SUPPLEMENTARY MATERIAL

This document presents the Supplementary Material for the manuscript: "*Assessing plastic waste discharges into the sea in Indonesia - an integrated, high-resolution modelling approach that accounts for hydrology and local waste handling practices"* by Veiga et al.

CONTENTS

File S1. Overview of data sources used in the SWM and environmental modelling, providing details **for section 2 - Material and Methods**

Solid waste management		
Indicator / parameter	**Data sources**	**Remarks**
Solid waste generated/capita (SWG) **Plastic content**	• Solid Waste Master Plans (SWMPs) • National Waste Management Information System database – SIPSN, Ministry of Environment and Forestry	• Data available for only half (257) of total kabupaten/kota in Indonesia • SWMPs data based on sampling of SWG and composition, considered to be good quality • SIPSN is self-reported, no data validation, not based on sampling, therefore lower reliability • For the kabupaten/kota without data, the average amount of SWG (based on combined SWMPs and SIPSN database for households and non-households) is a representative value • Average amount of SWG and plastic content are differentiated between kabupaten/kota
Total plastic waste formally collected	• Ministry of Public Works and Housing (PUPR) • SIPSN database • Cross-checked with SWG and HANSOS 2017 (Indonesian Statistics Bureau - BPS)	• Landfill data compared to SWG and BPS HANSOS 2017 and lowest number selected as final figure for formally collected plastic waste.
Collected by residential waste pickers	• World Economic Forum, 2020	• Values for four archetypes (mega, medium, rural, and remote) extrapolated to kabupaten/kota (recovery factor of 67%) is a representative value
Handling practices for uncollected waste (burning, burying, discard in water, dumping)	• HANSOS 2017	• Data only at provincial level • Split into urban and rural • Good quality data, although only collected every three years.
Recovery from TPS3R	• PUPR	• No systematic data available • Total plastic recycled is assumed at 78.3% of TPS3R design capacity • Based on three studies in kota Medan and Malang (2016, 2017, and 2019) and applied nationally
Recovery from waste bank	• SIPSN database	• No systematic data available • Total plastic recycled is assumed to be the same as Waste Bank design capacity
Disposal to sanitary landfills, controlled landfills and formal dumpsites	• Sanitary landfill gate data or design capacity: PUPR and SIPSN database • Expert opinion in case of poor data coverage	• Data only available for 351 out of 437 landfills • Weighbridge measurements limited (exact figure unknown) • 130 landfills have been in operation for more than 10 years, which is the minimum lifetime design capacity. The study assumes that the rate of plastic waste available for wash-off is not affected by the fact that these landfills have already reached their capacity but are still operational.
Leakage rate from sanitary landfills, controlled landfills and formal dumpsites	• Rate: expert opinion • Landfill coordinates: PUPR and SIPSN	• If landfill coordinates available: considered as point source • For controlled landfills and dumpsites, three ranges (%) defined: low, mid and high of the total plastic disposed

Environmental modelling		
Model parameters	**Data sources**	**Remarks**
Retention at dams	• Dams location: PUPR	• All dams assumed to have equal retention rate of 100% of plastic litter from upstream catchment
Weathering/degradation, burial on land and retention in rivers	• Expert judgement • Literature	• First-order removal processes

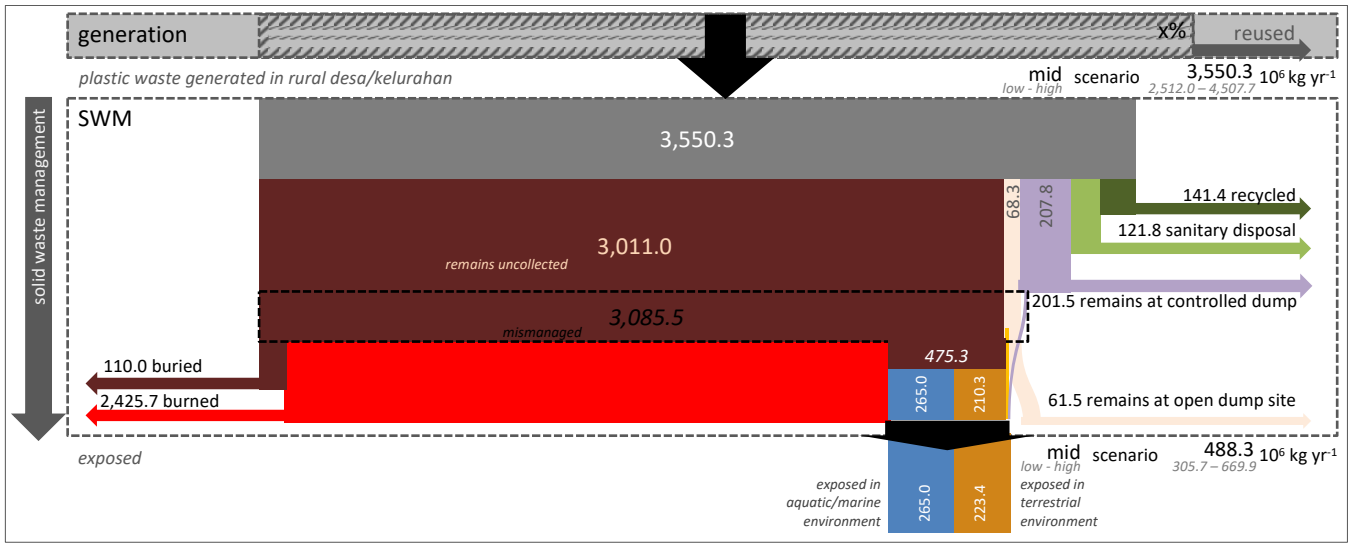
File S2. Rate of exposure to hydrology for the different destinations of formally collected and uncollected plastic waste. (*losses from collection and sorting are accounted under "uncollected"). This summarizes the exposure rates assumed for the study, as described in section 2 – Material and Methods.

