LABPLAS

Land-Based Solutions for Plastics in the Sea

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D7.2 Guideline for parameterizing and operationalizing ePLAS for Europe

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3	Bundesanstalt fuer Gewaesserkunde	BfG	GERMANY	RTO
4	LABORATORIO IBERICO INTERNACIONAL DE NANOTECNOLOGIA	INL	PORTUGAL	RTO
5	KATHOLIEKE UNIVERSITEIT LEUVEN	KUL	BELGIUM	HES
6	HELMHOLTZ ZENTRUM FUR OZEANFORSCHUNG KIEL	GEOMAR	GERMANY	RTO
7	NATIONAL OCEANOGRAPHY CENTRE	NOC	UNITED KINGDOM	RTO
8	SORBONNE UNIVERSITE	SU	FRANCE	HES
9	OPEN UNIVERSITEIT NEDERLAND	OUNL	NETHERLANDS	HES
10	LEIBNIZ INSTITUTE FOR BALTIC SEA RESEARCH	IOW	GERMANY	RTO
11	ASSOCIACAO PARA O DESENVOLVIMENTO DO ATLANTIC INTERNATIONAL RESEARCH CENTRE	AC	PORTUGAL	RTO
12	UNIVERSIDADE FEDERAL DO SAO PAULO	UNIFESP	BRAZIL	HES
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Executive summary:	This document corresponds to Deliverable 7.2. Technical report describing the ePLAS model. This report is the ePLAS (Emission of MicroPLAStics To The Envrioment) model, which is an adaptation of the original ePiE (exposure to Pharmaceuticals in the Environment) model, initially developed to predict concentrations of active pharmaceutical ingredients (APIs) in European rivers and lakes. Given the growing environmental concern about microplastic pollution and similarities between microplastics and pharmaceuticals as pollutants, the ePiE framework has been modified into ePLAS to simulate the transport and fate of microplastic particles. Leveraging high spatial resolution (~1x1 km) and extensive data integration capabilities based on existing spatial datasets on hydrography, terrain morphology, hydrology, wastewater treatment infrastructures, ePLAS models the complex dynamics of microplastics, considering their diverse sources, physical properties (such as size, shape, and density), and interactions with suspended particulate matter. This enables the prediction of microplastic concentrations and their distribution in European rivers, lakes, and sediments, helping to identify potential pollution hotspots and inform strategies for mitigating environmental impacts.

Version	Date	Comments
1	2025 Jan 20	First draft
2	2025 Mar 31	Final version

Disclaimer

The views and opinions expressed in this document reflect only the authors' views, and not necessarily those of the European Commission.

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ABBREVIATIONS AND ACRONYMS

Abbreviation / Acronym	Description
APIs	Active Pharmaceutical Ingredients
avg.	average
D	Deliverable
ePiE	exposure to Pharmaceuticals In The Environment
ePLAS	Emission of MicroPLAStics To The Environment
SPM	Suspended Particulate Matter
TRWP	Tyre and Road Wear Particles
TWP	Tyre Wear Particles
WP	Work Package
WWTP	Waste Water Treatment Plant

1 INTRODUCTION

The ePLAS (Emission of MicroPLAStics To The Environment) model is an adaptation of the original ePiE (exposure to Pharmaceuticals in the Environment) model, initially developed to predict concentrations of pharmaceuticals (APIs) in European rivers and lakes. Given the growing environmental concern about microplastic pollution and similarities between microplastics and pharmaceuticals as pollutants, the ePiE framework has been modified into ePLAS to simulate the transport and fate of microplastic particles. Leveraging high spatial resolution (~1x1 km) and extensive data integration capabilities based on existing spatial datasets on hydrography, terrain morphology, hydrology, wastewater treatment infrastructures, ePLAS models the complex dynamics of microplastics, considering their diverse sources, physical properties (such as size, shape, and density), and interactions with suspended particulate matter. This enables the prediction of microplastic concentrations and their distribution in European rivers, lakes, and sediments, helping to identify potential pollution hotspots and inform strategies for mitigating environmental impacts.

1.1 Background: From ePiE to ePLAS model

The original ePiE model (Figure 1), introduced by Oldenkamp et al. (2018), provides a spatially explicit framework implemented in the R programming environment, offering estimates of API concentrations in surface waters across Europe at approximately 1x1 km resolution. The model calculates API loads entering river systems based on national pharmaceutical consumption data. These loads are subsequently partitioned between two emission pathways: wastewater treatment plants (WWTPs), which serve as point sources releasing partially treated wastewater into rivers, and direct (diffuse) emissions from drainage and sewage systems not connected to WWTPs. Environmental fate processes such as biodegradation, photodegradation, hydrolysis, and sedimentation are then applied to simulate the reduction of API concentrations as they travel through rivers and lakes, with lakes notably functioning as sinks due to extended residence times.

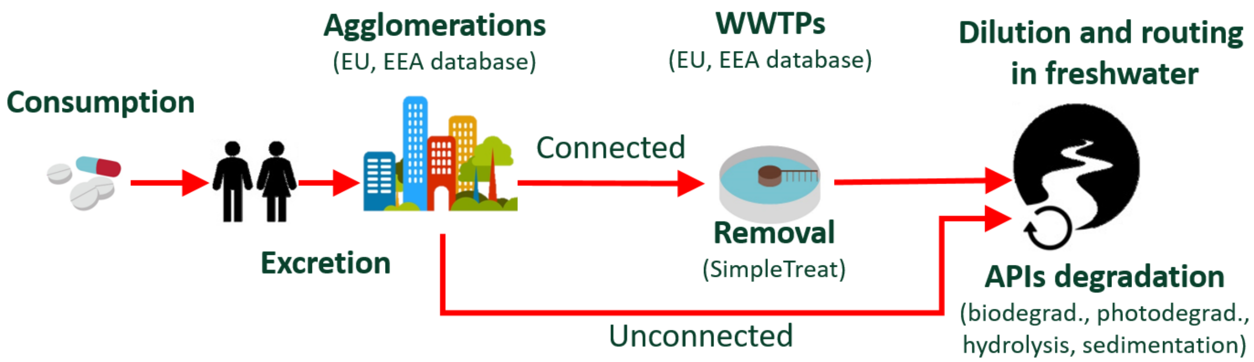

Figure 1. ePiE model core flowchart

Building upon this established ePiE framework, ePLAS (Figure 2) specifically addresses the environmental dynamics of microplastics. In ePLAS, microplastic emissions into river systems are similarly estimated from point sources connected via WWTPs and diffuse sources from areas lacking wastewater treatment connectivity. However, given the distinct characteristics of microplastics compared to APIs, the ePLAS model places a greater emphasis on particle-specific fate processes, including heteroaggregation, deposition, erosion, burial, and resuspension. By integrating these detailed physical interactions, ePLAS provides a powerful tool to simulate microplastic transport, distribution, and accumulation patterns in European freshwater environments.

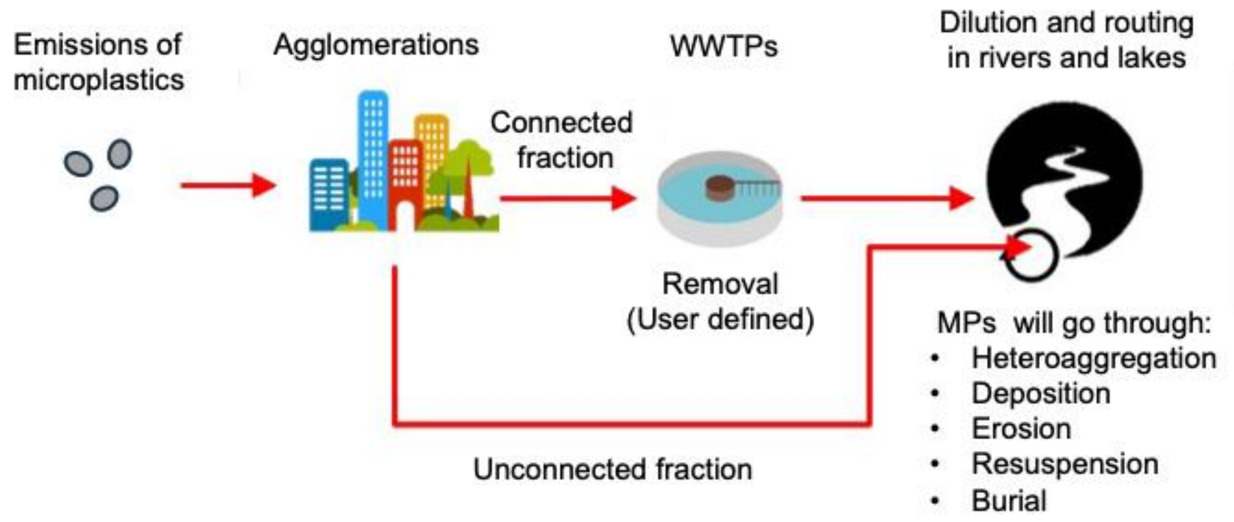

Figure 2. ePLAS model core flowchart

1.2 Overall computational framework of the ePLAS model

The computational workflow of the ePLAS model consists of four primary steps:

(1) Study goal definition;

(2) Model input data;

(3) Running the model;

(4) Model output and post-processing.

The first step, study goal definition, involves clearly identifying and defining the specific research objectives, including the selection of microplastic types, target river basins, hydrological scenarios, and microplastic fate processes.

The second step, model input data, requires preparing and reviewing necessary data inputs. These include fixed model parameters such as geographic information data, hydrological metrics, and environmental parameters, as well as user-defined parameters including microplastic properties, emission scenarios, and WWTP removal efficiencies.

The third step, running the model, executes the primary computational routines via the main R script. This step calculates environmental variables, simulates microplastic fate mechanisms (heteroaggregation, deposition, erosion, burial, and resuspension), and predicts spatial microplastic concentrations and distributions.

The final step, model output and post-processing involves generating visualizations and analyzing results, enabling interpretation of spatial distributions, identification of hotspots, and assessment of concentration trends, thus providing valuable insights into microplastic environmental dispersion and impacts.

