

# Plastic in global rivers: are floods making it worse?

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## Article

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## Abstract

Riverine plastic pollution is of global concern due to its negative impact on ecosystem health and human livelihood. Recent studies show a strong link between river discharge and plastic transport, but the role of floods is still unresolved. We combined high resolution mismanaged plastic waste data and river flood extents with increasing return periods to estimate flood-driven plastic mobilisation, aggregated at administration unit, country and global scale. We show that 10-year return period floods already tenfold the global plastic mobilisation potential compared to non-flood conditions. In the worst affected regions, plastic mobilisation increases up to five orders of magnitude. Our results suggest a high inter-annual variability in plastic mobilisation, previously ignored by global plastic transport models. Flood defences reduce plastic mobilisation substantially, but regions vulnerable to flooding often coincide with high plastic mobilisation potential during floods. Consequentially, clean-up and mitigation measures and flood risk management are inherently interdependent and need to be managed holistically.

## Introduction

Riverine plastic pollution is a growing, global concern. Although most research efforts have been focussed on riverine plastic as the primary source of plastic material emitted to the oceans, the effects at the local scale can be equally, or more severe<sup>1</sup>. Plastic pollution has been found to significantly disrupt economic activities such as fishing and tourism, hinder transportation over and along the river, and in some locations puts the availability of clean freshwater at risk, endangering the livelihoods of the communities living next to and depending on the river<sup>1</sup>. For riverine ecosystems, plastic is as detrimental as it is in the ocean, with the effects depending on the size of the debris. The negative effect of macroplastics (> 0.5 cm) are mainly mechanical. For example, fish and mammals get entangled in the plastic and occasional ingestion can cause blockages of their intestinal tracts, enhancing mortality rates<sup>1</sup>. Microplastic pollution is found to break down into its initial - sometimes toxic - components<sup>2,3</sup>, while many of the plastic particles can also act as natural adsorbent of hydrophobic chemicals<sup>4-7</sup>, acting as a vector of bioaccumulation of these substances. These chemical components move up through the food chain, although the resulting effect on riverine ecosystems and human health have not yet been conclusively studied. Of the globally produced 380 million metric tons (Mt) of plastic in 2015<sup>8</sup>, between 0.4 and 12.7 Mt has been reported to reach the ocean from rivers<sup>9-11</sup>. Plastic waste in the river system is potentially even higher, as many sinks have been identified, such as deposition on shores, deposition on and burial in riverbed sediments and accumulation within riverine species<sup>1</sup>.

An increasing number of studies estimated river plastic transport, accumulation and emissions into the ocean on local, national and global scales<sup>9-13</sup>. The temporal dynamics of the plastic load is less well understood, as most observational studies are single instance measurements or measurements over a very short period of time<sup>12</sup>. The first observational studies over longer periods have hinted at a strong link between discharge and the amount of plastic in the river<sup>14-16</sup>. This naturally leads to the question about the importance of extreme discharge events. So far, the only observational study on plastic load in river systems with respect to flooding is a study by Hurley et al.<sup>17</sup>. In this study the riverbed microplastic concentration was found to have decreased by about 70 percent after the flooding of the winter 2015/2016 in the UK, linking high discharges to an increase in plastic (re)mobilisation. At the global scale, the effect of the seasonal change in discharge and extreme flow events have only been quantified with the use of models, using an aggregated, lumped approach for monthly discharge, precipitation and runoff<sup>10</sup>, potentially causing a severe underrepresentation of the effects of flooding on the mobilisation of plastic. Together with the observational evidence that macroplastics clog drainage infrastructure<sup>18-20</sup>, consequentially raising urban flood risk, it shows the importance of studying the interaction between plastic mobilisation and floods at a global scale.

In this study we present the first global analysis of the impact of flood events on plastic mobilisation. In order to estimate this effect, we use publicly available global flood extent maps<sup>21</sup> together with recent, globally distributed data on mismanaged plastic waste (MPW)<sup>20</sup>. By overlapping the flood extents with the distribution of MPW we approximate the mobilised plastic potential within a given extent, thus making it possible to compare the amount of plastic mobilised during floods with different severity to the non-flood situation (as estimated by overlapping data on the spatial extent of the river network with mismanaged plastic waste). As flood defences are not accounted for in the flood extent maps directly, we use the FLOPROS global flood defence database<sup>22</sup> to adjust the plastic mobilisation estimates accordingly. By aggregating the total amount of mismanaged plastic waste in the flood extents, we show that floods dramatically increase plastic mobilisation potential. Many countries see over a 10-fold increase in plastic mobilisation for floods with relatively low severity (10-year return-period), but high spatial variation was found between and within countries. The worst affected areas are the coastal regions in Bangladesh, Vietnam and Gambia, suffering a four to five order of magnitude increase in plastic load during floods. Countries with flood defences protecting against higher return periods, such as the Netherlands and Japan, show few to

no additional plastic being mobilised during flood events. Globally, annual expected plastic mobilisation shows a net annual increase of 140% when accounting for flood events.

