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Climate change impact on EU rivers´ dilution capacity and ecological status

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Highlights

- EU Rivers' capacity to dilute wastewater treatment plants discharges is assessed
- Climate change will lead to a dilution factor decrease for 11% of the EU rivers
- 42% of the rivers will downgrade their ecological status due to climate change
- More vulnerable sites are located in the Mediterranean countries

Abstract

Impacts from urban wastewater treatment plants (WWTP) to receiving riverine surface water bodies (SWBs) depend on the load of contaminants discharged, as well as on their dilution capacity. Yet, climate change impacts on such dilution capacity and ultimately on the SWBs ecological status remain unclear. Here, we assess SWBs dilution capacity across the European continent to identify most vulnerable areas using information from centralized European databases. SWBs´ future dilution factor values are estimated based on representative concentration pathway scenarios impacts on rivers flow, and likely changes in European SWBs´ ecological status foretold. Results show that dilution factor in Europe increases by 5.4% in average. Yet, climate change effects are found to lead to a consistent dilution factor decrease for 11% of the 40074 European SWBs receiving WWTP discharge for the early century. This share reaches 17% for the midcentury period. We estimate that up to 42% of the SWBs receiving WWTP discharges and currently reaching a good ecological status show a 0.7 probability to have their ecological status downgraded due to climate change. Sites more vulnerable are located in the Mediterranean countries. Our findings highlight that climate change mitigation is essential for maintaining good ecological status in European SWBs.

1. INTRODUCTION

Assessing the impacts of our society on freshwater ecosystems is key to their current and future preservation (UN, 2012; Grigs *et al.*, 2013; Birk *et al.*, 2020). Treated urban wastewater discharged to rivers conveys contaminants, which might impact receiving freshwater ecosystems and compromise downstream water uses. The aftermath on receiving freshwater ecosystems depends on the load of contaminants in the discharged treated wastewater, as well as on the dilution capacity of the receiving ecosystem. In that regard, wastewater sanitation infrastructures (Thacker *et al.*, 2019) and wastewater management strategies (Tortajada, 2020) are crucial to meet several of the Sustainable Development

Goals (*i.e.* 6- Clean water and sanitation; 11- Sustainable cities and communities; or 13- Climate action) and targets set by the UN Agenda 2030 (UN, 2015; UNGA, 2018). Rivers capacity to dilute wastewater treatment plants (WWTP) discharges (*i.e.* the dilution factor -DF) is the ratio between the river flow and the WWTP discharge, and has been estimated up to national and subcontinental scales (*i.e.* U.S.A., China) to assess WWTP impacts on receiving freshwater resources (Rice & Westerhoff, 2017; Wang, *et al.*, 2017; Nguyen, *et al.*, 2018). However, the DF has not been assessed in the European river networks, except for Germany (Link *et al.*, 2017).

Here, we assessed the DF at the European hydrographic network scale, using the urban WWTP database from the European Environmental Agency Waterbase – UWWTD (EEA, 2020) and the EU river surface water bodies (SWBs) yearly average flow estimates from COPERNICUS datastore platform E-HYPE hydrological model results (Donnelly *et al.*,2016; EU, 2020). Our goals were to assess the differences in the DF across the continent to identify the most vulnerable areas in the EU to WWTP discharges (i), to assess to which extent the DF is correlated with the ecological status (as indicator of the impact on receiving ecosystems) (ii), and to predict how the DF might change under different climate change scenarios, thus identifying not only the current vulnerable areas, but also the future vulnerable areas (iii). We focused on ecological status rather than on chemical status or the specific concentration of selected contaminants because the ecological status reflects the impact of multiple stressors (including contaminants from WWTP) on freshwater ecosystems and is a key environmental goal of the Water Framework Directive (Directive 2000/60/EC). Our hypotheses were that the amount of discharged wastewater rather than the river flow would explain the vulnerable areas in Europe (i); that the SWBs ecological status classification would thus be connected to the DF levels (ii); and that the Mediterranean areas of Europe would be the most sensitive to climate change, with the highest reduction in the DF (iii). The rationale of the hypothesis i is that we expect the variability in river flows to be lower than the variability in the WWTP discharge across Europe (Keller *et al.*, 2014). Regarding the hypothesis ii, the rationale is that treated WWTP discharges are known to impact freshwater ecological status in several ways, from the indirect effects in the community by changes associated with the excessive algal growth by discharged nutrients (Carrey & Migliaccio, 2019; Yang *et al.*, 2019), to the direct effects of contaminants of emerging concern (Loss *et al.*, 2013; Nguyen *et al.*, 2019). Finally, the rationale for hypothesis iii is that river flows in the Mediterranean region are already experiencing decreases and are predicted to further decrease in the coming decades (Schneider *et al.*, 2013).