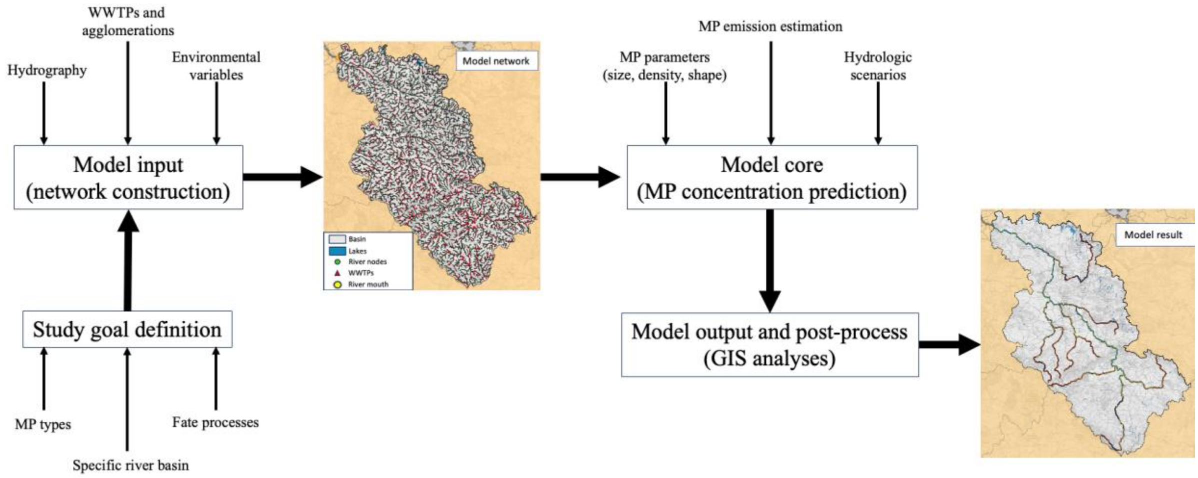

Figure 3. The overall ePLAS model core flowchart

1.3 Objective

The primary objective of this deliverable is to explain and demonstrate how ePLAS can be applied to European water systems. To illustrate this, three case studies are presented relating to three distinct European river basins: the Elbe River Basin, the Thames River Basin, and the Mero-Barcés River Basin. Ultimately, the goal is to extend the ePLAS model to encompass all major river basins across Europe. This broader implementation will help identify potential hotspots of microplastic accumulation across European river systems.

2 Study Goal Definition

This chapter begins by encouraging users to define their research objectives clearly. Users should consider:

- What is your primary research question?
- Which types of microplastics entering freshwater systems are you interested in modelling?
- What specific river basin(s) are you focusing on?
- Do you prefer to base your analysis on annual average flows, lowest monthly average flow conditions or highest monthly average flow conditions?
- Which microplastic fate processes should be integrated into your analysis?

Sections 2.1 to 2.4 introduce various model settings available in ePLAS, enabling users to make informed selections tailored specifically to their research objectives.

2.1 Selection of microplastic sources

Microplastics (MPs) entering freshwater environments may originate from various sources, each characterized by a different emission strength and specific particle properties. Sun et al. (2023) identified and characterized the major sources of microplastics in fresh surface waters based on source strength analysis, and developed algorithms to estimate their source strength. They distinguished the following source categories:

- Tyre wear particles (TWPs);
- Textile fibers;
- Road markings;
- Pellets;
- Scrubbing agents;
- Coatings.

Next to these direct sources of MP emissions, MPs can also originate from the fragmentation and degradation of macroplastics in fresh surface waters.

The final version of ePLAS will be able to simulate the fate of all the above source categories. Hence, users will need to define the specific type(s) of microplastics they are interested in and specify the source strength for each type. However, the current version only includes tyre wear particles. Hence, this user manual demonstrates the modelling process based on the emission of Tyre Wear Particles (TWPs) as a representative case study.

2.2 Selection of study area (River basin)

The ePLAS model framework theoretically allows simulations for all river basins across Europe. However, users need to specify their river basin of interest clearly.

- The current demonstration version focuses specifically on the Elbe River Basin (Basin ID:109965).

Users aiming to conduct simulations in other river basins within Europe should identify their targeted basin from the database that has been integrated into the model environment.

2.3 Selection of hydrological scenarios

Hydrological conditions significantly influence the fate and distribution of microplastics in freshwater systems. The ePLAS model provides three scenarios based on river flow data derived from the FLO1K dataset:

- Annual average flow;
- Lowest monthly average flow over a year;
- Highest monthly average flow over a year.

Users need to select the hydrological scenario most relevant to their research question, as each scenario yields distinct outcomes in microplastic concentration and distribution.

2.4 Selection of fate processes

Microplastic transport and accumulation in freshwater systems are governed by numerous fate processes. Currently, the ePLAS model incorporates the following processes:

- Heteroaggregation;
- Deposition;
- Erosion;
- Resuspension;
- Burial.

Future model versions will offer additional, optional fate processes, such as:

- Biofouling;
- Fragmentation and degradation.

3 MODEL INPUT DATA

This chapter provides detailed information on the input data required by the ePLAS model, clearly distinguishing between fixed model parameters rooted within the model (non-editable) and user-defined parameters.

3.1 Fixed model input parameters

This subsection describes the fixed model input parameters, which generally cannot be changed by the user. These environmental input variables include the geographic data of the river basin, the relevant hydraulic parameters of the river, and the relevant parameter settings for the water column and sediment layers.

3.1.1 Geographic information data

Geographic information was originally derived from the HydroSHEDS v1.1 database (15-second resolution). The European domain includes 1,484 identified basins, each assigned a unique numerical ID. The basin-specific data are organized into folders containing:

- HL.csv: Data file containing information about lakes within the basin.
- pts.csv: Data file listing all river network points with comprehensive attribute data, including rivers, lakes, and WWTPs.
- Shapefiles: ESRI shapefiles provided points network, rivers polylines and lake polygons for plotting purposes.

Each river basin is organized in nodes, i.e., stretches of approximately 1 km, matching the spatial resolution of the model. Figure 4 illustrates the network of the Elbe River basin, where each dot reflects a river node and the locations of the WWTPs are indicated by red squares.

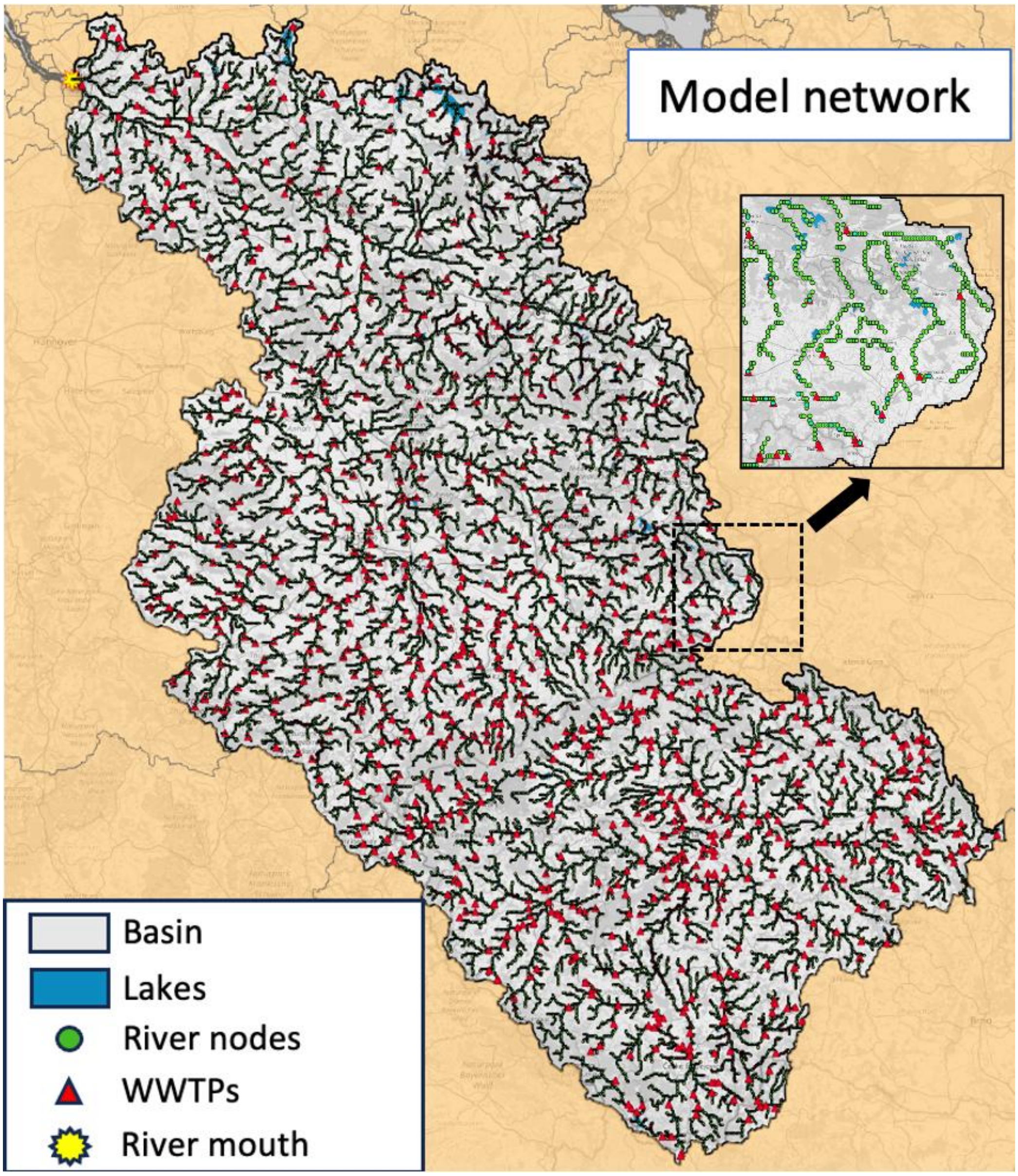

Figure 4. Geographic information output (Choose Elbe River Basin as an example)

3.1.2 Hydrological data

Hydrological data integrated into the ePLAS model primarily originate from two key datasets: HydroSHEDS v1.1 and FLO1K. Detailed information regarding the hydrodynamic input data (i.e., flow velocity, etc.) is provided in the ePLAS Technical Manual (D7.1).