## Results

### Global impact of floods on the mobilisation of plastic waste

Floods have the potential to substantially increase the amount of plastic that is mobilised by rivers, as displayed in Fig. 1A. The factor of increase of mobilisation for undefended flood events show a large global variation, with some countries experiencing only a marginal increase during floods, while others could expect up to a 30-fold increase. Of the ten countries with the highest plastic mobilisation potential during non-flood conditions (Table 1), the average factor increase during flooding is 10.3; whereas the ten countries with the lowest plastic mobilisation potential, the average factor increase is 2.4. According to our estimates, Bangladesh is the country with the highest increase in plastic mobilisation during floods, with a potential for mobilisation 40.6 times higher than during non-flood conditions.

Globally, the most substantial increase in potential plastic mobilisation occurs between the non-flood and 10-year return period flood (see Fig. 1B). During non-flood conditions an estimated 0.8 Mt per year of plastic is mobilised across the world. In contrast, 7.3 Mt per year (almost a 10-fold increase) is estimated to be mobilised globally under an undefended 10-year return period flood. Floods with higher return-periods mobilise even more plastic, but the relative increase is not as large due to the fact that extreme floods increase inundation depth rather than extent, hence reaching less new deposited plastic (see Figure S1). For example, the 500-year return-period flood could potentially mobilise globally 9.5 Mt of plastic per year, a 12.7-fold increase from non-flood conditions, but relatively small compared with the 10-fold generated by a 10-year flood.

Table 1

Representation of country data of Fig. 1, presenting the 10 countries with highest/ lowest plastic mobilisation potential under non-flood conditions.

Country	ISO code	Plastic mobilisation under non-flood conditions [ $\text{Mt y}^{-1}$ ]	Plastic mobilisation under a 10-year return-period flood [ $\text{Mt y}^{-1}$ ]	Relative factor of increase with a 10-year return-period flood [-]
<i>Countries with highest plastic mobilisation potential</i>				
China	CHN	1.84E-01	1.81E+00	9.84
India	IND	1.19E-01	1.36E+00	11.45
Brazil	BRA	3.90E-02	1.21E-01	3.11
Thailand	THA	3.17E-02	4.75E-01	15.00
Egypt	EGY	2.53E-02	5.47E-01	21.62
Philippines	PHL	2.48E-02	1.10E-01	4.43
Turkey	TUR	1.76E-02	5.42E-02	3.08
Congo	COD	1.72E-02	3.72E-02	2.16
Nigeria	NGA	1.67E-02	1.08E-01	6.47
Vietnam	VNM	1.66E-02	4.36E-01	26.24
<i>Countries with lowest plastic mobilisation potential</i>				
Ireland	IRL	1.02E-05	3.00E-05	2.95
Costa Rica	CRI	7.91E-06	2.70E-05	3.41
Western Sahara	ESH	7.31E-06	7.31E-06	1.00
Armenia	ARM	6.87E-06	1.76E-05	2.56
Oman	OMN	5.27E-06	1.45E-05	2.75
Somalia	SOM	4.19E-06	4.53E-06	1.08
Panama	PAN	3.53E-06	2.54E-05	7.20
Israel	ISR	2.51E-06	2.99E-06	1.20
Syria	SYR	4.71E-07	4.71E-07	1.00
United Arab Emirates	ARE	4.74E-08	5.19E-08	1.09

## Spatial patterns of plastic mobilisation during floods

The global patterns of mismanaged plastic waste in the flood zones shows a similar picture as described in observational studies on riverine plastic pollution<sup>10</sup>. The most severely impacted region is (South-East) Asia, showing mismanaged plastic waste load in the 10-year return-period flood footprint of over 2500 kg per square kilometre (see Fig. 2A and 2C). The spatial variability of the plastic load in river floodplains is substantial, with areas of low population density such as Australia, southern Algeria and northern USA showing a plastic load in the floodplain of less than 10 kg per square kilometre. Whilst those regions also have plastic load hotspots, they are small compared to the total surface of the floodplain within the administration unit, resulting in a low overall plastic load.

