sample collected at Šabac WWTP had also among the highest concentrations of antibiotics and ARGs. Šabac being also known for its pharmaceutical industry (production of antibiotics), together with the failure for WWTP at removing totally antibiotics and ARGs, it could explain the high concentrations of antibiotics. Ćirković *et al.* (2023) collected wastewater from the main sewer outlets near Belgrade before discharge into the Sava and the Danube rivers. Multiresistant Gram-negative bacteria were identified (all clinically-relevant species). Each strain harboured a high diversity of resistance genes for several classes of antibiotics.

6 Conclusions

The present report provides an overall analysis of the status of environment (air pollutants, GHG, soil and water) including their impacts on health (air quality) and the impacts of climate change on precipitation, drought, heat waves and forest fires in the WB as of 2023. It gives an overview of the progress in the alignment with the Chapter 27 of the EU *acquis* to support monitoring and policy design for the EU accession process. In addition, the information summarised in this study provides the basis for the implementation and monitoring of the actions included in the Green Agenda for the WB, particularly in the depollution and decarbonisation pillars.

The lack of data is still a significant obstacle for continuous spatial and temporal environmental monitoring in the WB. The availability of reliable field data is crucial in identifying the critical aspects in the status of environment, leading to the development of dedicated and effective policies. Thus, the establishment and constant improvement of monitoring networks including transparent reporting, with appropriate financial and human resources for the implementation of plans, is pivotal.

Cooperation among WB region and neighbouring EU countries is of the outmost importance in addressing the transboundary pollution. **Within the WB region, cooperation needs to be further enhanced, due to the highly interconnected ecosystems**. Further integration and implementation of the environmental legislation is needed within the key sectors that correspond to the pillars of the Green Agenda for the WB. Increasing intensity and frequency of climate disasters require adequate monitoring, early warning systems, and appropriate adaptation plans. Capacity building activities of all potential players (state administration, industry, academia, local governments, final users) are key to ensure effective implementation of legislation. At the same time, collaboration with and involvement of EU experts is essential to share relevant knowledge and best practices,

There has been general progress over the latest years in the status of **air quality** concerning the continued improvement of monitoring (in terms of data availability and coverage) and the decreasing trend in concentration of certain pollutants. **However, the WB region still faces challenges in meeting current air quality standards.** While an improvement is reflected in the decreasing trend of annual average values of PM_{10} and $PM_{2.5}$, the high daily and/or hourly concentrations (PM_{10}, SO_2, NO_2, O_3), leads to a number of exceedances (PM_{10}, SO_2) which is critical. **Limited air quality data collection sites and insufficient coverage in the existing time series is still a drawback for a comprehensive and reliable air quality status assessment in the WB region**.

$PM_{2.5}$ is the pollutant with the greatest direct impact on **human health** (number of premature deaths and years of life lost) with a significant pressure for the economy of WB. **Compared to the EU, the mortality rate attributable to PM is up to 4 times higher in the WB and shows a significantly slower declining trend.**

Emissions of air pollutants, such as NOx, SOx and PM, **increased in the latest years** compared to the situation before COVID-19. SOx presents the largest exceedance relative to the defined emission ceiling for the NERP, while dust (PM) increased its relative exceedance and NOx exceeded the ceiling for the first time. Coal-based power plants are the single largest source of GHG and air pollutant emissions (CO_2, SO_2, NOx, PM). Further significant key sectors are transport, combustion of solid fuels in households and industry. Therefore, phasing-out of the existing coal-based power plants is an effective measure to achieve the air depollution and decarbonisation targets of the Green Agenda for the WB. **Although a significant improvement was made in the alignment of the**

climate and GHG emissions monitoring and reporting legislation, the implementation is still slow and ineffective. The emissions of fossil CO_2 and overall GHG are stagnant, as well as the share of contributing sectors. However, biological CO_2 increased in the recent period in absolute and relative terms within total CO_2 emissions, as a consequence of the progressive replacement of fossil resources with renewable energy. **The reduction of overall GHG emissions needs to be intensified to reach the defined 2030 target.** The recommendations concerning this area are:

- Continue the efforts on air quality monitoring systems to improve data coverage and data management
- Take necessary steps for the implementation of both air pollutants and GHG emission reductions