2. MATERIALS AND METHODS

DF is here calculated, not as the DF of a given WWTP in a given river point or segment, but as the sum of the WWTP discharges in a given river network upstream of the considered river surface water body (SWBs). DF is computed using such conservative approach, for each receiving stream as follow: (1):

$$DF = (Qr + Qwwt\,p)/Qwwt\,p \tag{1}$$

where Qr is the river flow, and *Qwwtp* is the cumulated WWTP discharge, resulting from the sum of the discharges in the river network upstream from the discharge point, both in $m^3.s^{-1}$, and based on yearly averages estimates. Thus, the DF was calculated for each SWBs estimating the pan-European in the river network, produced using the Waterdatabase - UWWTD from the European Environmental Agency (EEA, 2020), and using EU river SWBs yearly average flow estimates from COPERNICUS datastore platform E-HYPE hydrological model results (Donnelly *et al.*, 2013; EU, 2020).

2.1. European wastewater data

The yearly volume of wastewater treated by the European wastewater treatment plans (WWTP) larger than 2000 population equivalents (P.E.) was obtained from the Urban Wastewater Treatment Directive – dataset UWWTD (EEA, 2020). This data is reported by the EU Member States in the framework of the 2nd River Basin Management Plan (2016-2021) under the umbrella of the EU Water Framework Directive (Directive 2000/60/EC). The validation and reconciliation of the Waterdatabase - UWWTD was a necessary step. Over a total of 28276 WWTP included in the database, 24892 discharge their effluents into freshwater units referred as river or inland catchments SWBs. The database provides the annual treated volume, which is here considered as the discharged volume, for only 9708 WWTP. Specifically, discharge data was only available for about 90% of the WWTP from 9 European countries (Supplementary Information Fig. SI1a). To estimate the treated volume of the remaining WWTP, the number of habitants connected to a WWTP was first estimated using the declared P.E., provided for all WWTP in the database, knowing that in EU one habitant releases in average 1.23 P.E. (Vigiak *et al.*, 2020). Then, for each WWTP, the treated volume was estimated by multiplying the number of habitants connected to the WWTP by the Member State average habitant water consumption. Lastly, a linear regression was conducted between the reported annual treated volume from the WWTP providing these values (using 8821 values when outliers are removed) and P.E of the WWTP. Outliers removed before the linear regression were the 0.99 and 0.01 percentiles of the estimated and provided discharge ratio as well as Poland values where reported treated volumes are multiple folds higher than the rest of EU member states. The equation obtained from the regression has a r^2 of 0.81 (Supplementary Information Fig. SI1b) and was then used to estimate the flow out of P.E. for the remaining WWTP.

2.2. European river flow data

The river flow data used for computation of the pan-European DF, is based on the dataset produced by the E-HYPEv3.1.2 hydrological model (Rice & Westerhoff, 2017). Data products of this multi-basin conceptual model are available through the Copernicus climate change Service portal (EU, 2020). E-HYPE is a semi-distributed hydrological modelling approach, which divides the 8.8 million of km^2 of European River Basins Districts in 35408 sub-catchments (Lindström *et al.*, 2010; Hundecha *et al.*, 2016). Gauged sub-catchments are divided in Hydrological Responses Units (HRU) based on their flow signatures, correlated to catchment physiography characteristics. E-HYPE classifies HRU into 75 categories where predictions in ungauged basins is performed based on similarities with a stepwise regionalization scheme in the calibration process. This hydrological modelling approach considers most of the standard natural hydrological surface and sub-surface processes (such as evapotranspiration, soil moisture, discharge generation, groundwater fluctuation). Main human activities directly impacting the hydrological cycle, such as irrigation or discharge control processes, are also included in E-HYPE modelling though considered as represented less accurately (Donnelly *et al.*, 2016; Grizzetti *et al.*, 2017). Thus, E-HYPE produces flow routing over the gauged and ungauged catchments of EU River basin units. For pan-European DF computation, the yearly average river flow was used, as well as the monthly 50th percentile.

2.3. Climate change data and scenarios

The yearly volume of wastewater treated is assumed to remain unchanged in future scenarios. This manuscript focuses on the influence of climate change, and other factors influencing the treated volume such as population growth in urban areas (increasing emission trend factor) and socio-political variables (habitant per capita consumption and water reuse policies -potential decreasing emission trend factors) are left aside for future research. The temporal range of the analysis is limited to the next 50 years (up to 2070) which is in the range of WWTP urban water infrastructures lifespan. Climate Impact Indicator (CII) products from COPERNICUS climate change Service portal include the above-mentioned river flow for Europe (EU, 2020; Grizzetti *et al.*, 2017). River flow change estimates are provided for three different 30-year periods 2011-2040, 2041-2070 and 2071-2100, following different emission scenarios (RCPs 2.6; 4.5; 8.5). These river flow changes are simulated and provided using combinations of multiple global climate, regional climate and hydrological models (EU, 2020; IPCC, 2013). Our study uses the 50th quantile monthly discharge estimates for the2011-2040 and 2041-2070 periods, provided by the hydrological model E-HYPEv3.1.2 simulation results. These discharge estimates are provided for the three RCPs (2.6; 4.5; 8.5) respectively using 2, 5 and 4 and global climate change models/regional climate change models input forcing combinations (Grizzetti *et al.*, 2017) for the E-HYPE hydrological modelling in Copernicus. Thus, the 50th quantile monthly discharge estimates were used to compute the DF while averaging the DF result for each RCP scenario.