Besides the between-country variability (Fig. 1A), the relative impact of floods on the plastic mobilisation potential shows a substantial within-country variability (Fig. 2B). Large countries show spatial heterogeneity in the factor increase in plastic mobilisation in orders of magnitude, with for example the USA having low plastic mobilisation increase factors in mountainous states such as Wyoming and Colorado (~ 1.4), while that of the coastal state Louisiana exceeds 30 (~ 31). In fact, the same pattern is found across the globe, with

only three out of the twenty administration units with the highest relative increase in plastic mobilisation not coastal. The seven administration units with the highest factors of increase are located in Vietnam, Egypt and Gambia, respectively in the Mekong, Nile and Gambia river delta, together mobilising 11.6 tonnes during non-flood conditions and 0.1 Mt during a 10-year return-period flood event, which is a four orders of magnitude increase (Table 2). When aggregating the data at riverbasin level the same patterns arise: most of the administration units with a factor of increase higher than 10 fall within the 25 biggest basins.

Table 2  
plastic mobilisation potential during non-flood and 10-year return-period flood conditions and their relative difference. The 10 administration units with highest factor of increase are presented here.

Administration unit	Country	ISO code	Plastic mobilisation under non-flood conditions [Mt $y^{-1}$ ]	Plastic mobilisation under a 10-year return-period flood [Mt $y^{-1}$ ]	Relative factor of increase with a 10-year return-period flood [-]
Bến Tre	Vietnam	VNM	9.81E-08	1.03E-02	1.05E + 05
Lower River	Gambia	GMB	4.89E-09	1.26E-04	2.58E + 04
Tiền Giang	Vietnam	VNM	8.83E-07	1.93E-02	2.19E + 04
Al Qalyubiyah	Egypt	EGY	2.01E-06	3.15E-02	1.57E + 04
Ad Daqahliyah	Egypt	EGY	1.70E-06	1.38E-02	8.13E + 03
Vĩnh Long	Vietnam	VNM	2.99E-06	1.27E-02	4.23E + 03
Sóc Trăng	Vietnam	VNM	3.91E-06	1.55E-02	3.96E + 03
Wanica	Suriname	SUR	2.34E-06	3.26E-03	1.39E + 03
Greater Accra	Ghana	GHA	5.98E-07	6.32E-04	1.06E + 03
Glodeni	Moldova	MDA	5.65E-08	4.00E-05	7.05E + 02

## Reduction of plastic mobilisation by flood defences

During floods with low return-periods, flood defences avert a substantial part of the increment in plastic mobilisation (Fig. 1B). For a 10-year return period flood, the mobilised plastic potential is reduced by 53% (from 7.3 to 3.4 Mt per year), while for a 20-year return-period flood, this is estimated to reduce by 33% (from 7.8 Mt to 5.2 Mt). The effect of flood defences at higher return periods, however, is much lower, with an estimated reduction of less than 2% for a 100-year return-period flood, and a reduction approaching zero for floods with higher return-periods. This mirrors the global presence of flood defences; many rivers have flood defences in place that protect against low severity floods, while relatively few flood defences can avert a 100-year return period flood.

As medium to severe floods do not occur every year, we have also estimated the expected annual plastic mobilisation potential (EAM) accounting for the probability of flood events in each year, by integrating the mobilised plastic over all available flood extents (see Figure S2 for a graphical representation). This yields an expected total of 2.8 Mt mobilised plastic per year, reduced to 1.8 Mt per year when flood defences are accounted for, compared to an estimated 0.8 Mt for a year without flood event (Fig. 1B).

Figure 3 shows the EAM for each country with and without the effect of flood defences. The 1:1 line represents the case in which flood defences have no effect on the mobility of plastic while the horizontal line represents the 100 percent reduction of flood induced plastic mobilisation. The reducing effect of flood defences on the EAM varies drastically, with half the countries showing less than a 10% reduction in EAM and only a handful of countries reducing the additional plastic mobilisation related to flooding to 0. Of the locations with the highest increase factor, both Gambia (GMB) and Vietnam (VNM) lie close or on the 1:1 line, suggesting that relatively few flood defences are present or only protecting against relatively low return period floods, while flood defences in Egypt achieve a 53% reduction in plastic mobilisation. Other countries that stand out are Pakistan (PAK) and Bangladesh (BGD), both showing expected annual plastic mobilisation that is more than 10 times higher than what would be expected if no flood would happen, while their flood defences are not sufficient to reduce this number significantly. Other strongly impacted countries are Japan and the Netherlands displaying an 86% and a 100% reduction in flood induced plastic mobilisation, respectively, as a consequence of their flood defences.