- Hydrography data, including basin outlines, lake polygons, and river network polylines, are sourced from the HydroSHEDS v1.1 database, provided at a 30-second spatial resolution (approximately 1km). The dataset was spatially clipped and filtered to include only basins larger than 100 km² within the European domain, resulting in 1,483 basins, excluding northernmost areas above 60 degrees North latitude.
- River flow data used in ePLAS were derived from the FLO1K dataset, offering global flow rasters at approximately 1 km² spatial resolution (30 arc seconds). FLO1K provides hydrological data including annual mean flow, as well as monthly maximum and minimum flows, covering the period from 1960 to 2015. For ePLAS model scenarios, these data are averaged over the years 2000–2015.

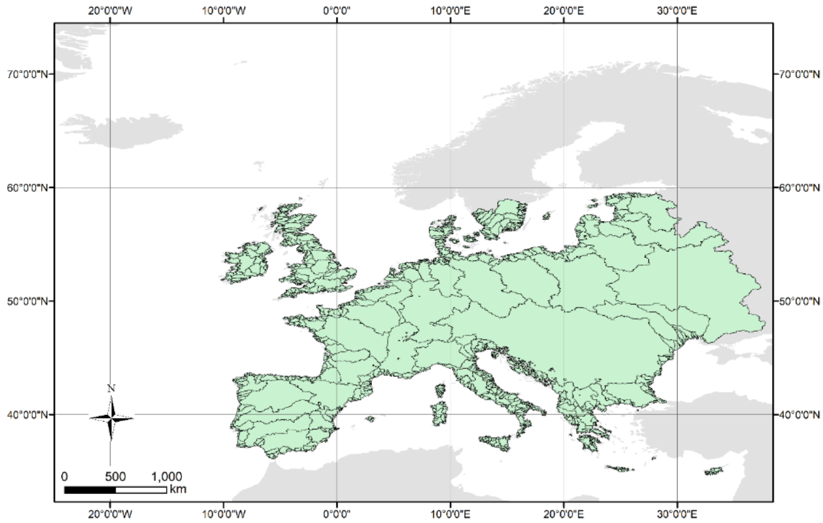

Figure 5. The 1483 HydroSHEDS river basins after clipping in the ePiE target model domain and filtering out small basins.

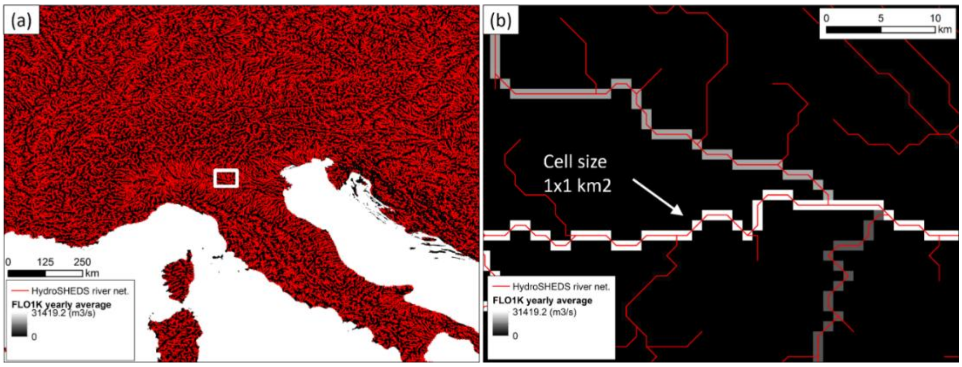

Figure 6. Coupling of HydroSHEDS v1.1 hydrography (Lehner et al., 2008) and FLO1K hydrology (Barbarossa et al., 2018) in a portion of Europe (a) and zoom in the selected square area in North Italy (b).

3.1.3 Water column, bed load layer and sediment layer characterization

This section describes critical physical and chemical properties defining the aquatic environment and sediment compartments in the ePLAS model, derived by running the R function 'Set_local_parameters_parallel_custom_removal_TWP'. Accurate representation of these parameters is essential, as they significantly influence microplastic transport dynamics, fate, and accumulation patterns. Parameters for the water column include water temperature, dynamic and kinematic viscosity, river flow velocity, and river width, all of which directly affect microplastic particle transport and dispersion. Additionally, characteristics of suspended particulate matter (SPM), such as particle radius distribution, density, and mass concentration, are described due to their significant role in microplastic aggregation and deposition processes. Lastly, sediment layer parameters including sediment density, sediment layer thickness, bed load layer thickness, and sediment porosity are presented. These factors govern the exchange processes between water and sediment layers and the long-term fate of microplastics in sediment compartments. A comprehensive summary table containing all parameter values and references is provided for clarity and ease of reference (Table 1).

All these parameters are subsequently stored within the 'pts' and 'HL' data frames, facilitating their use in iterative calculations and simulations throughout the model execution.

Table 1. Parameterization of different layers for the river nodes

Parameter	Symbol	Value	Unit	Reference
River discharge volume	*Q*	-	m^3/s	Barbarossa et al., 2018
Distance between river nodes	*dist_nxt*	-	m	
River flow velocity	v_w	$v_w = n^{-\frac{2}{3}} * Q^{\frac{2}{5}} * W^{-\frac{2}{5}} * S^{\frac{3}{10}}$	m/s	Pistocchi and Pennington, 2006; Schulze et al., 2005
River width	*W*	$W = 7.3607 \cdot Q^{0.52425}$	m	Andreais et al. 2013
River depth	H_w	$H_w = \frac{Q}{v * W}$	m	Pistocchi and Pennington., 2006
Local water temperature	T_w	285	K	Markovic et al., 2013
Dynamic viscosity of fluid at 11.4℃	μ_w	0.001255	kg/m*s	
kinematic viscosity of fluid at 11.4℃	k_n	1.5E-6	m^2/s	
Density of suspending medium water, at 11.4℃	ρ_w	0.9996	g/cm^3	
Radius of SPM	r_{spm}	0.5; 1.5; 5; 15; 50	µm	

Density of SPM	ρ_{SPM}	*2.12*	*g/cm³*	
Mass concentration of SPM	C_{Mass_SPM}	*0.5µm: 6.5E-7* *1.5µm: 1.4E-3* *5µm: 2.6E-2* *15µm: 2.3E-3* *50µm: 6.5E-7*	*mg/L*	*Praetorius et al., 2012*
Heteroaggregation attachment efficiency	$\alpha_{het\text{-}agg}$	*0.01*	*-*	*Praetorius et al., 2012*
Boltzmann constant	k_B	*1.38E-23*	*J/K*	
Depth of the bed load layer	H_{bed}	*0.01*	*m*	*Boudreau, 1994*
Depth of the sediment layer	H_{bed}	*0.50*	*m*	*Boudreau, 1994*
Density of sediment	ρ_{sed}	*2.5*	*g/cm³*	*Praetorius et al., 2012*
Bulk density of sediment particles	C_{sed}	*1.5*	*g/cm³*	*Hamburg Port Authority, 2011*
Porosity of the sediment	Φ_{sed}	*0.85*	*-*	*Praetorius et al., 2012*
Velocity of bed load transfer (bed load shift)	$v_{bed\_transfer}$	*9.00*	*kg/s*	*Faulhaber et al. 2007*

3.1.4 Wastewater treatment plant parameters

The ePLAS WWTP and urban agglomeration database builds upon Version 5 of the European Environmental Agency's UWWTD database (uploaded on 19/02/2015, archived on 14/12/2017, retrieved last on 30/04/2019; available at EEA Website). This database includes essential WWTP attributes:

- WWTP or agglomeration name, geographic coordinates, and country [pts$uwwName; pts$uwwLongi_1; pts$uwwLati_1; pts$rptMStateK];
- Agglomeration inhabitants (population equivalent), including fractions connected or unconnected to the WWTP [pts$f_STP; pts$F_direct];
- WWTP capacity in terms of population equivalents [pts$uwwLoadEnt];
- Types of treatment implemented (primary, secondary, advanced methods such as UV, chlorine, ozonation, nutrient removal, sand filtering, microfiltration) [pts$f_rem_WWTP], which will be discussed separately in the next section;
- Additional attributes, including emission discharge points (river, lake, or sea) and WWTP design capacities [pts$uwwCapacit].

3.2 User-defined input parameters

This section describes the parameters within the ePLAS model that users can define and adjust, directly linking to the study goals defined in Section 2. These parameters primarily cover three aspects: first, the basic properties and fate processes of microplastic particles; second, methods for allocating estimated microplastic emissions into river nodes as either point-source or diffuse-source emissions; and third, customizable microplastic removal efficiencies at WWTPs. This section is structured into the following three detailed parts:

3.2.1 Tyre wear particles' specific parameters

Among various types of microplastic particles, the ePLAS model considers six primary sources entering river systems (Section 2.1). The current demonstration version specifically focuses on tyre wear particles (TWPs), which are a significant source of environmental microplastics. Table 2 provides default parameter values, including dimensions (long, intermediate, and short axes), distribution, shape, and density for TWPs. Users can either apply these default values directly or customize these parameters to match their specific research requirements or local conditions.

Table 2. Tyre wear particles' specific parameters (default values)

Size (um)	Relative Share	Density (g/cm^3)	Shape factor	Long dimension (um)	Intermediate dimension (um)	Short dimension (um)
5	6%	1.8	0.7	5	3.2	3.2
30	11%	1.8	0.7	30	19.2	19.2
75	38%	1.8	0.7	75	48	48
125	32%	1.8	0.7	125	80	80
200	19%	1.8	0.7	200	128	128

3.2.2 Allocation of microplastic emissions

Microplastic emissions are calculated based on country-specific per capita emission values outlined in the ePLAS Technical Manual (D7.1). The per capita emissions are further categorized into two components: point-source emissions, directly entering rivers via WWTPs, and diffuse emissions, entering surface waters without treatment. Methods for estimating per capita emissions for various types of microplastic particles, as well as corresponding results, can be obtained from Sun et al. (2023) and applied within the ePLAS model.