2.4. Dilution factor computation process

The cumulated urban wastewater effluent discharge ( ) and the river flow ( ) were first computed under the format of raster grids before applying Eq. (1) to obtain the DF for Europe. The process to spatially cumulate along the course of the European streams the discharge contributions of each WWTP, was based on a GIS approach using Flow Direction (FD) grids, location of the WWTP discharge points, and estimated WWTP discharge. Here, the FD grid is a combination of the HydroSheds FD grid (Lehner *et al.*, 2008) of ~500m resolution, and above 60ºN, of the HYDRO1K FD grid (USGS, 2020) of ~1km resolution. Those two FD grids were originally generated using a standard D8 methodology (Garbrecht & Martz, 1997) based on Digital Elevation Models (DEM). DEM have been pretreated to ensure the hydraulic continuity of the streams by the data providers (Lehner *et al.*, 2008; USGS, 2020). These two FD grids are identical to the data sources used in the E-HYPE hydrological model (Donnelly *et al.*, 2016) which produced the river flow data we used in our approach for the pan-European DF computation. Here, to cumulate the WWTP discharge, each of the discharge points was used to generate a drainage line base on the combined FD grids. Each drainage line respectively had the weight of the estimated WWTP discharge value (in $m^3.s^{-1}$). The sum of all the individual drainage line grid provided the cumulative WWTP discharge gridded for Europe.

The river flow grid results from the conversion of the river flow data estimated at each of the 35408 sub-catchments by the E-HYPEv3.1.2 hydrological model conversion to a raster grid. Combination of the cumulative WWTP discharge grid with river flow grid using Eq. (1) allowed to compute the DF grids.

European SWBs are provided as vectors (polylines) layer by the European Environmental Agency (EEA,2020). Here, the process to supply a DF value in a conservative manner for the SWBs was to extract, using a 250m spatial buffer for each SWB polyline, the minimal DF value of the DF grid. Shortcoming of spatial buffering selection routine exist, coming from the fact that several SWBs can potentially be selected in dense hydrographic regions where upstream SWBs could be over selected.

2.5. DF and ecological status logistic regressions

The ecological status is an assessment of the quality of the structure and functioning of SWBs. It shows the influence of pressures (i.e., pollution and habitat degradation) on the identified quality elements. Following the implementation of the Water Framework Directive (WFD), the ecological status is determined for each of the SWBs of rivers, lakes, transitional waters and coastal waters, based on biological quality elements and supported by physico-chemical and hydromorphological quality elements (EC, 2015a). The assessed ecological status for each SWB is reported by member states at each reporting cycle (every 6 years) and stored by the European Environmental Agency (EC 2015b; EEA, 2012).

Ordinal logistic regression was here used to perform a generalized linear model (McCullagh & Nelder 1987) predicting the probability of SWBs to belong to the different ecological status classes based on DF values. This method establishes a probabilistic classification of SWBs using the DF value as predictor (Fig. 2b). Computed DF datasets and the SWBs ecological status classification reported in 2016 for the second River basin management cycle (2016-2021) dataset where used. The temporal extent of the analysis does not refer to a specific year but is centered on the full 2016-2021 period. Following the same principle, binomial logistic regression was used to perform a generalized linear model assessing the probability of SWBs to belong to one of the two state of the binary response (reaching good ecological status or not reaching the good ecological status), based on the DF predictor. These models were performed using R packages `glm.predict´ (Schlegel, 2019 and `MASS´ (Venables & Ripley, 2002). The logistic regression process was performed using training data representing 75% of the total dataset. The accuracy (ratio of samples correctly predicted over the total number of sample) was estimated with the remaining 25% of the data for model validation. The accuracy is reported as the mean of the logistic regression model ran 100 times with random sampling for the training/validation dataset selection.

3. RESULTS AND DISCUSSION

3.1. Assessment of current dilution factor across Europe

In the process of pan-European DF estimation, the estimate of cumulated WWTP discharge across Europe (Fig. 1a) is already a valuable result of the study.

The comparison of this map of WWTP discharge with the SWBs indicates that 40074 out of the 106654 river SWBs included in the database directly or indirectly (from upstream discharges) receive WWTP effluents. These SWBs are thus affected by this point source pollution mapped and quantified for the first time at European level. This *Qwwtp* mapping recalls and enhances the prime importance in Europe of WWTP effluent contribution to river flow quantity bearing in mind potential impacts regarding quality of low concentration effluent components (Schneider *et al.*, 2013; Mani *et al.*, 2015; Loss *et al.*, 2019). As an illustrative figure, the three largest shares of treated effluent in European River Basin Districts´ main rivers can represent up to 149, 84, and 54 $m^3.s^{-1}$ at the estuary of Rhine, Danube and Po SWBs, representing respectively 6, 1 and 3% of their yearly average flow (Supplementary Information Tab. SI1 provides listing of the maximal contribution per EU River Basin Districts).

The analysis of the obtained map of DF across Europe (Fig. 1b) indicates that central Europe, and the Mediterranean region to a lesser extent, are the regions with lowest DF (Supplementary Information Fig. SI2a). This supports our first hypothesis, as the driver of the differences across Europe is the WWTP discharge rather than the river flow. Indeed, the observed variability in terms of cumulated WWTP discharge is *ca.* 3 orders of magnitude higher than the observed river flow variability (Supplementary

Information Fig. SI2b). This is reflected at the European scale, but it is more evident in some specific countries, such as Belgium or Spain (Supplementary Information Fig. SI2c). If locally, the magnitude of our DF values results compares to regional DF studies results (Germany, see Karakurt *et al.*, 2019), overall DF values are lower by a factor 10 compared to US or Chinese studies as they have larger and more populated river basins and thus higher QWWTP values (Nguyen *et al.*, 2018; Thacker *et al.*, 2019;).