## Discussion

We have conducted the first global assessment of the increase in plastic mobilisation caused by river flooding. In comparison with other global assessments of plastic transport through river systems a simplified approach was used to solely focus on the mechanism of flood induced mobilisation. Nevertheless, our findings of expected annual plastic mobilisation (1.8 Mt per year, accounting for existing flood defences) fall in the same range as river plastic emissions found by Lebreton et al. (2017) (1.15 to 2.41 Mt per year) and Schmidt et al. (2017) (0.4 to 4 Mt per year), based on similar mismanaged plastic waste data but using a hydrological modelling approach accounting hydrological extremes (although lumped to monthly/yearly values and averaged over the catchment). Further, with our approach we were able to express plastic mobilisation potential as a function of flood severity, which reveals a range of 0.8 to 9.5 Mt per year between the non-flooded and 500-year return period flood, suggesting that temporal variability cannot be ignored when assessing riverine plastic pollution. This opens up the potential to estimate both past trends with flood extent reanalysis data<sup>23</sup>, and provide forecasts of flood plastic mobilisation potential in real-time by coupling flood inundation extents from a global flood forecasting system, such as GloFAS (<https://www.globalfloods.eu/>)<sup>24</sup> to the mismanaged plastic waste exposure data, thus enabling the implementation of targeted mitigation measures before, during and after pollution peaks.

Focussing on flood events specifically, the results show a ten-fold worldwide potential plastic mobilisation increase even during low severity floods (10-year return-period). The increase varies substantially between and within countries, with the worst affected areas in the world showing a four to five orders of magnitude increase in plastic mobilisation during flood events. These worst affected regions are almost exclusively located in coastal regions, with the administration units showing the highest increase factors being situated in the Mekong, Nile and Gambia river delta. People have lived on the floodplains for millennia and many of today's megacities are (partly) situated in floodplain-rich delta areas. At the same time, both flood defence protection levels and mismanaged plastic waste were found to negatively correlate with GDP<sup>20,22</sup>. Severe flood induced plastic mobilisation occurs when these patterns come together, hence defining a nexus between people, plastic, and flood defence on floodplains.

When interpreting the results, several assumptions and shortcomings in the data need to be considered. Firstly, mismanaged plastic waste used in this study is an estimation based on GDP and waste statistics at national level. Although currently the most accurate global data available, it relies on simplified assumptions such as a linear relationship between GDP and waste collection, and excludes any informal waste collection. Additionally, it does not include intentional waste redistribution (e.g. dumping) which has been hypothesised to be substantial additional source of plastic load in rivers<sup>1</sup>. Furthermore, the data is described as (plastic waste generation) rates, rather than quantities, ignoring a potential build-up of plastic over time, which is inherently hard to validate. Note also that this study only focuses on mismanaged plastic waste, whilst actual plastic mobilisation during flood events is likely to be higher as properly disposed plastic waste and non-waste plastic can be generally transported as well.

Secondly, we only account for plastic mobilisation in inundated areas during flood events in larger rivers. Plastic mobilisation pathways and mechanisms through smaller (urban) streams<sup>25</sup> are not resolved in the river network and flood extent maps in this global study, as they only include river grid cells with an upstream area of at least 5000 km<sup>2</sup>. Note that only plastic within the floodplain is accounted for here. As floods are not always singular events, but also occur as complex, compound events<sup>26–29</sup> plastic mobilisation potential might be considerably higher when for example including transport with surface runoff (especially in urban areas) and strong (gust) winds during such compound events. Additionally, storm surges or tsunamis can transport massive amounts of plastic, such as observed after the tsunami in Japan in 2011, when an estimated 5 Mt of plastic was transported into the ocean<sup>30</sup>. This catastrophic event attributed was attributed to have transported "thousands of years worth of 'normal' litter flux from Japan's urbanized coastline"<sup>31</sup>. Future research is needed to shed additional light on the role of natural hazards (e.g. floods, storms, tsunamis, landslides), especially when they cooccur, on plastic mobilisation, transport as well as emission into the ocean.

The results of our study have important management and future research implications. By overlapping high resolution global flood extent estimates with spatially distributed data on mismanaged plastic waste, we highlight the vulnerability of individual countries and administration units to plastic pollution during flood events. This was subsequently used to identify global hotspots, where floods have the greatest potential of increasing plastic mobilisation. Furthermore, it emphasises that in order to tackle the problem of riverine plastic pollution globally, the whole river system - including flooding - needs to be considered holistically. Depending on the localities this could for example mean displacing waste management facilities outside the floodplain or creating a buffer zone between the river and floodplain that could function to retain the mobilised plastic, thus facilitating clean-up and preventing further displacement of the waste. Floods, and their ability to transport plastic pollution, are not contained by borders of the political entities and reducing river plastic mobilisation will therefore require multilateral policies on plastic waste and flood risk management. With the current predictions of

increased occurrence of (compound) natural hazards, high urbanisation rates and an ever-increasing production of plastic, understanding the spatial and temporal distribution of flood induced mobilisation is an important step towards targeted policy and prevention/clean-up strategies in the global effort to reduce plastic waste in the environment.