Plastic waste	Destination	Rate of exposure of waste to hydrology	Source type
Formally collected (*)	Sanitary landfill, TPS3R, waste banks	0%	Point sources, terrestrial environment
	Controlled landfill	2% (low), 3% (mid) and 5% (high)	
	Formal open dumpsite	5% (low), 10% (mid) and 20% (high)	
Uncollected	Disposal in water	100%	Diffuse sources, aquatic environment
	Dumping/fly-tipping	100%	Diffuse sources, terrestrial environment
	Burning	0%	
	Burying	0%	

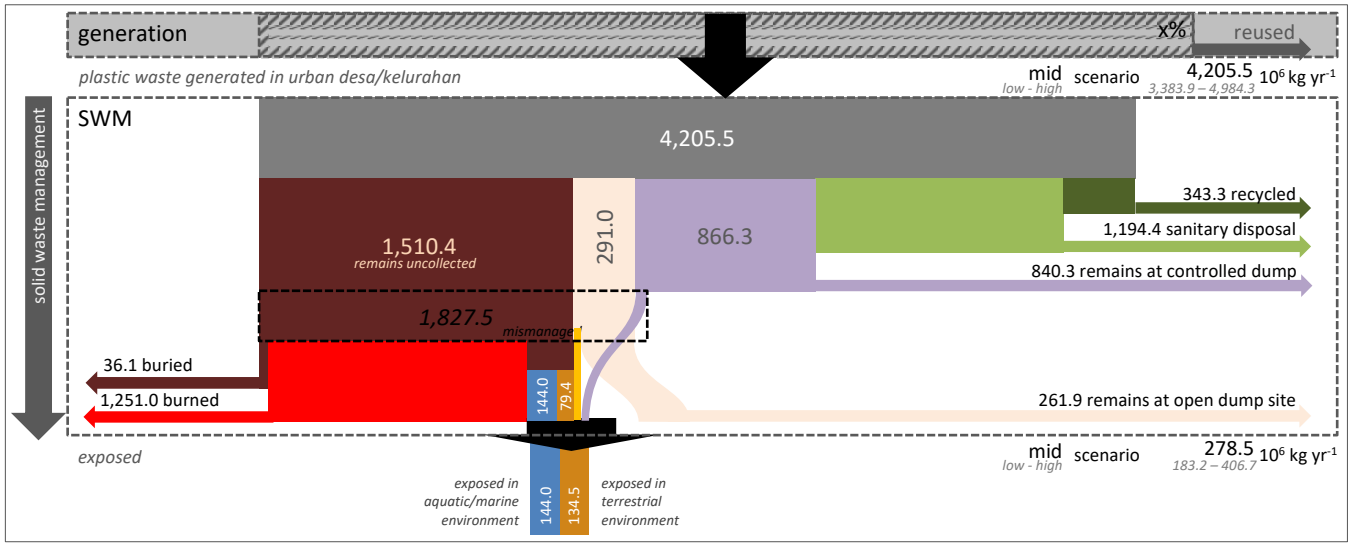
File S3. Environmental fate parameters used in the D-Emissions and D-Water Quality software as **referred to in section 2 – Material and Methods.**

Parameter	**Value**	**Unit**
terrestrial retention rate r_t, paved surfaces	0.02	(d^{-1})
terrestrial retention rate r_t, unpaved surfaces	0.03	(d^{-1})
aquatic retention parameter k_a	0.5	(m d^{-1})
threshold for start of mobilization by runoff t_{lo}	2	(mm d^{-1})
threshold for complete mobilization by runoff t_{hi}	5	(mm d^{-1})