3.2. The effects of the dilution factor on the SWBs' ecological status

As a reminder, the ecological status values reported in 2016 for the second reporting cycle (2015-2021) were used in our study to compare with the estimated DF values.

Specifically, the DF estimated for the 40074 SWBs were grouped by their ecological status categories and presented as box plots (Fig. 2a). The share of European SWBs across these categories is 2% High, 27% Good, 44% Moderate, 19% Poor, and 8% Bad. Here, results show that the ecological status of SWBs worsens as their dilution factor decreases as illustrated by the shift in DF distribution per ecological status categories. A logistic regression was performed considering the DF and a binary classification of the SWBs as a function of their ecological states (good or higher than good versus lower than good), thus allowing to estimate the probability of compliance with the WFD objectives for a given dilution factor (Fig. 2b). The classification accuracy of this binary logistic regression model is of 0.70, and results indicate that there is probability of not achieving the good ecological status of 72% for those SWBs with DF values lower than 100. When considering a DF of 10, the probability of not achieving the good ecological status rises to more than 80%. Hence, our results support the second hypothesis, as ecological status is proportional to the DF.

Furthermore, the binary logistic regression allows using DF to estimate ecological status in those cases where the member states did not report ecological status, or in climate change scenarios. In the first case, we used our regression to estimate the ecological status for 8083 SWBs (out of the 40074 SWBs receiving WWTP contribution) with unreported or unknown ecological status. In these SWBs, their DF

(Fig. 3a) was used to estimate the probability of achieving the good ecological status, and results indicate that 38% of these SWBs will not achieve the good ecological status (Fig. 3b).

3.3. Climate change impact on dilution factor and ecological status

The DF was recalculated using the 50th percentile of the predicted flows in the European SWBs based on the RCPs 2.6, 4.5 and 8.5 (IPCC, 2013; EU ,2020;) for the early (2011-2040) and mid (2041-2071) century periods. Climate Impact indicator (CII) products from COPERNICUS climate change Service portal provide above mentioned river flow estimates for Europe, simulated by several hydrological model including E-HYPE model that were used in this study (SMIH, 2016). Compared to the reference period, DF decreases consistently for the three RCPs in 11% and 17% of the European SWBs receiving WWTP discharges for the early and the midcentury periods, respectively (Fig. 4). The magnitude of the decrease is in average of -0.9% and -1.7% and median value shift is -8.3% and -9% for the two respective periods. A DF increasing trend occurs consistently for the three RCPs in 41% and 45% of the SWBs over the two respective periods, by an average of 5.2% and 6.3% and a respective median DF value shift by 8% and 8.2% (Fig. 4). The spatial analysis of these patterns indicates that the SWBs consistently decreasing are located mostly in the Mediterranean region, as well as in western Europe, with a greater decrease for those scenarios with higher greenhouse gas concentration (*i.e.*, RCP 8.5). In contrast, the DF of the SWBs in central and eastern Europe consistently increased. These results support only partially our third hypothesis, as we expected only the Mediterranean region to suffer DF decreases. These observations are strengthened when comparing against the reference period high RCPs scenarios (4.5; 8.5), as results enhance that there is three times more SWBs affected by a consistent (RCPs and period independent) DF increase (15433) compared to those suffering a consistent decrease (5261). Here, Western and Southern EU Member states (Spain, France, Portugal, Italy, Ireland and Greece) own 94% of the 5261 SWBs with a consistent decrease jointly observed for the two high RCPS during the two periods. For detailed analysis considering exclusively the RCPs 4.5 and 8.5, and showing the results at the national scale, see Supplementary Information Tab.SI2.

Using the obtained DF for these scenarios, and the binary logistic regression, we estimated the ecological status for each SWB and for each one of the 6 considered scenarios (3 storylines and 2 time periods). Results in Fig. 5 are expressed as consistent change (RCPs scenario and time-period independent) with respect to current ecological status. Overall, in Europe, 42% of the 9390 SWBs receiving WWTP discharge with a current good ecological status would be at risk, with a 0.72 probability of not reaching this good status anymore. In contrast, SWBs affected by DF increases in the RCPs scenarios only lead to a limited number (100 out of 22601) of SWBs currently not reaching a good ecological status, but with a 0.6 probability of reaching the good ecological status. A focused analysis on the SWBs experiencing a consistent DF decrease in all considered scenarios was performed, and results illustrate that 15.5% of these SWBs with a current good ecological status will not reach good ecological status anymore. A member state level detailed description (Supplementary Information Tab.SI3) supports our third hypothesis, as Mediterranean countries (*i.e*. Portugal, Spain, France and Italy) represent 95% of the SWBs with a 0.72 probability to have their good ecological status downgraded due to climate change. Overall, statistical classification models such as the binary logistic regression-based DF/ecological status probabilistic relationship established here, do not aim to bring evidence of cause-relationship. However, not only they allow patterns to be displayed, but to predict future ecological status changes. Compared to approaches more complex or requiring larger variety of data (Grizzetti *et al.*, 2017; Hess, 2019), the present findings permit to identify SWBs classified with a good ecological status at risk of being downgraded due to climate changes impacts on rivers dilution capacity.