- Point-source emissions: These are calculated by multiplying the per capita emission rates designated for WWTP-connected populations by the number of inhabitants connected to each WWTP [pts$uwwLoadEnt]. If the connected population data is unavailable, the WWTP maximum treatment capacity [pts$uwwCapacit] is used instead. Subsequently, the emission amounts calculated for each WWTP node are adjusted based on WWTP-specific removal efficiencies for TWP, described in the following sub-section, yielding the final point-source emission values for each WWTP river node.
- Diffuse-source emissions: These represent emissions directly entering surface waters, distributed across river network nodes without WWTPs. To allocate diffuse emissions, river network nodes without WWTPs are first identified. The length of each river segment is then divided by the total river length within each corresponding country, generating a fractional allocation. Total diffuse-source emissions for the country are multiplied by these fractions to obtain diffuse emission values for each respective river node.

Both point-source and diffuse-source emission values are ultimately stored in the data frame pts$E_w. Using the particle size distribution parameters defined in section 2.4.1, the emission values for each TWP size category at each river node are derived. For subsequent use in the model calculations, these emission values, originally expressed in kg/year, are converted into kg/s and will be finally stored in pts$Num_initial_w_i.

3.2.3 Wastewater treatment plant parameters

This section specifically addresses the microplastic removal efficiencies of WWTPs within the ePLAS model framework. WWTP removal efficiency varies significantly based on both the type of microplastic particle and the specific treatment technologies employed by different WWTP categories. Recognizing these variations, the ePLAS model provides default removal efficiency values specifically tailored for tyre wear particles (TWP) across different categories of WWTPs. Users have the flexibility to either apply these default values or modify them to better reflect local conditions or specific scenarios.

Table 3. Removal efficiency of different levels of WWTPs for TWP particles (default values)

Level of WWTPs	MP removal effiency
Primary	78%
Secondary	98%
Tertiary	99.7%

4 Model input data

To execute the ePLAS model, users should utilize the main script named ePiE_v4.1_tertiary_custom_removal_TWP.R. The workflow for running this script involves the following sequential steps:

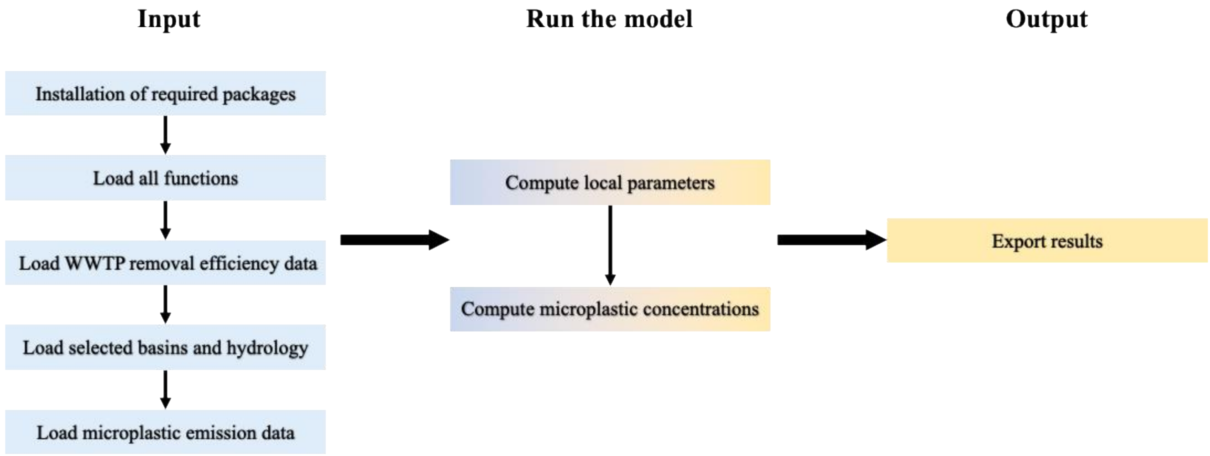

Figure 7. Steps in the ePLAS model

- **Step 1: Installation of required packages**
  Before starting the model, users must install the following R packages if not already present: "sp", "raster", "rgeos", "rgdal", "geosphere", "htmlwidgets", "plyr", "shiny", "leaflet", "leaflet.extras", "maptools", "doParallel", "geojsonio", "geojsonlint", "tictoc"
- **Step 2: Load all functions**
  All essential R functions for the ePLAS model should be loaded from the /Functions/ directory at this stage.
- **Step 3: Load WWTP removal efficiency data**
  Open the CSV file containing microplastic removal efficiency data for WWTPs, currently named TWP_data_separate_custom_removal.csv for the demonstration version (Refer to Table 3). Verify that the appropriate removal efficiencies are correctly assigned within the CSV file. Verify that the appropriate removal efficiencies are correctly assigned within the CSV file by using the function Check_TWP_WWTP_removal_data.R. Confirm that "TWP parameters are loaded."
- **Step 4: Load Selected Basins and Hydrology**
  Load basin data using the function Select_basin_overwrite_pts3.R, and associated hydrology parameters using Select_hydrology.R. The current demo version is set for the Elbe River Basin, identified as Basin ID 109965. Verify the successful loading of basins and hydrological data.
- **Step 5: Load Microplastic Emission Data**
  Import the CSV file TWP_amount_Europe.csv, which includes per capita point-source emissions and diffuse-source emission values. Confirm that TWP release data are accurately loaded by executing the function Check_cons_v2_TWP.R.
- **Step 6: Compute local parameters**
  Execute the function Set_local_parameters_parallel_custom_removal_TWP.R to calculate relevant environmental variables, microplastic physical property parameters, and fate process parameters (refer to Table 1 and Table 2).
- **Step 7: Compute microplastic concentrations**
  Apply the function Compute_env_concentrations_v2_TWP.R to determine mass concentrations for different sizes of microplastic particles at each river and lake node within the selected basin.
- **Step 8: Export results**
  Finally, export the resulting datasets in CSV format, ESRI shapefiles, and GEOJSON files for further analysis and visualization.

5 MODEL OUTPUT DATA AND POST-PROCESSING

5.1 Output format

The output of the pre-processing step is provided as CSV files and shapefiles. Specifically, it produces: (1) the "pts.csv" file, containing comprehensive data for all river network points, including rivers, lakes, and information on WWTPs; (2) the "HL.csv" file, listing lakes and their detailed attributes; and (3) ESRI shapefiles of network points, river polylines, and lake polygons for visualization purposes.

The ePLAS model core generates output in multiple formats: (1) ESRI shapefiles containing network points with microplastic (MPs) concentrations, presented both as mass concentration in kg/m³ and particle concentration in particles/m³, which will be plotted in GIS and for further analysis; (2) CSV files providing detailed MPs concentration data at each network point, again including both mass concentration (kg/m³) and particle concentration (particles/m³); and (3) HTML – GEOJSON files, which allow for immediate visualization of MPs concentration results within any standard graphical web browser.

5.2 Case study results for Elbe River Basin

- **Study Goal Definition**
  The primary scope of this study focuses on the transport and fate of tyre wear particles (TWPs) in freshwater systems, specifically within the Elbe River Basin. The aim is to study the transport pattern of TWPs in riverine systems under hydrological conditions corresponding to the long-term annual average river flow scenario.
- **Model Input Data Gathering**
  The study began by compiling critical input data. First, the removal efficiencies of TWP particles in wastewater treatment plants (WWTPs) were determined by reviewing relevant literature (refer to Table 3). Geographic and hydrological data for the basin were gathered from the HydroSHEDS v1.1 and FLO1K databases, respectively. For microplastic emission inputs, per capita emission data specific to TWP particles were extracted from Sun et al. (2023), providing emission rates for Austria, the Czech Republic, Germany, and Poland. These data were spatially reallocated within the Elbe River Basin, considering each country's geographic contribution to the basin. For the physical properties of TWP particles, five size classes were selected, ranging from 5um to 200um, as shown in Table 2.
- **Model Execution and Results**
  The results presented in this subsection are generated from the demonstration version of the ePLAS model. Please note that these results are preliminary, have not yet been validated, and may not yet reflect real-life conditions. The current demonstration version assumes steady-state conditions and does not account for (realistic) variations in flow. The results are based on average flow conditions derived from the FLO1K dataset, representing an average hydrological scenario.