RURAL



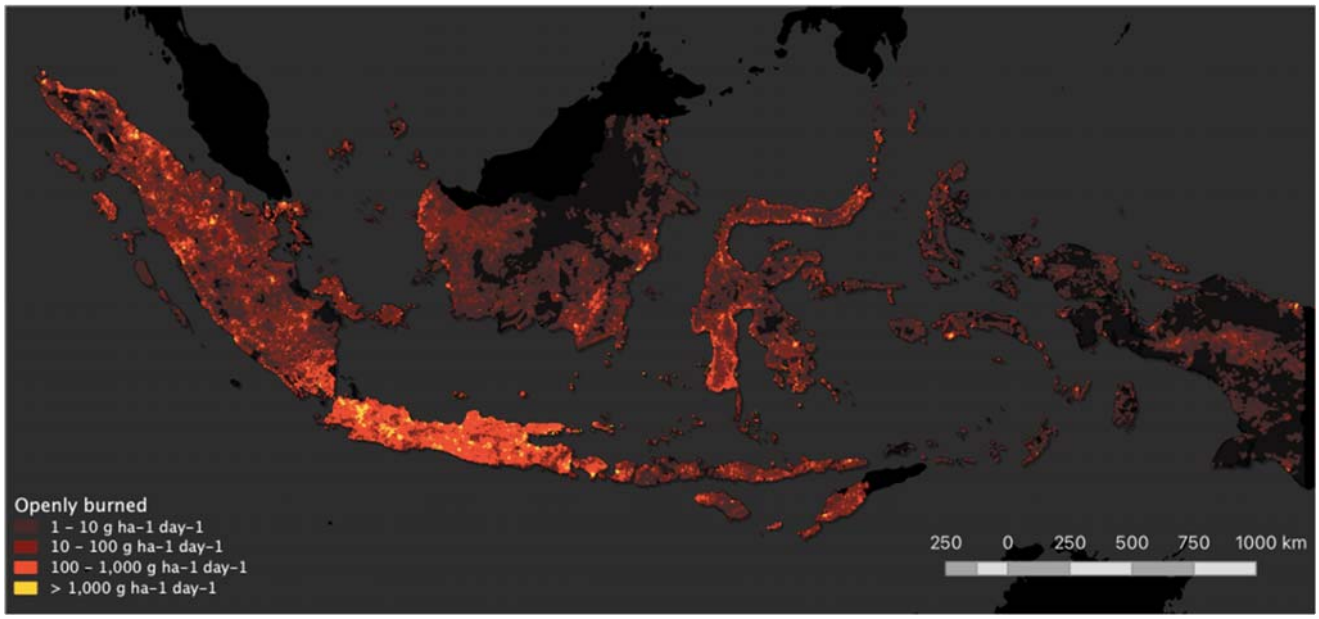
URBAN



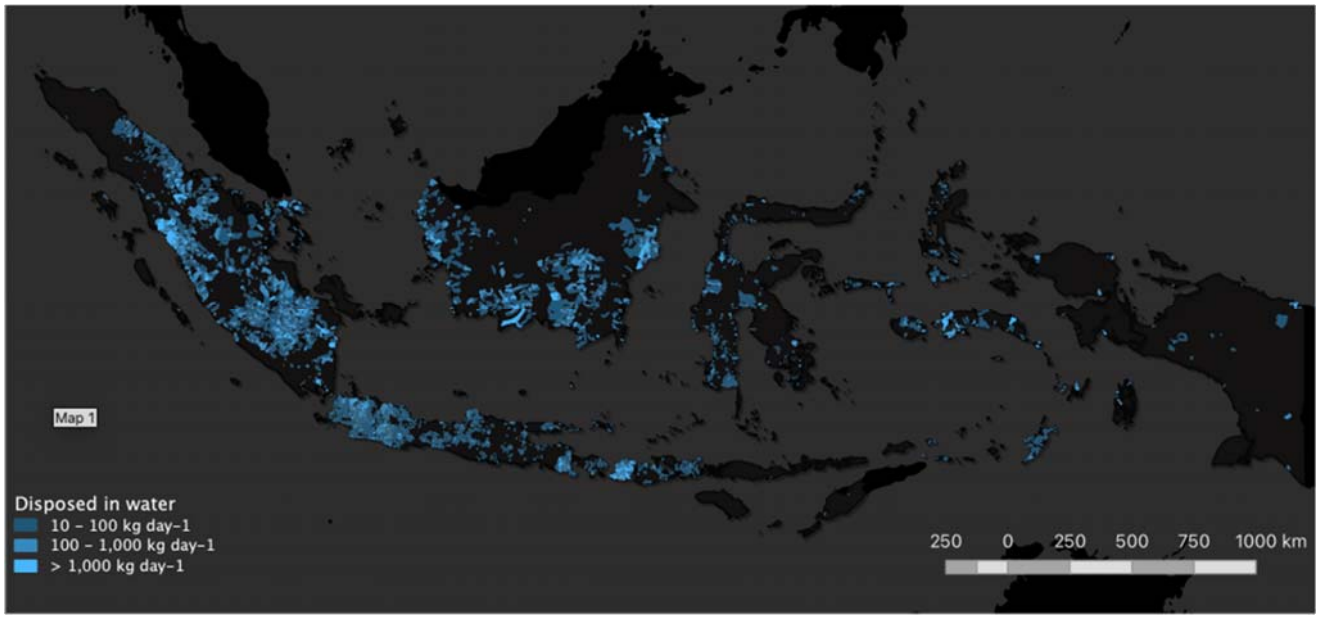
File S4. Mass flow diagrams showing the estimated amounts of plastic waste across different waste handling and environmental processes, from its generation to discharge into the marine environment (values representative for mid-range estimate in 106 kg yr^{-1}). Top: solid waste management in rural villages; Bottom: solid waste management in urban villages. This complements Figure 2 **in section 3 - Results**, providing insight into the mass flow of plastic waste in rural and urban areas.