## Methodology

The potential for floods to mobilise plastic in rivers is quantified combining mismanaged plastic waste (MPW) data with information of flood/non flood footprints and flood defence. The resulting estimates are aggregated for an annual net plastic mobilisation risk, accounting for the likelihood of flood events

## Input data

### Flood Extents

Global, openly available (<https://data.jrc.ec.europa.eu/collection/id-0054>), static flood extent maps at 30 arc-second resolution<sup>21</sup> were used as an estimate of flood footprint for different flood severity levels. The data were generated from 0.1 degree streamflow climatologies derived from the Copernicus Emergency Management (CEMS) Global Flood Awareness System (GloFAS)<sup>24</sup>, using estimated river discharge maxima for the 10, 20, 50, 100, 200 and 500 years return period severity levels downscaled to 30 arc second and fed into the CA2D hydrodynamic model<sup>21,32</sup>. Additionally, a river network map, based on the HydroSHEDS hydrologically corrected digital elevation model (DEM) by Dottori et al.<sup>21</sup>, was used to represent the non-flood conditions. Both the river network and flood extent data exclude river cells with an upstream area of less than 5000 km<sup>2</sup>. As the river network map does not extend above 60 degrees North, all input data have been clipped to the same extent. Note that there will be some uncertainties matching flooded and non-flooded conditions at the edge of the domain resulting in a small number of overestimates, particularly in Canada and Russia.

### Modelled Mismanaged Plastic Waste

As observational data on the global abundance of land-based plastic pollution is scarce, we use a global modelling dataset of mismanaged plastic waste<sup>20</sup>. This dataset was created using country level data on total waste generation, estimates of the plastic fraction of this waste and estimates of the fraction of this waste that is not managed by the public waste systems. Subsequently, this data was distributed within countries on the basis of high-resolution GDP and population estimates, yielding a 30 arc second map of annual mismanaged plastic waste generation. The data is publicly available as supplement to the paper of Lebreton and Andrade (2019).

### Flood Defences

As there is no global dataset of flood defence assets, flood defences were accounted for using the 'merged' layer of the publicly available, global flood protection database FLOPROS<sup>22</sup>. This dataset was constructed from local policy standards and the design return periods from technical documents on flood defences, with gaps filled by using relationships between GDP and flood defences at global scale. The resulting dataset contains maximum flood return periods at sub-country administration level (using GADM polygons - <https://gadm.org/index.html>), for which the flood defences provide protection<sup>22</sup>.

### Analysis procedure

The estimates of mobilised plastic potential were created by overlapping the footprint of the river network and flood extents with the annual modelled mismanaged plastic waste layer and aggregating the sum of the data in the GADM administration units, obtained from the FLOPROS database. By overlapping MPW with the river network the base plastic mobilisation is defined, while the flood extents (including the river network) provide estimates of mobilisation during floods with different severities (for a visual example see Figure S1).

To estimate the net annual effect of floods of different severities on plastic mobilisation we calculated the expected annual plastic mobilisation (EAM) following Tiggeloven et al.<sup>33</sup>, where the EAM is given as the integral of the mobilised plastic over each return period using the flood footprint maps (see Figure S2). The method is often used to calculate damages that happen during flooding<sup>33</sup>, and is adjusted here to account for the pollution that happens during non-flood conditions as well. The mobilised plastic during non-flood conditions is attributed to annual exceedance probabilities exceeding 50 percent, with the assumption that a two-year return-period flood does not exceed the natural water holding capacity of the riverbanks<sup>34</sup>. As the flood extent footprint maps exclude any flood protection

structure EAM is calculated twice: (1) excluding any flood defences and (2) while assuming EAM estimates of 'non-flood conditions' for return periods smaller than the critical return period of the flood defences from FLOPROS. To facilitate the interpretation of the results were aggregated to administration unit (FLOPROS), river basin (HydroSHEDS<sup>35</sup>) and global scale.

## Declarations

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We thank Francesco Dottori (JRC) for providing information and data on the flood extent and river network maps.

### Author contribution

CTJR, TvE and SH designed the analysis, CTJR executed the analysis, DE contributed by introducing FLOPROS, CB obtained the data. All co-authors contributed to the interpretation of the results and the writing of the manuscript.

### Competing Interests

We declare that there are no competing interests.