4. CONCLUSIONS

Differences in the DF across the European continent are assessed to identify the most vulnerable areas in the EU to WWTP discharges:

- Central Europe and the Mediterranean region, to a lesser extent, are the EU regions with lowest DF.
- The driver of the differences across Europe is the WWTP discharge rather than the river flow as the observed variability in terms of cumulated WWTP discharge is several orders of magnitude higher than the observed river flow variability.

The DF used as indicator of the ecological status of river SWBs showed statistical significance, allowing to discriminate the probability of SWBs to reach or not a good ecological status. DF estimation enables to build up new knowledge on climate change impact on river SWBs DF throughout the use of RCPs future river flow estimations and thus, the approach permits to forcast SWBs future ecological status.

- 38% of the SWBs receiving UWWTP discharge with a currently unknown/unreported ecological status have a higher than 0.7 probability not to achieve good ecological status.
- Overall, for the three RCPs (2.6; 4.5; 8.5) climate change effects lead to a consistent DF decrease for 11% of the 40074 EU SWBs receiving WWTP discharge from current status to 2040.
- This share reaches 17% when extrapolating to 2070, where SWBs from Spain, France, Portugal and Italy represent 80% of the total 5261 EU SWBs affected by this consistent DF diminution.
- The northern part of Europe shows a slight increasing future trend for DF, an effect that diminishes for higher RCP. and the later the considered period.
- Assessment of high RCPs (4.5; 8.5) impacts on the DF allow to estimate that, in 40% of the 9390 European SWBs receiving WWTPs discharge with a good ecological status will have a higher than 0.7 probability not to reach this good status anymore.

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6. AUTHORS CONTRIBUTION

A.M.: conceptualization, data curation, modelling and writing. V.A.: conceptualisation, writing and supervision. G. W.: conceptualization, modelling, revision, and supervision. I.R.-R. and M.P.: conceptualization, revision. Ll. C.: conceptualization, writing, revision, supervision.

Competing interests

The authors declare no competing interests.

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DATA AVAILABILITY

All data used in this paper are publicly available. The Waterbase - UWWTD wastewater data are available from EEA (https://www.eea.europa.eu/data-and-maps/data/waterbase-uwwtd-urban-waste-water-treatment-directive-6). The Drainage direction grid data are available from USGS (https://www.usgs.gov/centers/eros/science/usgs-eros-archive-digital-elevation-hydro1k?qt-science_center_objects=0#qt-science_center_objects) and HydroSHEDS portals (https://hydrosheds.org/downloads). The river discharge data from COPERNICUS climate change service portal (https://cds.climate.copernicus.eu/cdsapp#!/dataset/sis-water-quantity-swicca?tab=form). The European surface water bodies from EEA (https://www.eea.europa.eu/data-and-maps/data/wise-wfd-spatial/surface-water-body/shapefile-2016). The dilution factor datasets calculated in this study are available for download through http://doi.org/10.5281/zenodo.4686530.