File S5. Summary of modelling outputs for the main Indonesian regions, detailing results of total MPW exposed to hydrology and subject to environmental processes. This is **referred to in section 3 - Results**, where we compare the inputs of plastic discharged by rivers and directly from coastal areas.

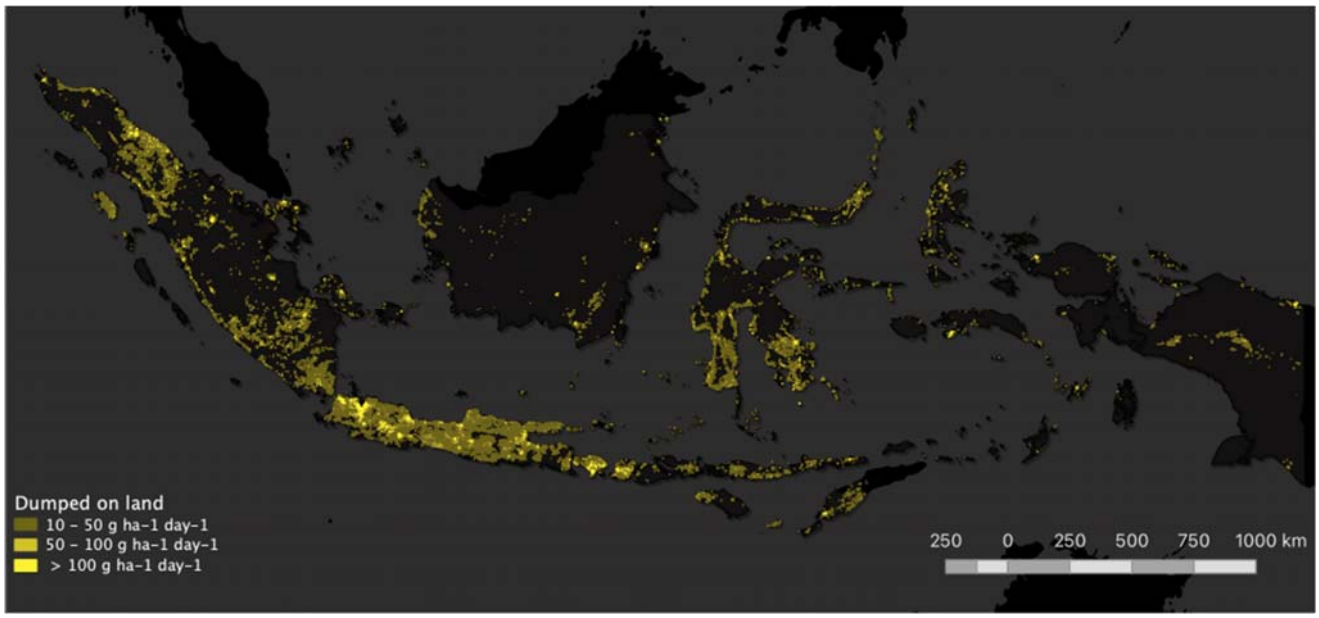
			Indonesia	Sumatra	Java	Bali & Nusa Tenggara	Kalimantan	Sulawesi	Maluku	Papua
		Urban population	131,129,774	22,492,162	88,138,336	5,693,960	6,704,096	6,229,888	832,169	1,039,163
		Rural population	130,959,862	34,616,853	60,034,882	8,795,488	9,289,130	12,905,476	2,092,559	3,225,474
SWM model	29	**Mismanaged plastic waste from terrestrial sources that may be washed-off an**	**766.8**	**202.1**	**318.4**	**52.1**	**67.7**	**81.7**	**21.8**	**23.1**
	30	to dry terrestrial environment	357.9	98.5	144.6	30.3	18.9	41.7	9.3	14.6
	31	*as point sources*	*68.2*	*21.2*	*34.9*	*2.7*	*3.5*	*4.2*	*1.2*	*0.5*
	32	*as diffuse sources*	*289.8*	*77.2*	*109.7*	*27.6*	*15.4*	*37.6*	*8.1*	*14.1*
	33	to wet terrestrial environment	408.9	103.6	173.8	21.8	48.9	39.9	12.4	8.5
	34	*as point sources*	-	-	-	-	-	-	-	-
	35	*as diffuse sources*	*408.9*	*103.6*	*173.8*	*21.8*	*48.9*	*39.9*	*12.4*	*8.5*
DelWAQ model	36	**Total disposed in the dry environment**	**322.5**	**89.9**	**139.1**	**24.8**	**18.9**	**33.0**	**3.7**	**13.0**
	37	retained in soils	168.8	23.6	78.4	21.4	10.3	22.5	3.3	9.4
	38	washed-off to rivers	153.6	66.4	60.7	3.4	8.7	10.5	0.4	3.6
	39	**Final destination (riverine environment)**	**520.6**	**159.3**	**228.4**	**21.9**	**53.5**	**42.3**	**4.8**	**10.4**
	40	captured behind dams	20.6	0.3	19.2	1.0	0.0	0.2	-	-
	41	buried or stored in river	212.3	74.1	88.6	5.4	23.2	14.2	2.0	4.8
	42	total discharged into marine environment	287.7	84.9	120.6	15.6	30.3	27.9	2.8	5.6
	43	**Total discharged into marine environment from rivers**	**287.7**	**84.9**	**120.6**	**15.6**	**30.3**	**27.9**	**2.8**	**5.6**
Coastal zone	44	**Coastal zone**	**78.4**	**18.6**	**11.6**	**8.8**	**5.3**	**16.9**	**13.6**	**3.5**
	45	to dry environment (coastal zone)	37.3	8.5	5.6	5.5	1.5	8.7	5.6	2.0
	46	washed-off directly to marine environment	17.8	4.1	2.6	2.6	0.7	4.2	2.7	0.9
	47	disposed directly into marine environment	41.1	10.0	6.1	3.4	3.9	8.2	8.0	1.5
	48	Total into marine environment from coastal area	58.9	14.1	8.7	6.0	4.6	12.3	10.7	2.5
Result	49	total discharged into marine environment from rivers	287.7	84.9	120.6	15.6	30.3	27.9	2.8	5.6
	50	total leaked into marine environment from coastal areas	58.9	14.1	8.7	6.0	4.6	12.3	10.7	2.5
	51	**Total leaked into the Marine Environment**	**346.5**	**99.1**	**129.3**	**21.5**	**34.9**	**40.2**	**13.5**	**8.1**
		MPW disposed into marine environment per capita (Urban) [kg/cap/year]	0.73	0.97	0.62	0.74	1.29	0.85	0.44	0.80
		MPW disposed into marine environment per capita (Rural) [kg/cap/year]	1.46	1.82	1.09	1.29	2.33	1.75	1.18	1.47