### Data Availability

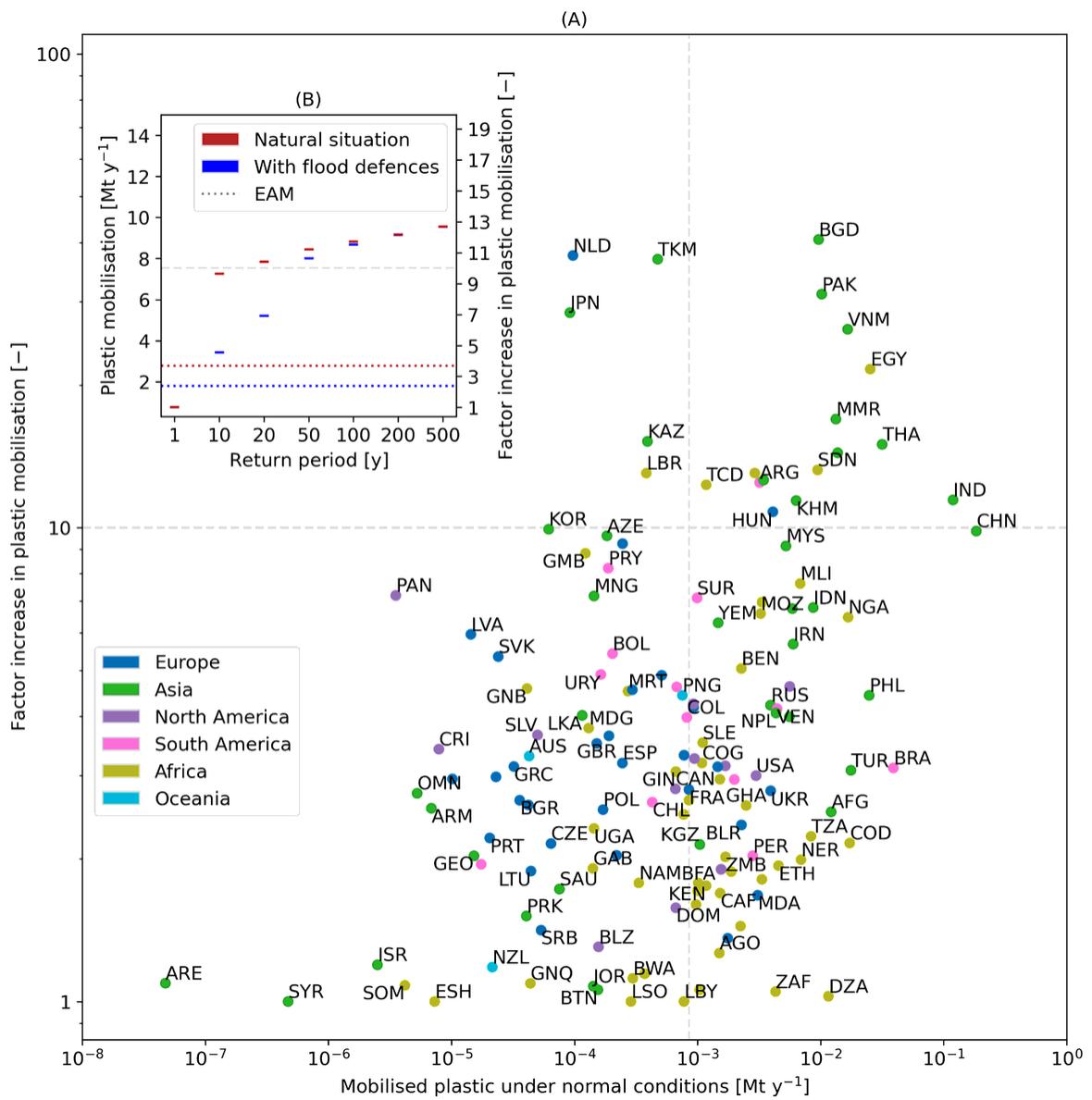
All data used in this study are openly available. The data on mismanaged plastic waste can be found as supplement to Lebreton et al.<sup>20</sup> ([https://figshare.com/articles/Supplementary\\_Data\\_for\\_Future\\_scenarios\\_of\\_global\\_plastic\\_waste\\_generation\\_and\\_disposal/\\_5900335](https://figshare.com/articles/Supplementary_Data_for_Future_scenarios_of_global_plastic_waste_generation_and_disposal/_5900335)), the river flood extents as supplement to Dottori et al.<sup>21</sup> (<https://data.jrc.ec.europa.eu/collection/id-0054>), the FLOPROS flood defence database as a supplement to Scussolini et al.<sup>22</sup> (<https://www.nat-hazards-earth-syst-sci.net/16/1049/2016/>) and the HydroSHEDS basins are published in Lehner et al.<sup>35</sup> (<https://www.hydrosheds.org/>).