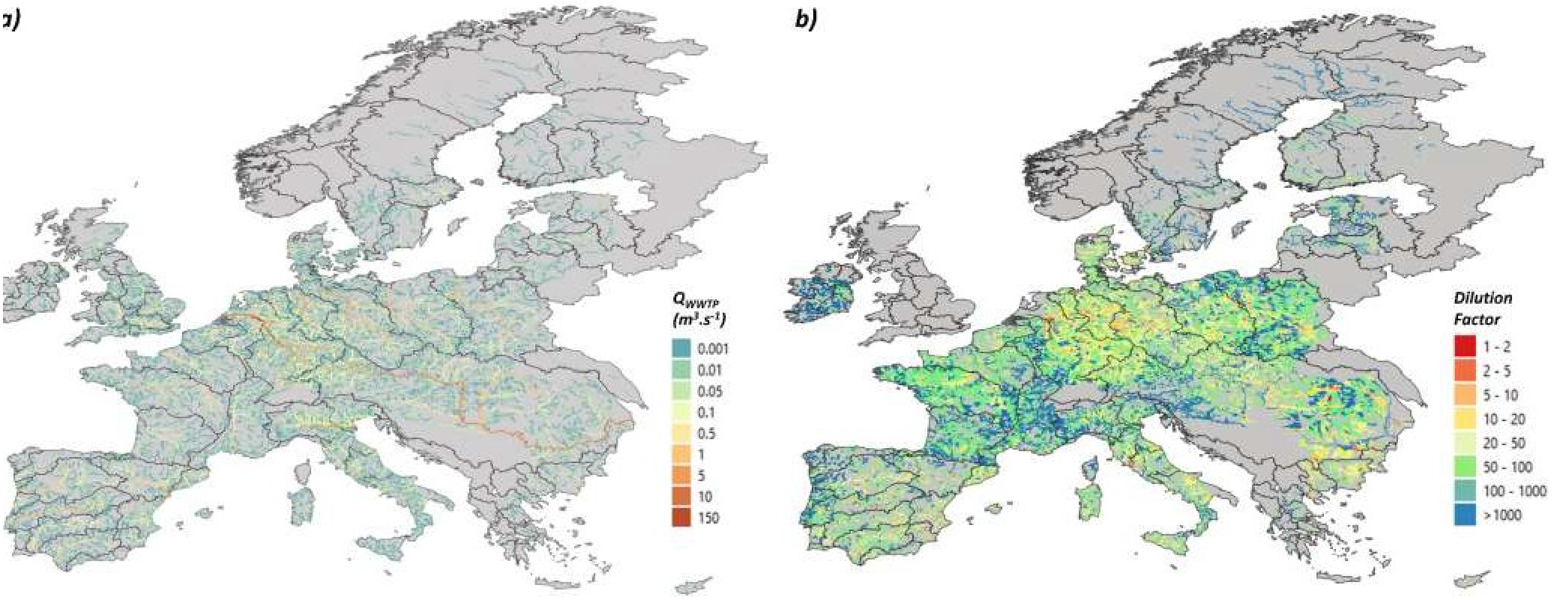

Fig. 1| WWTP cumulated discharge and dilution factor of EU SWBs.

***a**, Yearly averaged urban wastewater treatment plants (WWTP) cumulated discharge in EU stream network. **b,** Dilution factor of the EU river surface water bodies (SWBs) receiving direct or indirect WWTP discharge.*

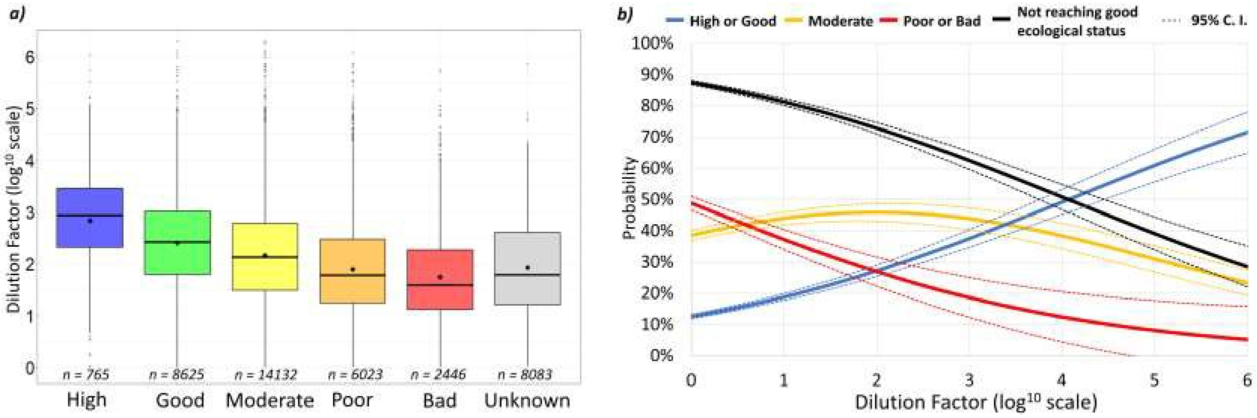

Fig. 2| Dilution factor and ecological status correlation analysis

__a__, Distribution of the dilution factor among the ecological status or potential categories. __b__, Logistic regression analysis displaying probabilities of a river surface water body to belong to an ecological status classification group- high or good (blue line), moderate (yellow line) and Poor or bad (red line)- for a given dilution factor value. Including (black line) the binary logistic regression probability of compliance with the EU Water Framework Directive regulation (reaching or not a good ecological status) for a given dilution factor which mirrors the High or Good ecological status classification probability (blue line).