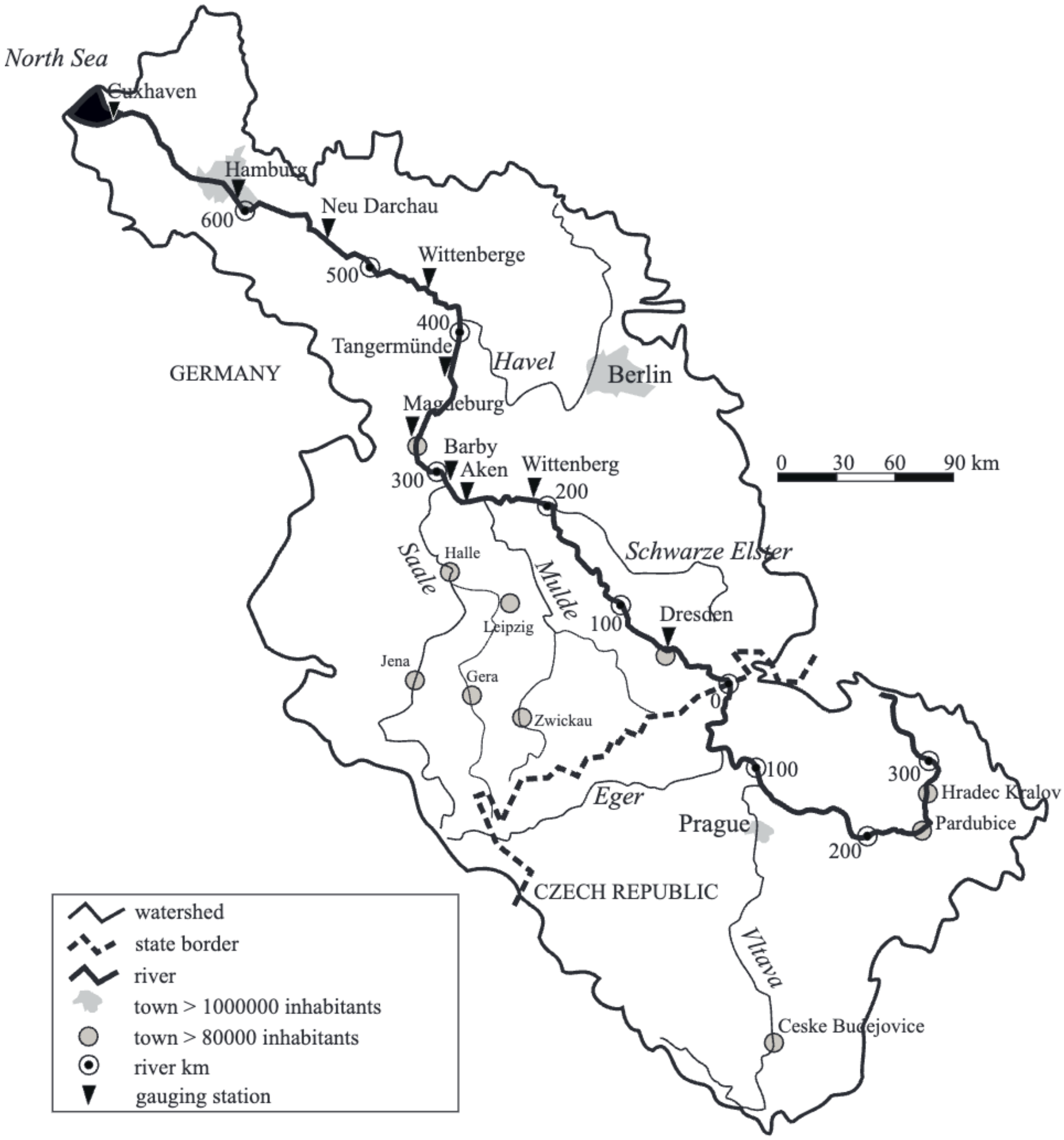

Figure 8. Geographic overview of the Elbe River Basin. The main channel is represented by the bold black line in the center, marked with river kilometers indicating distances from the source downstream. The thinner black lines denote tributaries, including the rivers Havel, Saale, Mulde, Eger, Vltava, and Schwarze Elster.

5.2.1 Mass concentration in the water layer

Figures 9-11 present spatial distributions of tyre wear particle (TWP) mass concentrations in the water layer within the Elbe River Basin, representing three distinct size categories (smallest, medium, and largest) selected from the five size categories used for TWPs. These results were obtained by executing the primary function ePiE_v4.1_tertiary_custom_removal_TWP.R and subsequently visualized using GIS tools. Overall, the analysis highlights the following key conclusions:

- Smaller-sized TWP particles exhibit higher mass concentrations retained within both the main river channel and tributaries;
- TWP mass concentrations generally decrease along the main river channel from upstream to downstream;
- Tributaries consistently display higher TWP mass concentrations compared to the main river channel.

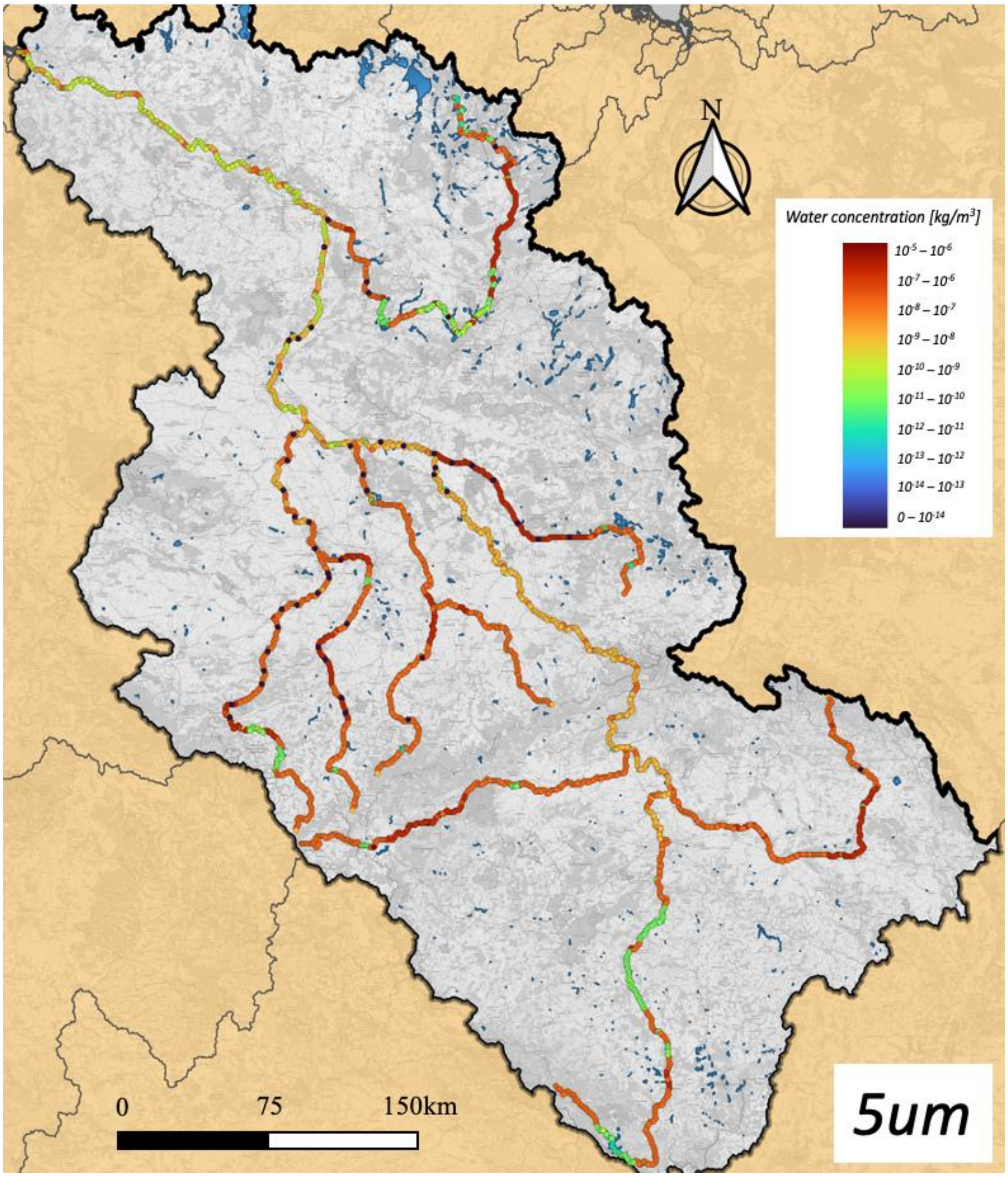

Figure 9. Mass concentration of TWPs (5um) in the water layer [avg. flow conditions].

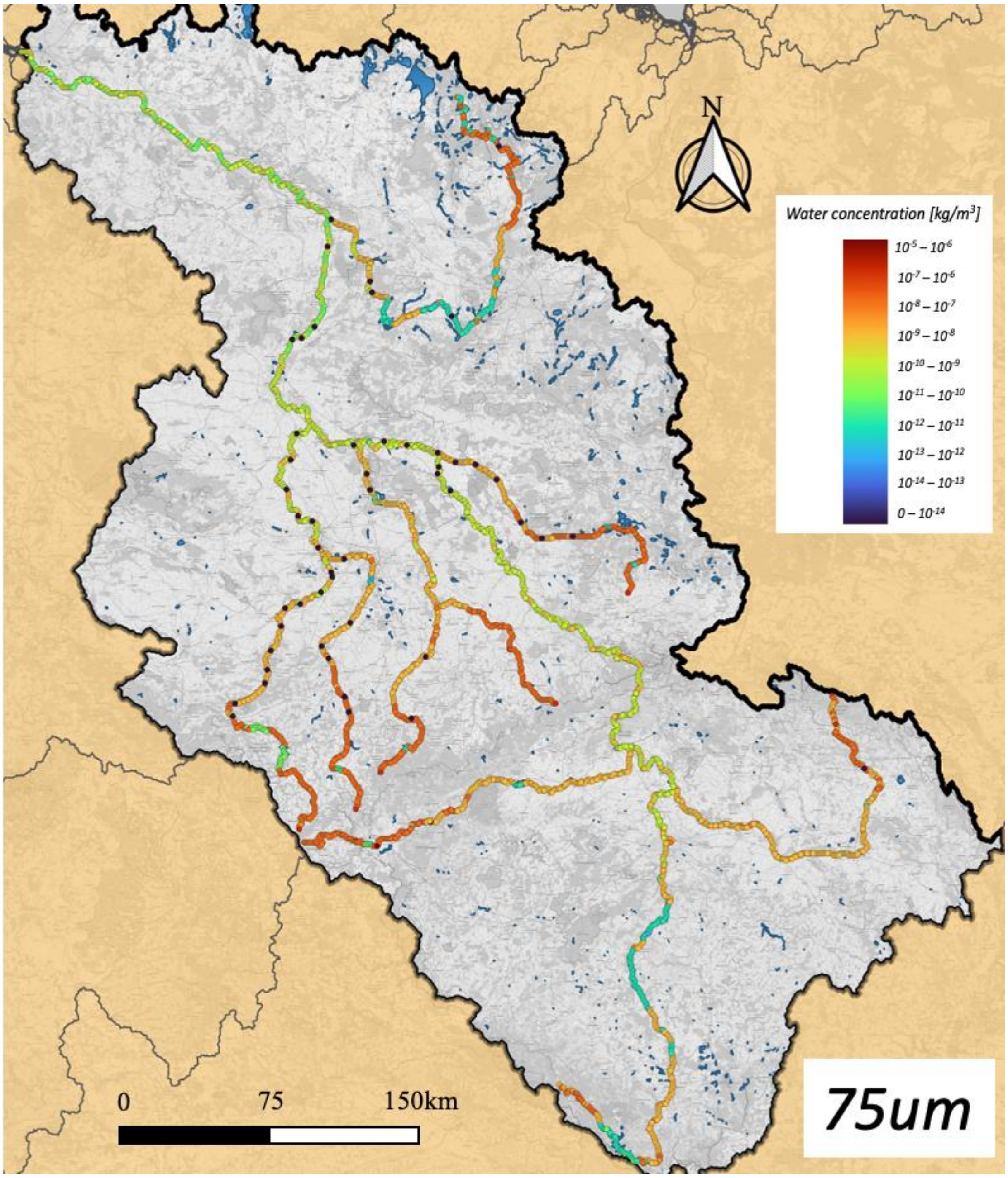

Figure 10. Mass concentration of TWPs (75um) in the water layer [avg. flow conditions].