Climate change has shown negative influence on several environmental indicators which are relevant for human activities and well-being. **Concerning the water cycle, the analysis of trends indicates more significant inland precipitation across the WB region, and increased precipitation in winter thereby increasing the risks of both droughts and flooding**. Droughts, floodings and temperature changes are affecting water ecosystems by causing alterations in hydrological and sediment regime (release and movement of nutrients, mobility of heavy metals, increase runoff and decomposition rates of some organic micropollutants such are pesticides and pharmaceuticals, decrease autochthonous and increase of allochthonous pathogens species). The **heat waves** intensity shows a significant growth near the Adriatic coast in the latest years, and it spreads to the north-west. Longer heat waves are the dominant cause of increased intensity, followed by higher maximum temperatures. The magnitude and the number of **forest fires** decreased in some of the analysed WB economies (North Macedonia and Serbia). **However, the large share of negligence among the causes of this type of wildfires is an area for improvement to consolidate the decreasing trend in the future**. Compared to the EU27 average burnt area, in WB economies this parameter is lower. Sustainable and responsible management of forest ecosystems and resources, as well as enhanced protection, is also an important link towards air depollution, but also in the preservation of water resources and soil. Moreover, the following steps towards adaptation to the climate change are recommended:

- Develop and enhance early warning systems and disaster risk reduction strategies to minimize the impact of extreme climatic events on communities and infrastructure.
- Engage local authorities/stakeholders in creating and implementing local based adaptation plans that address climate vulnerabilities within their locality

The soils of the WB are under significant pressure, leading to widespread degradation across the region. Soil health is critical for sustaining agriculture, ecosystems, and human well-being, yet unsustainable land use and management practices have resulted in major threats such as soil erosion, pollution, sealing, and nutrient mismanagement. Metal contamination from industrialisation and mining activities, further compound these challenges. The complexity and diversity of soil types, along with a lack of updated data, make it difficult to provide a comprehensive assessment of soil health across the region. To address these issues, it is recommended to:

- Establish comprehensive soil monitoring systems: WB economies must implement harmonized soil monitoring systems that provide reliable data on soil health; these systems should align with the EU Soil monitoring and Resilience Directive and involve continuous data collection, such as using LUCAS soil survey methodologies;

- Address soil pollution: The identification and remediation of contaminated sites, particularly in industrial and mining regions, should be prioritized to reduce the harmful impacts of soil pollution.

The WB region faces significant challenges in water management, characterized by underdeveloped infrastructure, insufficient wastewater treatment, and the continued impact of anthropogenic pressures on aquatic ecosystems. Key stressors include untreated municipal and industrial wastewater, agricultural runoff, and the combined effects of climate change and hydromorphological degradation. Despite these challenges, efforts to improve water management are underway. National strategies focus on aligning with EU standards, particularly those in the Urban Wastewater Treatment Directive and Water Framework Directive. There are ongoing investments in wastewater infrastructure, regulatory improvements, and monitoring systems.

Key recommendations to address the abovementioned challenges are:

- Strengthening of wastewater treatment infrastructure is needed to increase capacity and coverage;
- Monitoring and data collection for emerging contaminants should be enhanced;
- Mitigation of faecal pollution should be achieved through decentralized sanitation solutions;
- Aligning with EU directives for compliance and capacity building is needed;
- Antibiotic and ARB concentrations, ARGs quantification, and correlation studies with physical and chemical parameters (temperature, antimicrobial substances) in wastewater effluents (before discharge into surface water) should be further explored;
- Implementation of Integrated Water Resources Management (IWRM) is recommended with climate adaptation strategies;
- Promoting nature-based solutions (NbS) is needed for improving water quality and resilience to climate change.