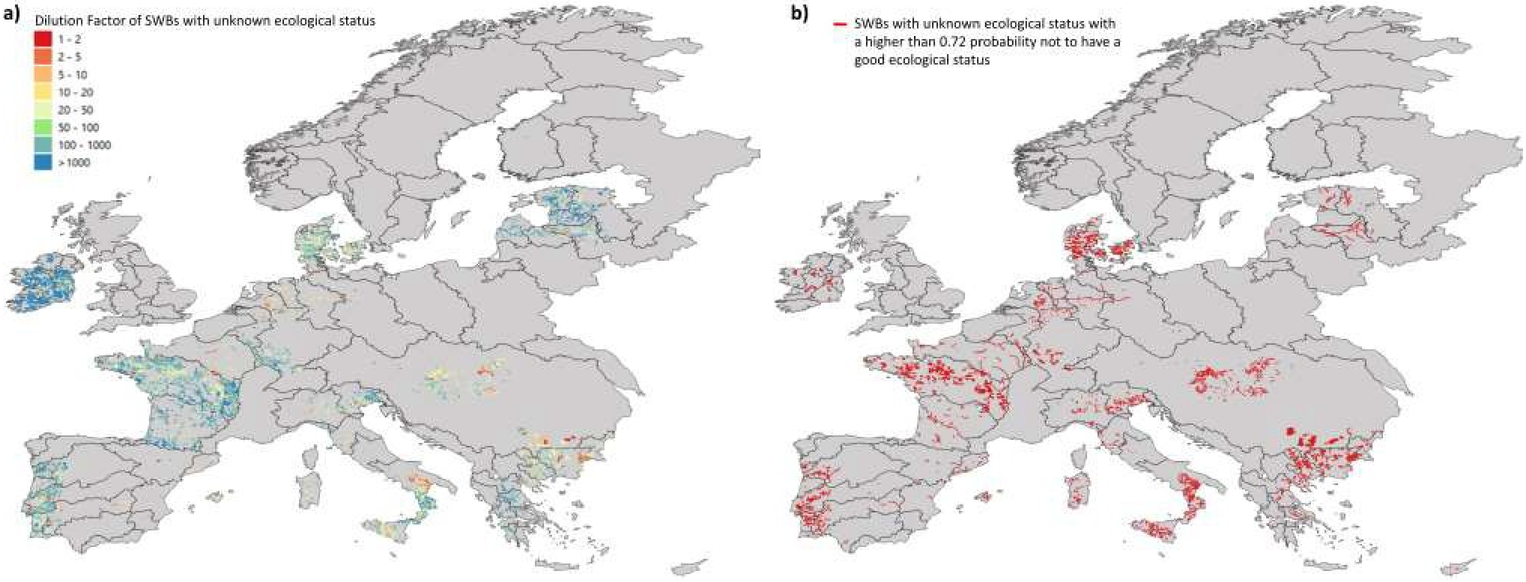

Fig. 3 | Dilution factor and forecast status of SWBs with unknown ecological status

***a**, Dilution factor mapping of the 8083 river surface water bodies (SWBs) receiving urban wastewater treatment plants (WWTP) discharge with an unknown or unreported ecological status. **b**, Probability mapping of SWBs receiving WWTP discharge with an unknown or unreported ecological status with a 0.72 or higher chance not to reach a good ecological status.*