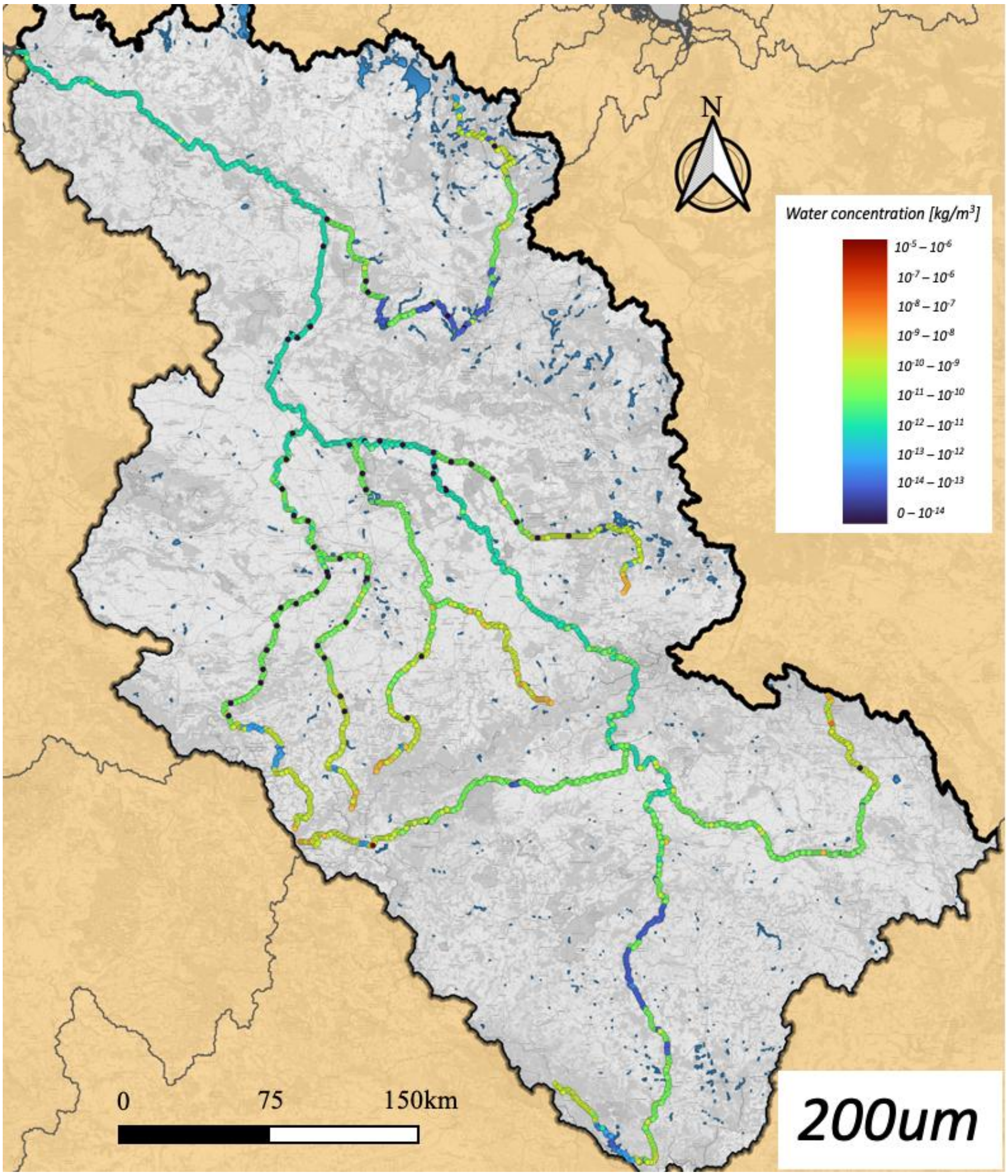

Figure 11. Mass concentration of TWPs (200um) in the water layer [avg. flow conditions].

5.2.2 Mass concentration in bed load layer

This section (Figures 12-14) reports the mass concentration of TWPs specifically within the bed load layer of the Elbe River Basin. The following key conclusions drawn from the results:

- Mass concentrations of TWP in the bed load layer across river nodes are consistently two orders of magnitude higher compared to concentrations observed in the water column;
- Particularly for the 5 µm TWP particles, mass concentrations within the bed load layer are significantly elevated in tributaries;
- Unlike trends observed in the water column, TWP mass concentrations within the bed load layer of the main channel do not notably decrease downstream. Instead, they remain relatively consistent along the river's length.

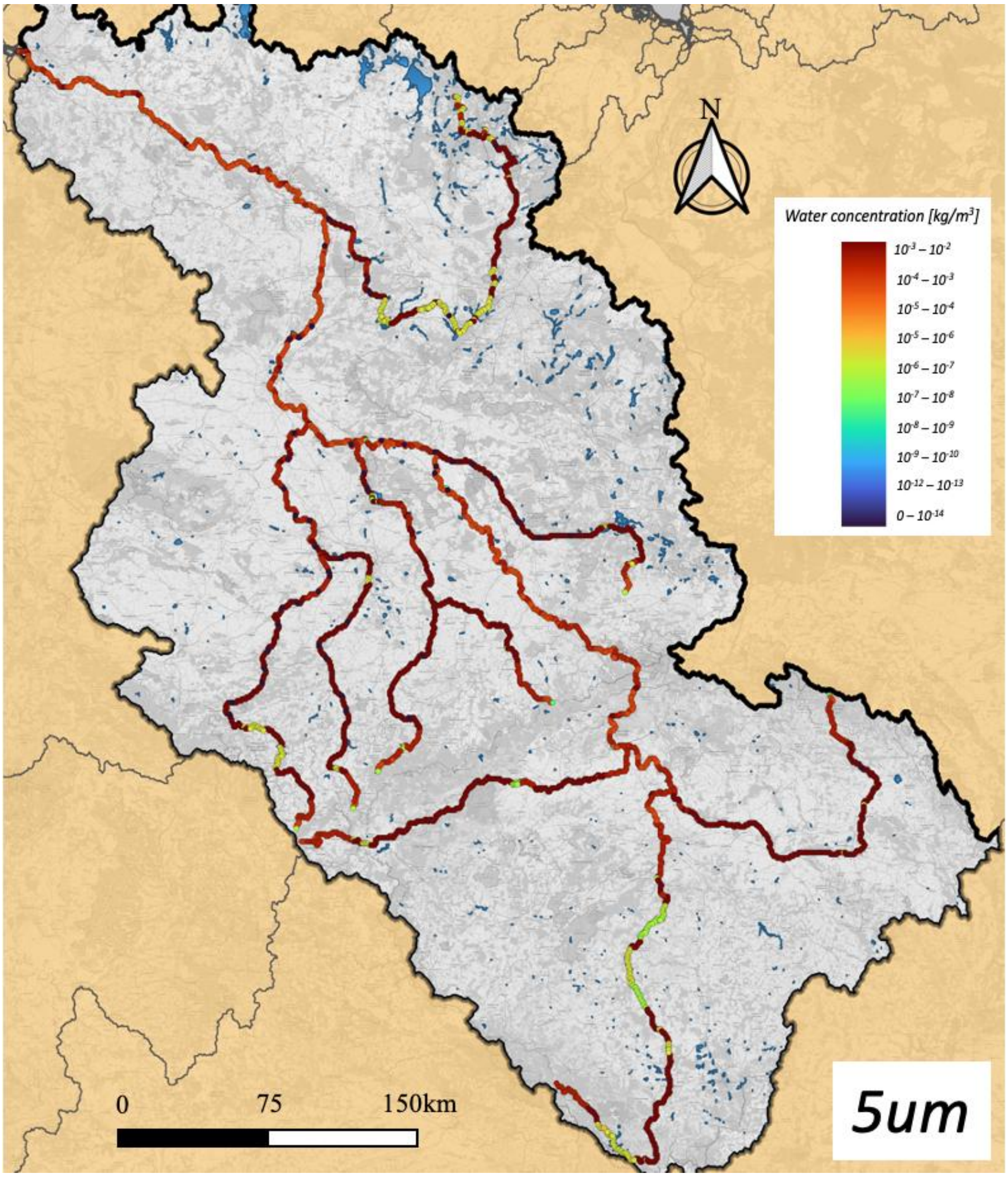

Figure 12. Mass concentration of TWPs (5um) in the bed load layer [avg. flow conditions].