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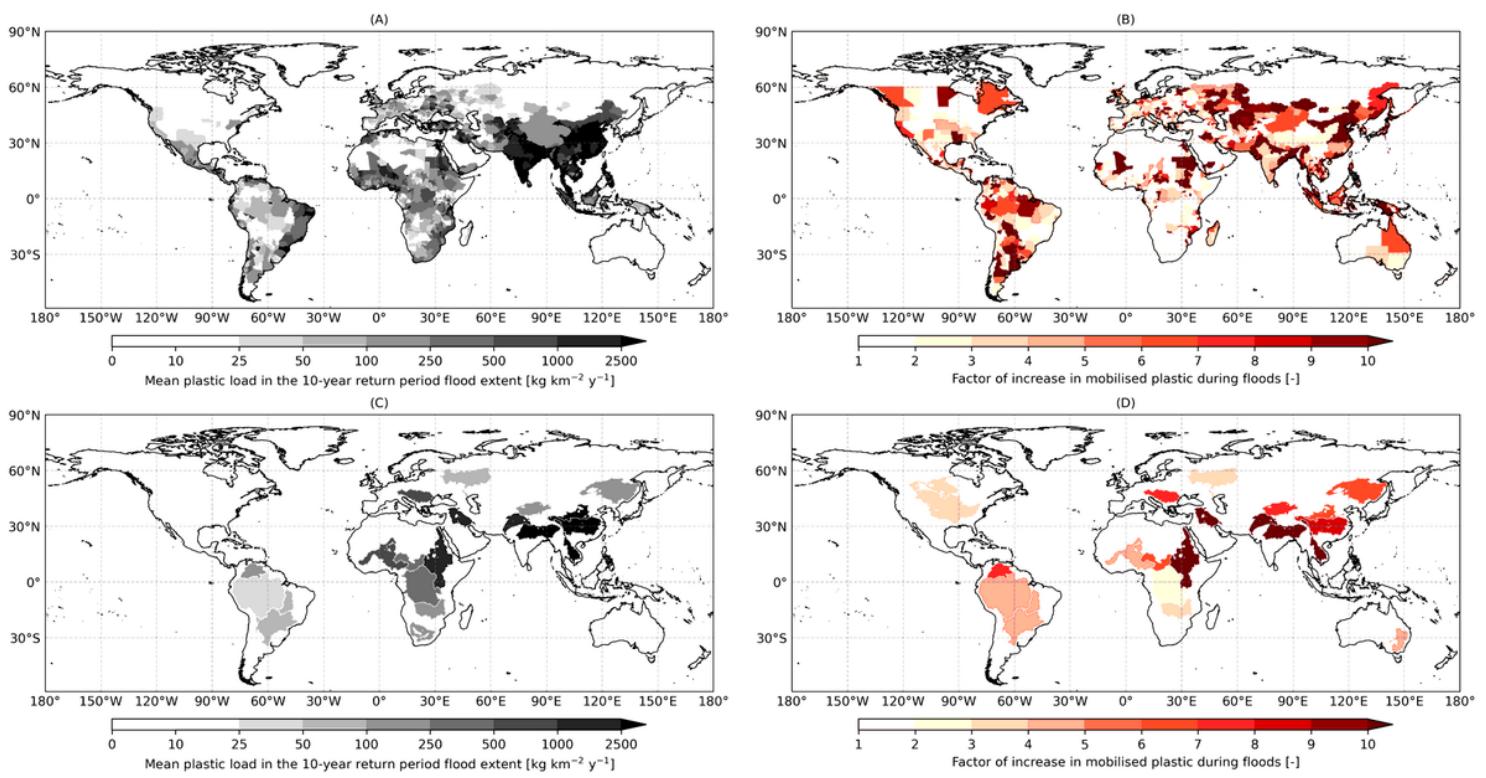
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## Figures