File S6. Estimated daily rates of MPW that is openly burned (g $ha^{-1}day^{-1}$) across Indonesia. This is **referred to in section 3 - Results**, to illustrate how widespread open burning of plastic waste is and the detailed spatial differences across the country.



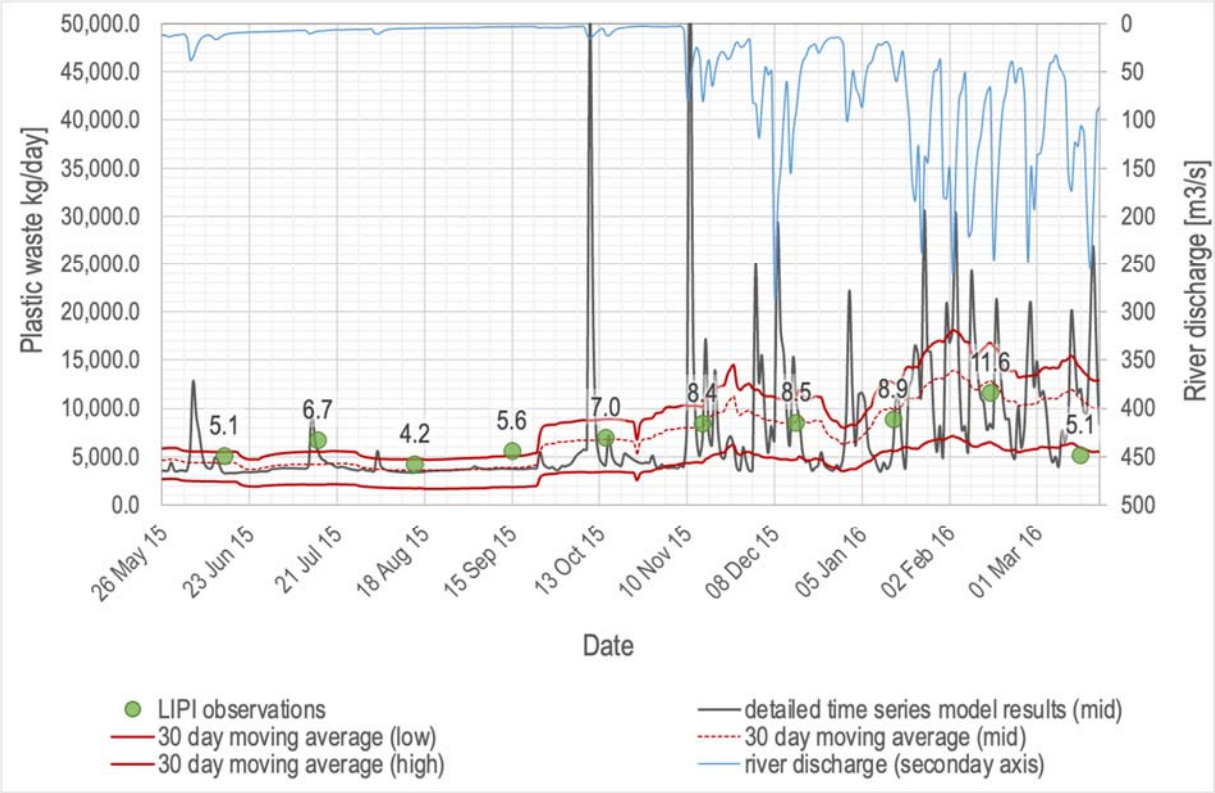
File S7. Estimated daily amounts of MPW that is directly disposed of in waterways (kg day^{-1}) across Indonesia. This is **referred to in