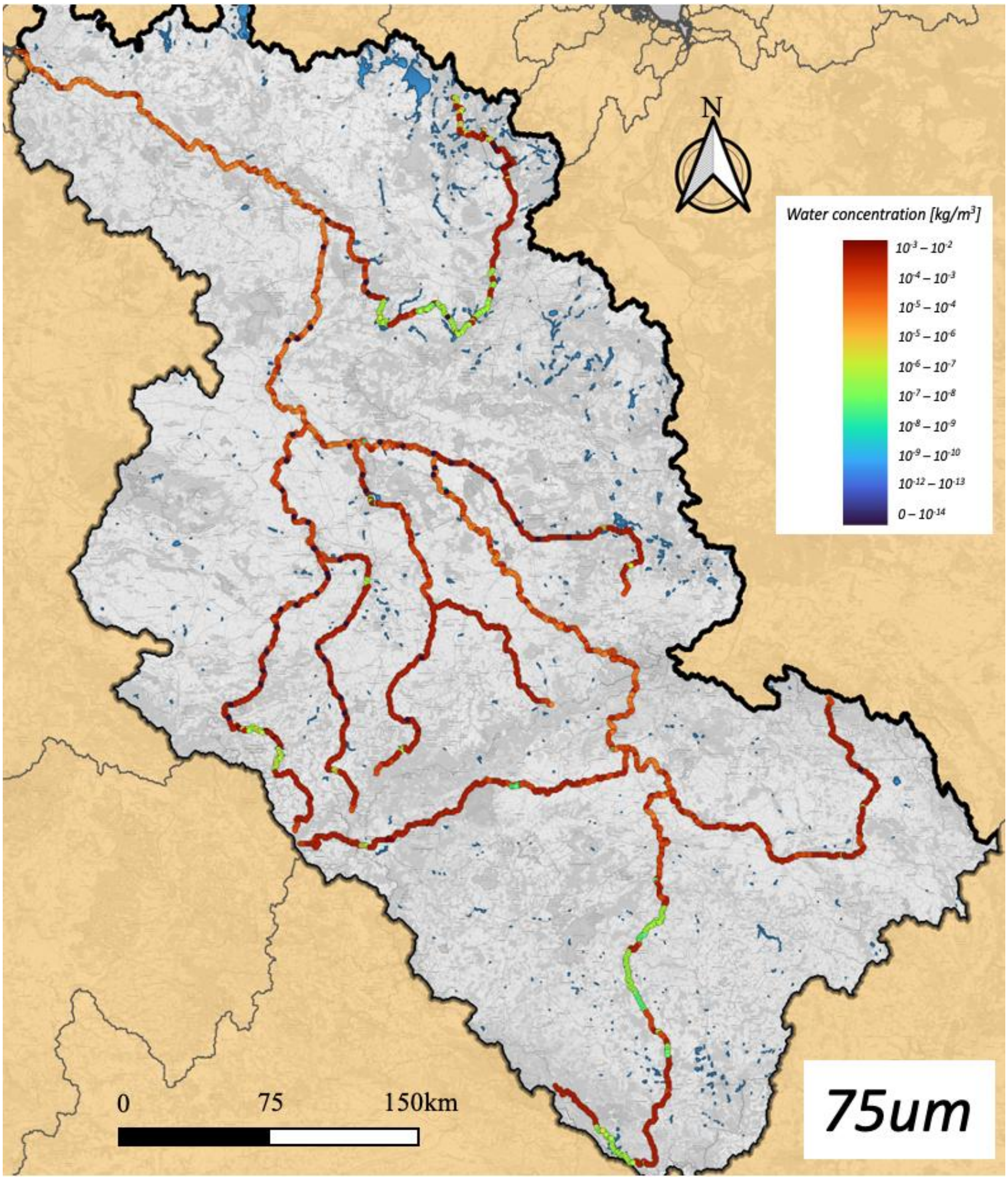

Figure 13. Mass concentration of TWPs (75um) in the bed load layer [avg. flow conditions].

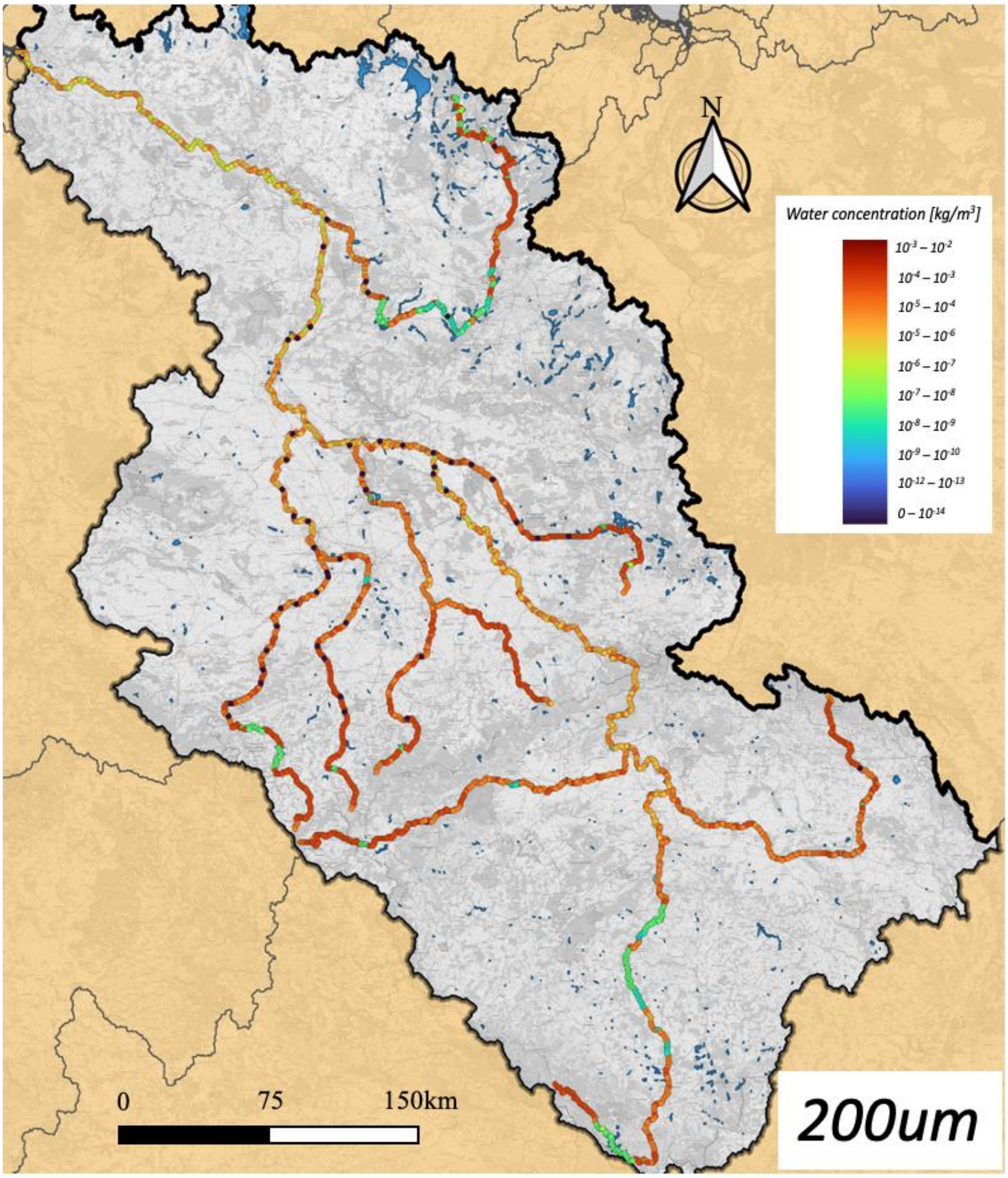

Figure 14. Mass concentration of TWPs (200um) in the bed load layer [avg. flow conditions].

5.2.3 Mass concentration for the sediment layer

Figures 15-17 illustrate the trends of tyre wear particle (TWP) mass concentrations within the sediment layer of the Elbe River Basin. Key conclusions from these results are as follows:

- The mass concentrations observed in the sediment layer are comparable in magnitude to those found in the bed load layer;
- A notable difference from the bed load layer is observed in lake nodes; concentrations within the sediment layer of lakes are substantially higher, reflecting realistic accumulation processes, whereas bed load layer concentrations at these locations are typically lower;
- While mass concentrations in the main channel sediment layer are lower compared to the bed load layer, tributary sediment layer concentrations closely match those of the bed load layer. This suggests that stronger flow dynamics in the main channel prevent significant settling of TWP particles into the sediment layer, maintaining their transport predominantly within the bed load.