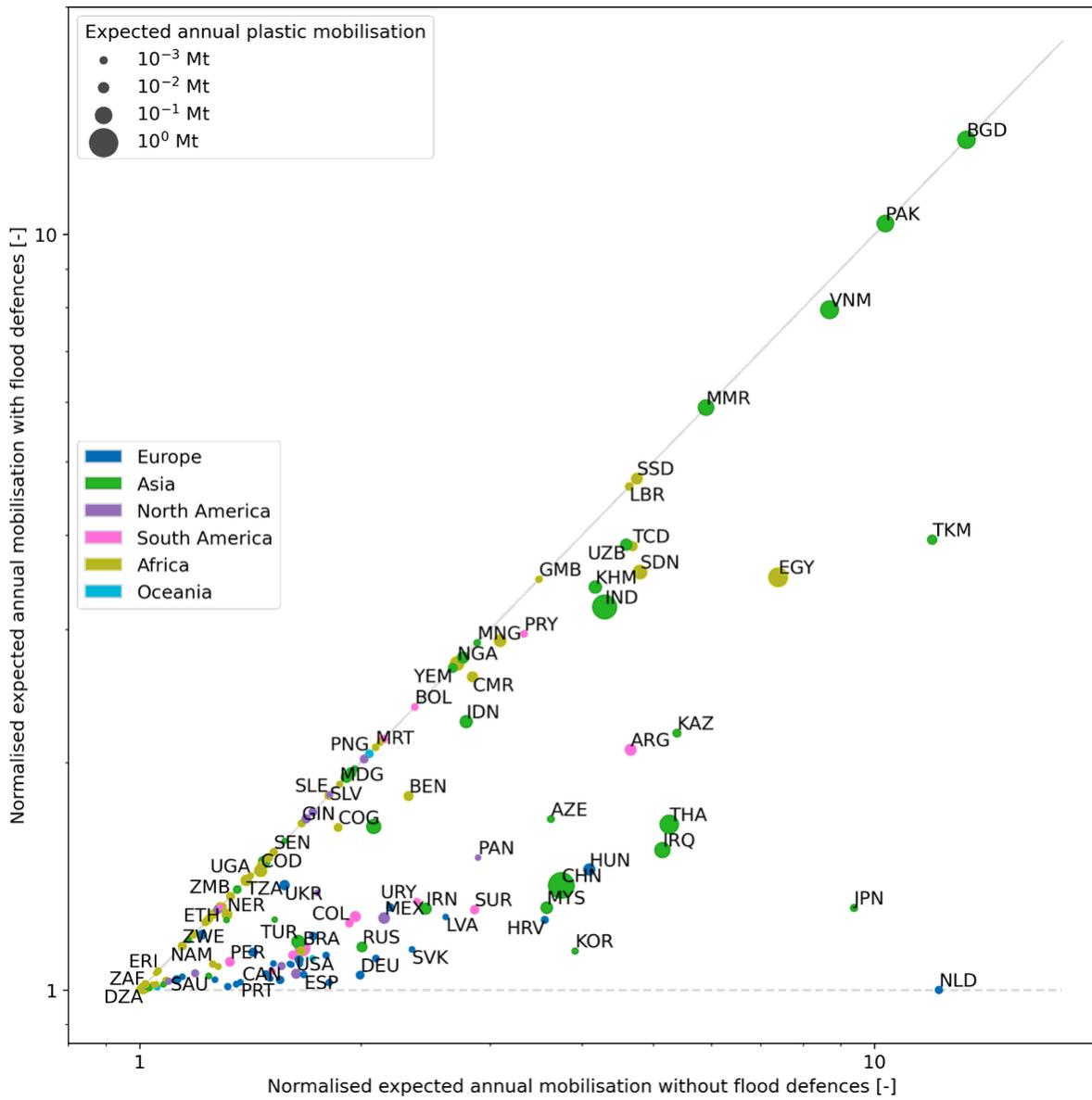
**Figure 1**

Flood induced plastic mobilisation potential at country and global scale. (A) Plastic mobilisation potential during non-flood conditions (x-axis) versus the factor of increase of mobilised plastic during a 10-year return-period flood without flood defences. The five percent of countries with the smallest 10-year return-period flood footprint have been left out, as their relative uncertainty is highest. (B) Displays the global plastic flood mobilisation potential in function of flood severity with (blue) and without (red) flood defences. The dotted horizontal lines display the expected annual mobilisation (EAM), which is calculated by integrating the mobilisation during flood and non-flood conditions, again blue displaying with and red without flood defences. The grey dashed horizontal lines in both (A) and (B) display a 10-fold factor increase, while the dashed vertical line represents the median plastic mobilisation potential under normal conditions for all countries.



**Figure 2**

Global distribution of plastic mobilisation potential during 10-year return-period flood conditions. (A, C) represents the values normalised by the flood extent, and (B, D) normalised by the non-flood plastic mobilisation potential. (A) and (B) aggregate the values over the FLOPROS administration units; (C) and (D) aggregate the values over the 25 largest river basins in the HydroSHEDS dataset. See Figure S3 and S4 for the factor of increase of potential plastic mobilisation during floods with different severities in the administration units (in Figure S4 the administration units with flood defences exceeding the flood are greyed out). Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.



**Figure 3**

Reduction in expected annual plastic mobilisation by flood defences. Expected annual mobilisation potential (EAM) (aggregated mobilisation over the different return periods), normalised by potential plastic mobilisation during non-flood conditions, per country, without (x-axis) and with (y-axis) flood defences. The size of the points depicts the absolute EAM values per country.

## Supplementary Files

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