section 3 - Results**, to illustrate the estimated disposal of plastic waste directly in water and the detailed spatial differences across the country.



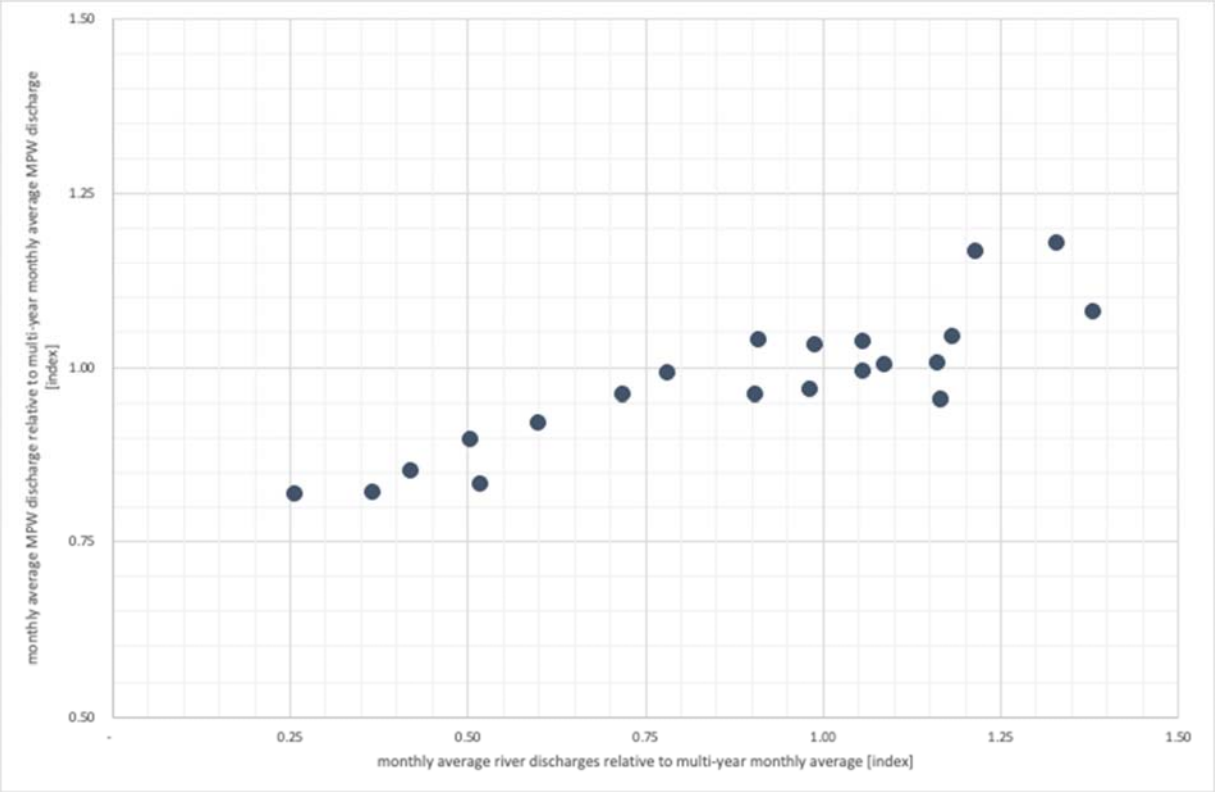
File S8. Estimated daily rates of MPW (g $ha^{-1}day^{-1}$) that is illegally dumped on land. This is **referred to in section 3 - Results**, to illustrate the extent of this waste handling practice and the detailed spatial differences across the country.