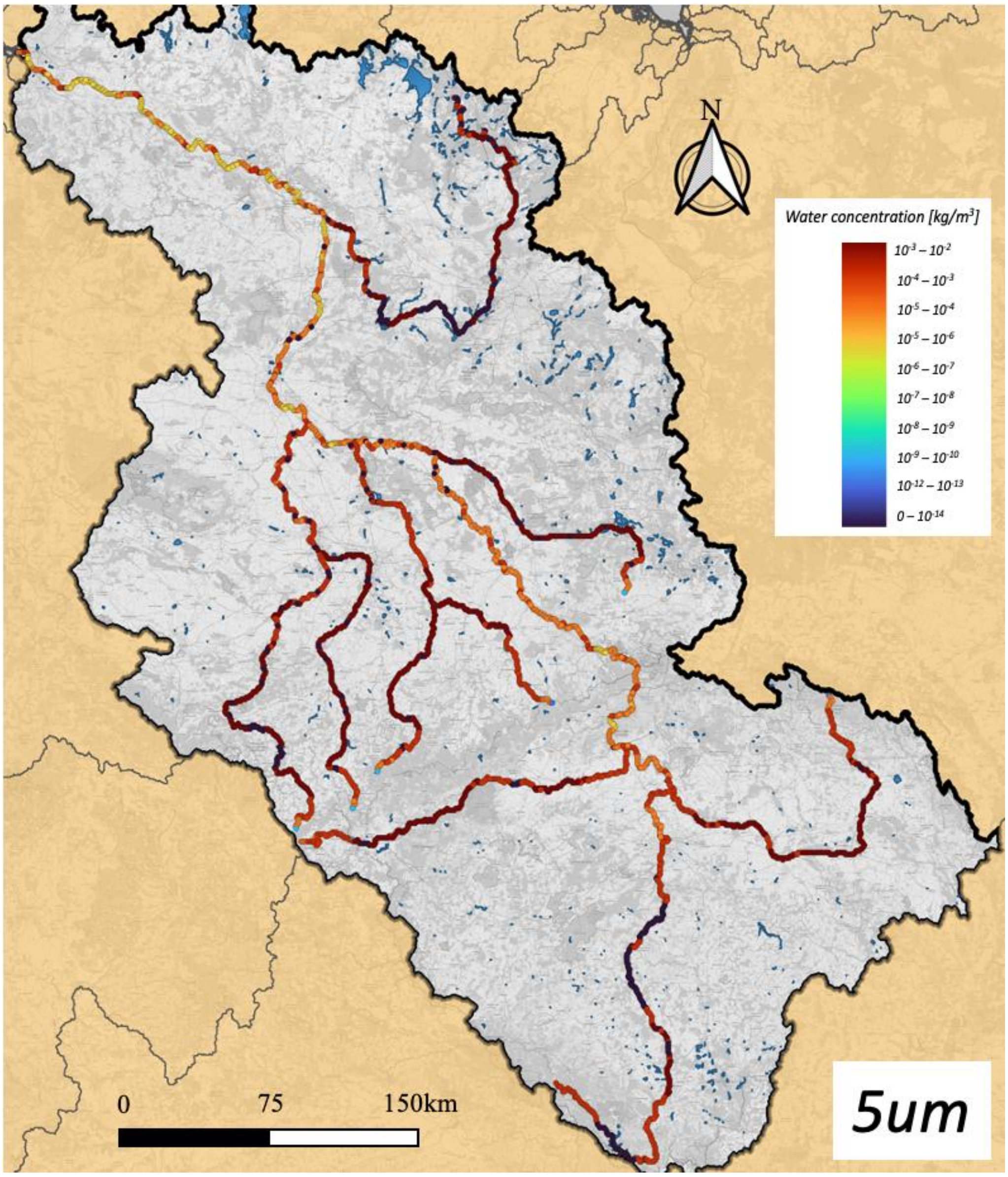

Figure 15. Mass concentration of TWPs (5um) in the sediment layer [avg. flow conditions].

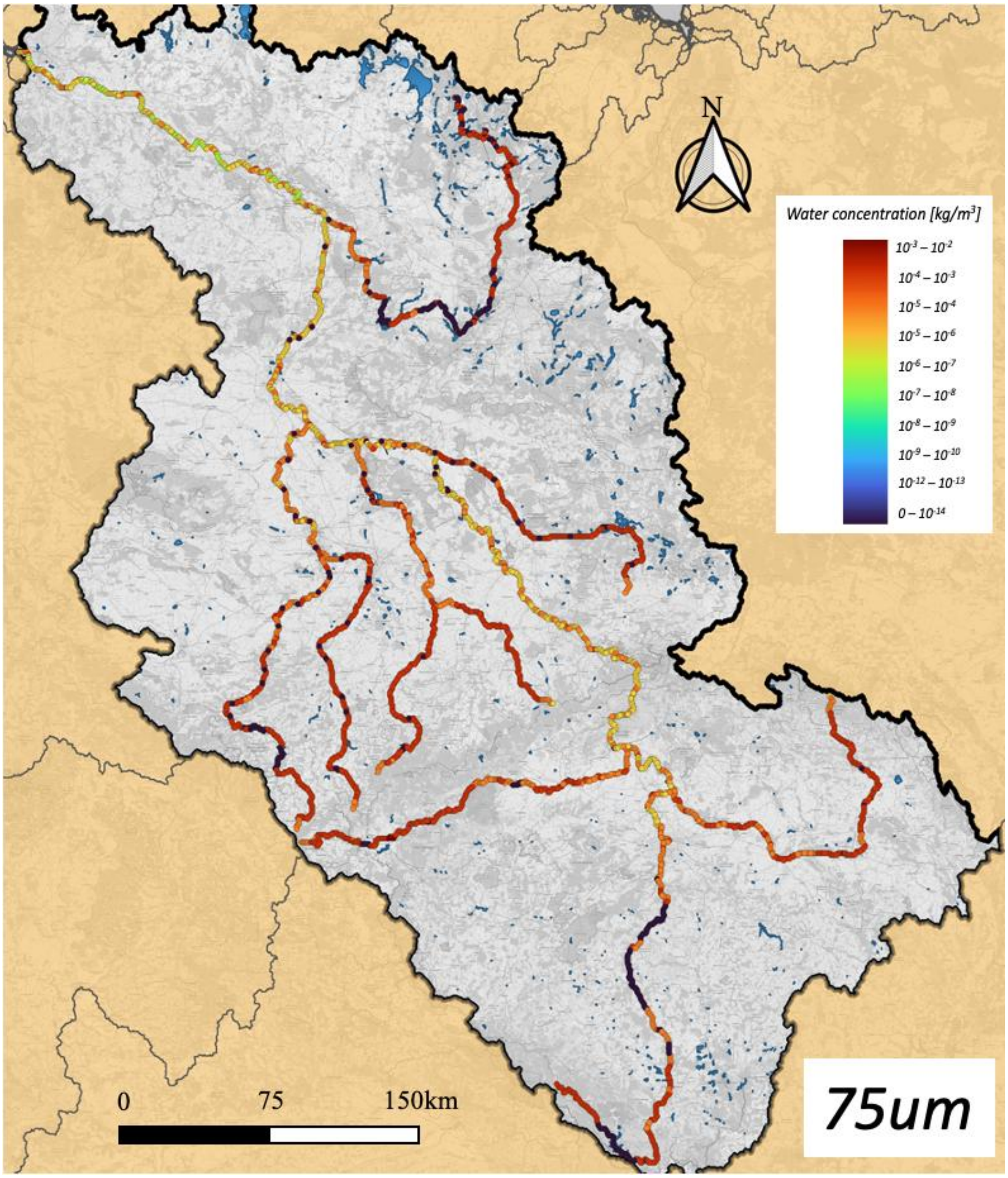

Figure 16. Mass concentration of TWPs (75um) in the sediment layer [avg. flow conditions].

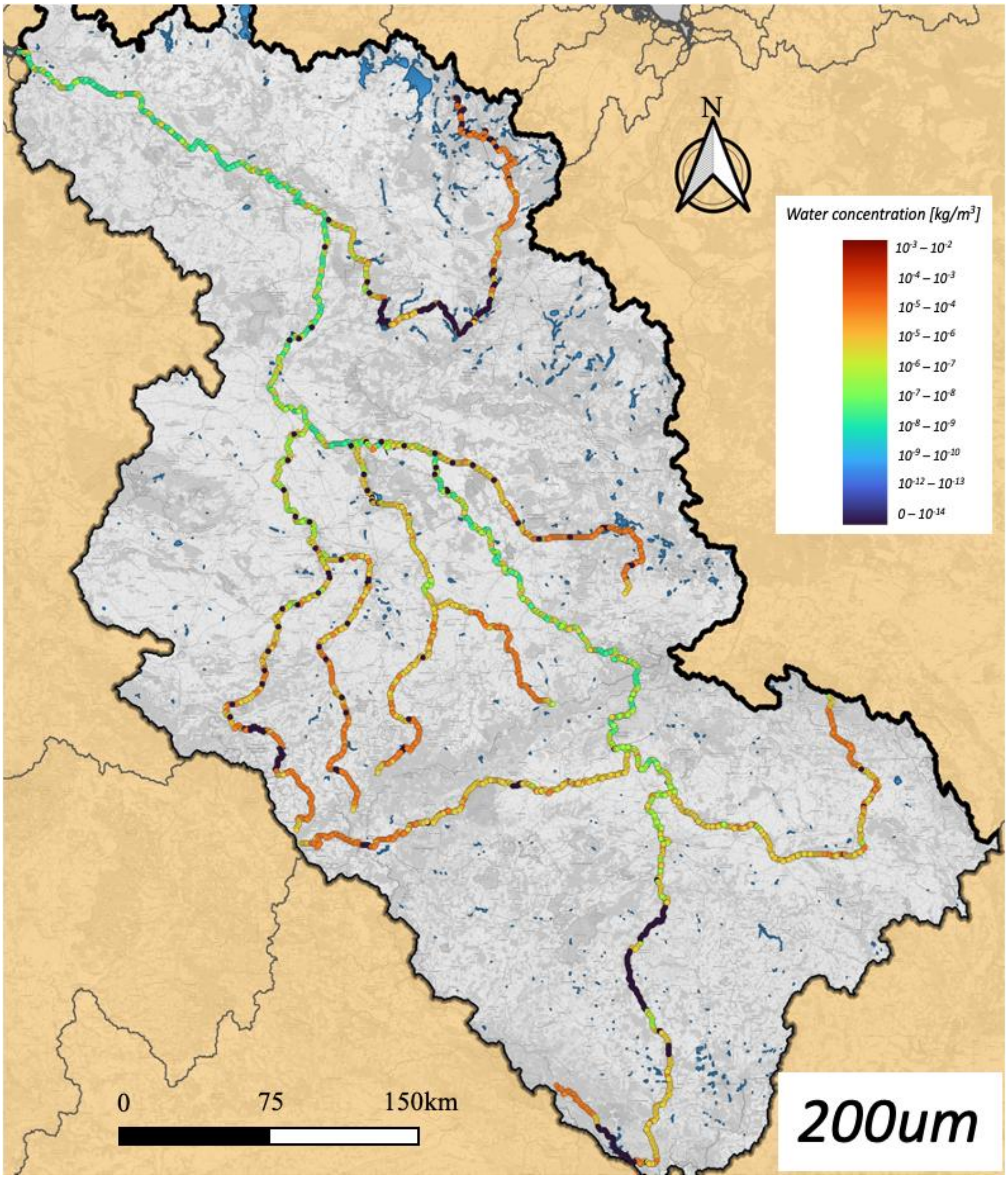

Figure 17. Mass concentration of TWPs (200um) in the sediment layer [avg. flow conditions].

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