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List of abbreviations and definitions

Abbreviations	Definitions
AL	Albania
AMR	antimicrobial resistance
ARB	antibiotic-resistant bacteria
ARGs	antibiotic resistance genes
AST CHI	asthma in children
BA	Bosnia and Herzegovina
BacHum	Human-sourced *Bacteroides*
BPA	bisphenol A
BR AD	bronchitis in adults
BR CHI	bronchitis in children
CECs	contaminants of emerging concerns
CEIP	Center on emission inventories and projections
CHIRPS	Center InfraRed Precipitation with Station
CLRTAP	Convention on Long Range Transboundary Air Pollution
COPD	chronic obstructive pulmonary disease
CRF	concentration-response function
CVAD	cerebrovascular disease
DMT2	diabetes mellitus
EDCs	Endocrine Disrupting Chemicals
EEA	European Environmental Agency
EFFIS	European Forest Fire Information System
EIONET	Environmental Information and Observation Network
EMEP	European monitoring evaluation programme
EnC	Energy Community
EnCS	Energy Community Secretariat
EPR	extended producer responsibility
EQSD	Environmental Quality Standards Directive
ESBLs	extended-spectrum β-lactamases
EU	European Union
FAO	Food and Agriculture Organization
FBiH	Federation of Bosnia and Herzegovina
GAWB	Green Agenda for Western Balkans
GDP	gross domestic product
GHG	greenhouse gas
GWD	Groundwater Directive
HA CVD	hospital admissions due to cardiovascular diseases
HA RD	respiratory diseases
HGT	horizontal gene transfer
HWMId	Heat Wave Magnitude Index daily
IEA	International Energy Agency
IER	Integrated exposure response
IPCC	Intergovernmental Panel on Climate Change
IPCHEM	Information Platform for Chemical Monitoring
IWRM	Integrated Water Resources Management
JDS	Joint Danube Surveys

Abbreviations	Definitions
JRC	Joint Research Center
LC	lung cancer
LCP	large combustion plant
LULUCF	land-use, land-use change and forestry
ME	Montenegro
MI	myocardial infarction
MK	North Macedonia
MS	member state
NECD	National Emission reduction Commitments Directive
NERP	National Emissions Reduction Plan
NH_3	ammonia
NMVOC	non methane volatile organic compound
NO_2	nitrogen dioxide
nrMS	non-relevant metabolites of pesticides
NTVC	non-toxigenic *Vibrio cholerae*
O_3	ozone
PAHs	polycyclic aromatic hydrocarbons
PCBs	polychlorinated biphenyls
PD	premature deaths
p.e.	Population equivalent
PFASs	poly- and perfluoroalkyl substances
PFHpA	perfluoroheptanoic acid
PFHxA	perfluorohexanoic acid
PFHxS	perfluorohexanesulfonate
PFOA	perfluorooctanoic acid
PFOS	perfluorooctane sulfonate
PM	particulate matter
PM_{10}	particulate matter size 10 micrometers or less
$PM_{2.5}$	particulate matter size 2.5 micrometer or less
PNEC	predicted no-effect concentration
PS	priority substances
RAD	restricted activity days
RCC	Regional Cooperation Council
rDNA	ribosomal deoxyribonucleic acid
RND	resistance nodulation division
rRNA	ribosomal ribonucleic acid
RS	Serbia
Rs	Republika Srpska
SHPP	small hydroelectric power plants
SPI	standard precipitation index
UNEP	United Nations Environment Programme
UWWTD	Urban Wastewater Treatment Directive
WB	Western Balkans
WFD	Water Framework Directive
WGS	Whole Genome Sequencing
WHO	World Health Organization

Abbreviations	Definitions
WII	Water Impact Index
WL	Watch List
WLD	working lost days
WMO	World Meteorological Organization
WOAH	World Organization for Animal Health
WRB	World Reference Base
WW	wastewater
WWTP	wastewater treatment plants
XK	Kosovo
YLL	years of life lost

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Annexes

Annex 1. Air quality standards for health protection in the Western Balkans compared with EU limit values and WHO air quality guidelines (AQG). year: y; hour: h

Pollutant	Averaging period	Limit value		Air Quality Guidelines
		WB	EU	WHO
PM_{10}	24h µg/m^3	50	50	45
	1y µg/m^3	40	40	15
$PM_{2.5}$	1y µg/m^3	25	25	5
SO_2	1h µg/m^3	350	350	
	24h µg/m^3	125	125	40
	1y µg/m^3	50 *		
NO_2	1h µg/m^3	150 ** 200	200	
	24h µg/m^3	85 *		25
	1y µg/m^3	40	40	10
CO	8h mg/m^3	10	10	10
O_3	8h µg/m^3	120	120	100

Values for specific WB economies: *BA & RS; **RS

Source: European Parliament and European Council, World Health Organization, Government of the Republic of Serbia, Government of the Federation of Bosnia and Herzegovina.

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