File S9. Waste handling/waste management destination of plastic waste (total amounts; share) generated rural and urban areas for the whole Indonesia and per regions. This provides the details of the estimated amounts of plastic waste for different disposal destinations in rural and urban areas, as discussed **in section 3 - Results**. It includes the data used to produce Figure 4, Figure S6 and Figure S7.

	Destination	Indonesia	Sumatra	Java	Bali_NT	Kalimantan	Sulawesi	Maluku	Papua	SI
Rural	Plastic Waste Gen.	3,550.3	938.3	1,602.9	242.8	275.4	344.0	59.8	87.3	10^6 kg/yr
	Recycled	141.4	27.6	87.1	4.2	4.6	12.3	4.2	1.4	10^6 kg/yr
	Sanitary Landfill	121.8	9.0	50.5	17.1	30.3	10.4	2.9	1.6	10^6 kg/yr
	Controlled Landfill	207.8	70.1	50.7	27.1	25.8	24.1	7.5	2.5	10^6 kg/yr
	Open Dumping	68.3	17.4	29.9	7.9	4.3	4.1	2.9	1.8	10^6 kg/yr
	Buried	110.0	24.8	51.5	6.3	10.7	9.5	2.5	4.7	10^6 kg/yr
	Burned	2,425.7	650.6	1,181.3	142.8	153.6	220.2	21.7	55.5	10^6 kg/yr
	Dumping	210.3	61.4	61.2	22.4	12.4	32.6	7.4	12.9	10^6 kg/yr
	Water	265.0	77.4	90.6	15.0	33.8	30.8	10.7	6.8	10^6 kg/yr
Urban	Plastic Waste Gen.	4,205.5	786.6	2,697.1	212.8	233.6	210.2	30.9	34.2	10^6 kg/yr
	Recycled	343.3	57.3	227.3	14.6	15.0	21.2	3.2	4.7	10^6 kg/yr
	Sanitary Landfill	1,194.4	49.3	912.6	106.6	73.9	45.0	0.4	6.8	10^6 kg/yr
	Controlled Landfill	866.3	275.8	404.5	22.7	66.3	73.8	18.7	4.4	10^6 kg/yr
	Open Dumping	291.0	91.1	182.5	4.0	3.5	8.1	1.2	0.7	10^6 kg/yr
	Buried	36.1	5.5	25.4	1.8	1.7	0.9	0.5	0.3	10^6 kg/yr
	Burned	1,251.0	265.6	813.0	51.1	55.2	47.1	4.5	14.5	10^6 kg/yr
	Dumping	79.4	15.9	48.5	5.2	3.0	4.9	0.8	1.2	10^6 kg/yr
	Water	144.0	26.2	83.2	6.8	15.1	9.2	1.7	1.7	10^6 kg/yr
Rural	Plastic Waste Gen.	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	%
	Recycled	4.0%	2.9%	5.4%	1.7%	1.7%	3.6%	7.1%	1.6%	%
	Sanitary Landfill	3.4%	1.0%	3.2%	7.0%	11.0%	3.0%	4.8%	1.9%	%
	Controlled Landfill	5.9%	7.5%	3.2%	11.1%	9.4%	7.0%	12.6%	2.9%	%
	Open Dumping	1.9%	1.9%	1.9%	3.3%	1.6%	1.2%	4.9%	2.0%	%
	Buried	3.1%	2.6%	3.2%	2.6%	3.9%	2.8%	4.3%	5.3%	%
	Burned	68.3%	69.3%	73.7%	58.8%	55.8%	64.0%	36.2%	63.6%	%
	Dumping	5.9%	6.5%	3.8%	9.2%	4.5%	9.5%	12.3%	14.8%	%
	Water	7.5%	8.3%	5.7%	6.2%	12.3%	8.9%	17.9%	7.8%	%
Urban	Plastic Waste Gen.	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	%
	Recycled	8.2%	7.3%	8.4%	6.8%	6.4%	10.1%	10.4%	13.7%	%
	Sanitary Landfill	28.4%	6.3%	33.8%	50.1%	31.6%	21.4%	1.3%	19.8%	%
	Controlled Landfill	20.6%	35.1%	15.0%	10.7%	28.4%	35.1%	60.4%	12.9%	%
	Open Dumping	6.9%	11.6%	6.8%	1.9%	1.5%	3.8%	3.8%	2.0%	%
	Buried	0.9%	0.7%	0.9%	0.9%	0.7%	0.4%	1.5%	0.8%	%
	Burned	29.7%	33.8%	30.1%	24.0%	23.6%	22.4%	14.5%	42.4%	%
	Dumping	1.9%	2.0%	1.8%	2.4%	1.3%	2.3%	2.5%	3.4%	%
	Water	3.4%	3.3%	3.1%	3.2%	6.5%	4.4%	5.6%	5.0%	%