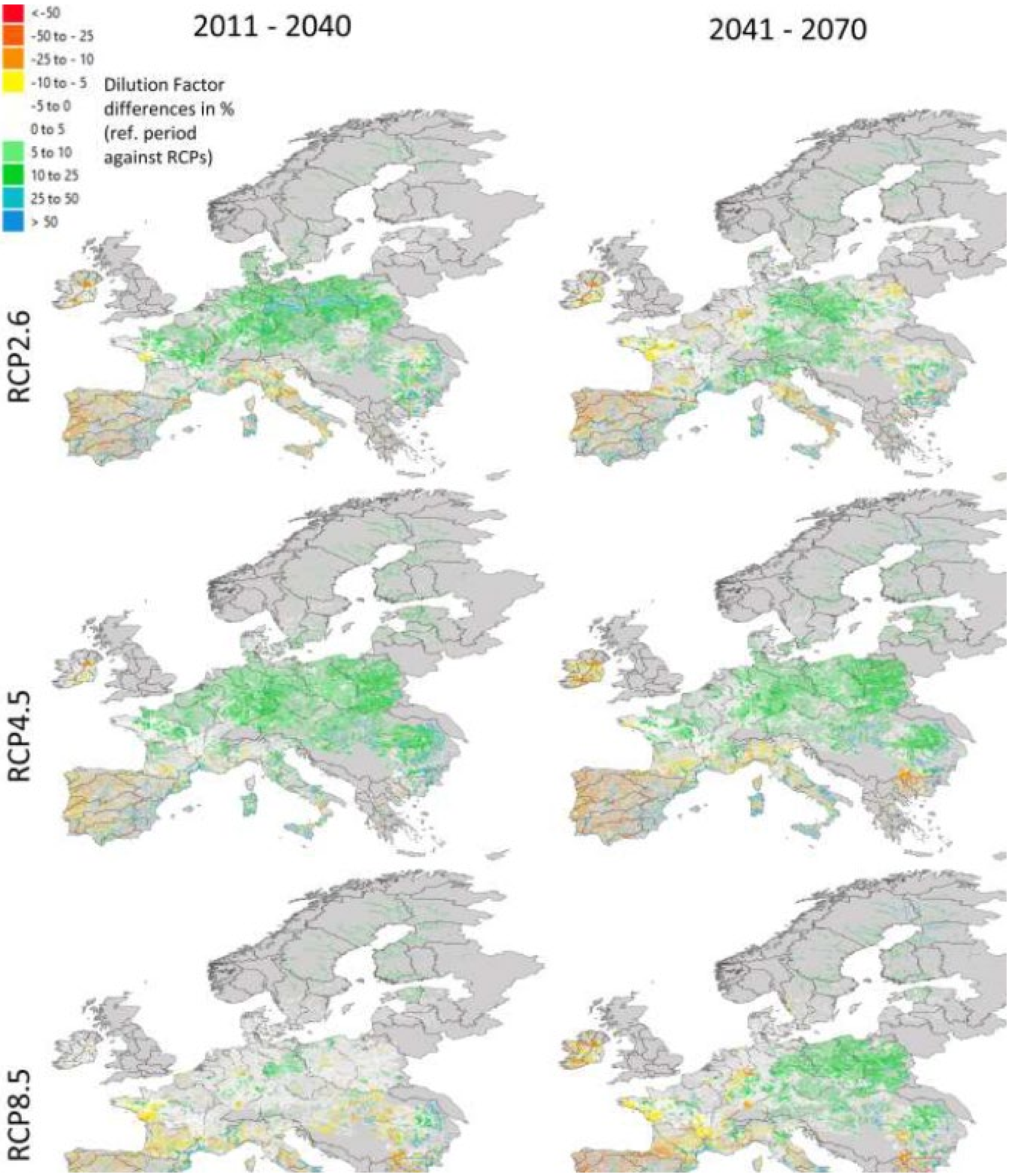

Fig. 4|RCP2.6, RCP4.5 and RCP 8.5 scenarios impacts on dilution factor

Mapping of the differences in percentage, between reference period values of the European river surface water bodies dilution factor (DF) and predicted DF values based on representative concentration pathways (RCPs) scenarios.

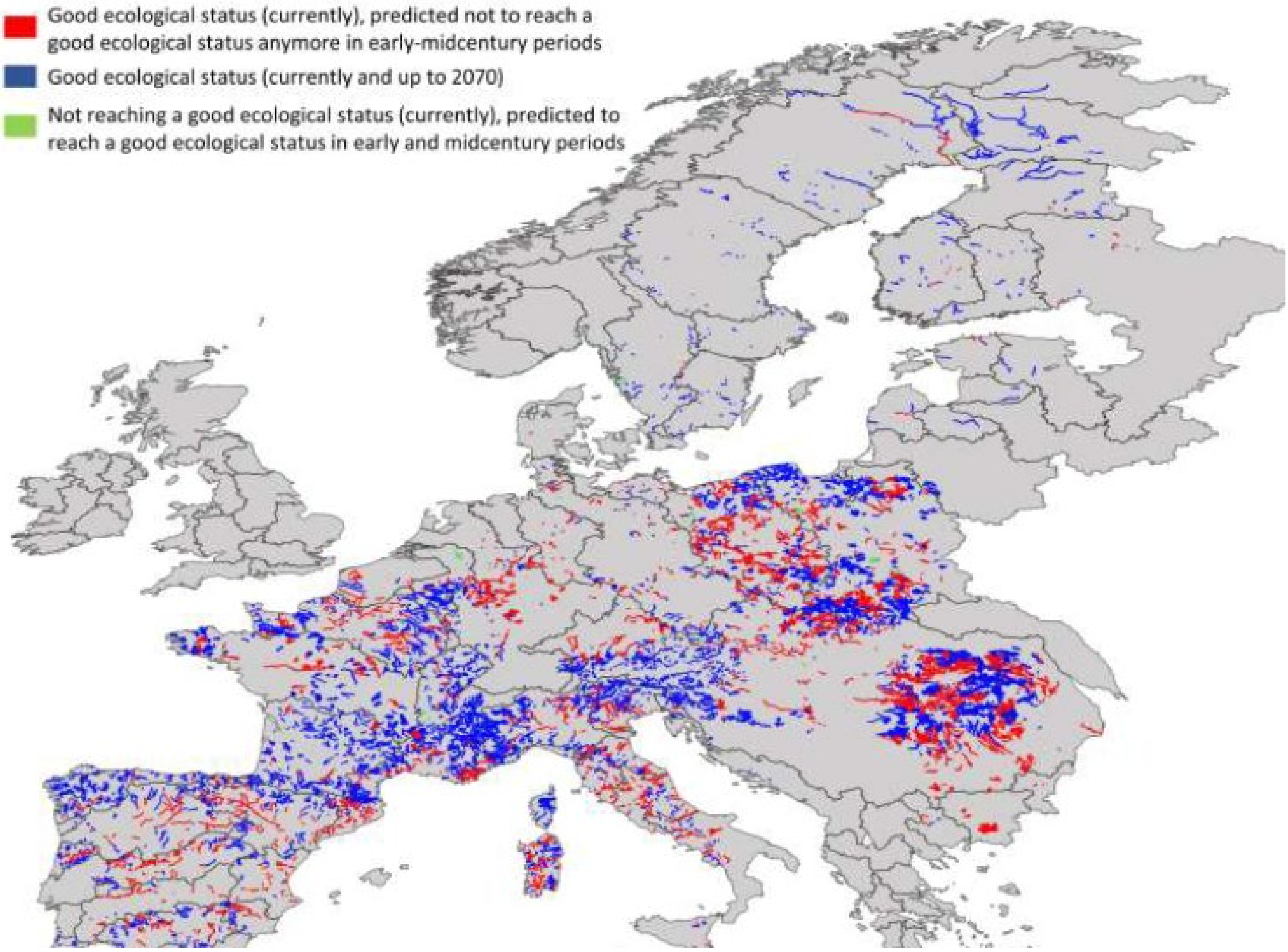

Fig. 5|SWBs ecological status changes for the early-midcentury periods

Mapping of river surface water bodies (SWBs) receiving urban wastewater treatment plants (WWTP) discharge and having a reported ecological status in the current (2015-2021) reporting period with discrimination of SWBs having consistently a high probability (>0.72) not to reach a good ecological status anymore in both the early and midcentury periods and according to all RCPs scenarios (2.5; 4.5; 8.5).