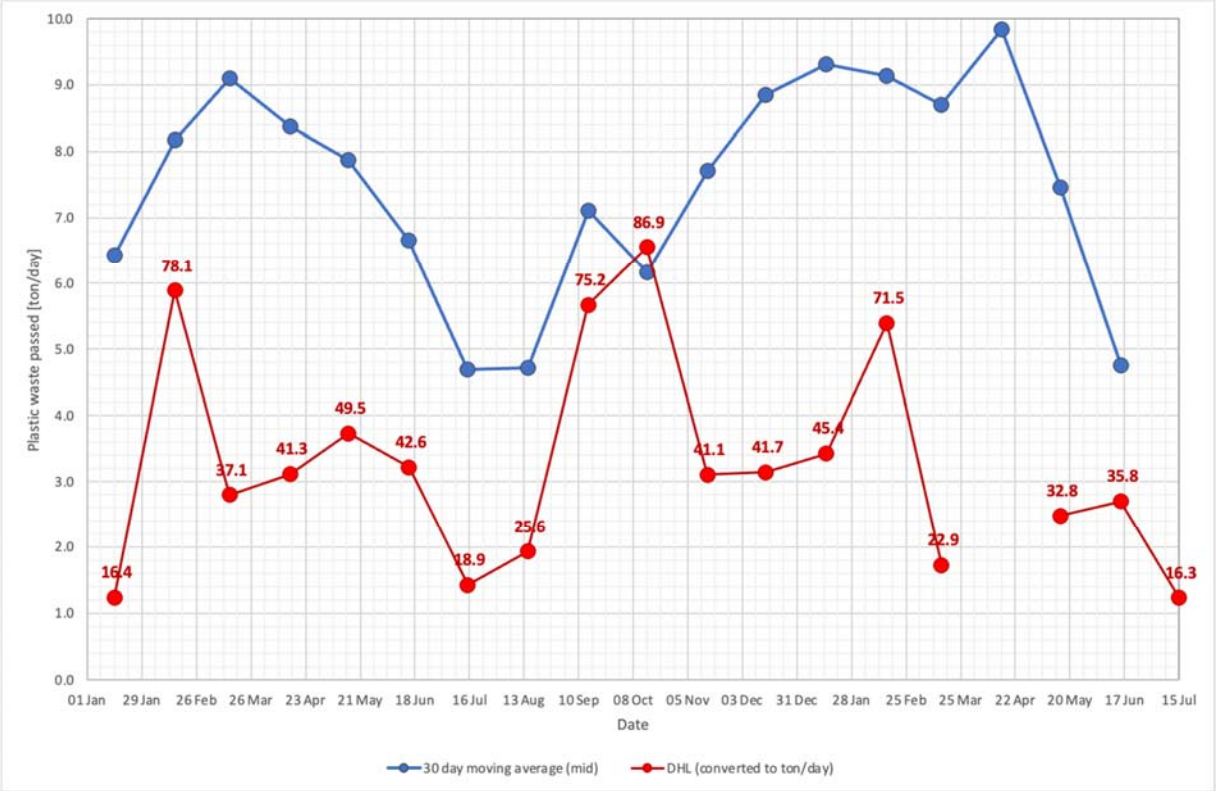
File S10. Plastic estimations resulting from Bekasi River mouth observations (Cordova and Nurhati, 2019) (green dots), daily discharge timeseries derived from model results (grey spiky line); 30-day moving average plastic discharge derived from model results (blue line); daily average river discharges (light blue, reverse right axis). This is referred to in **section 3 – Results.**



File S11. Indexed monthly average MPW discharges compared to multi-year indexed average river discharges for Java, both derived from model results. This figure shows the correlation between average riverine discharge and plastic waste discharges, as referred to in **section 3 – Results.**

File S12. Plastic discharges (thousand tons per year; low, mid and high estimates) for the top Indonesian rivers and share of total amount discharged in Indonesia. Note that for DKI Jakarta, results are combined for several rivers that flow through the area.

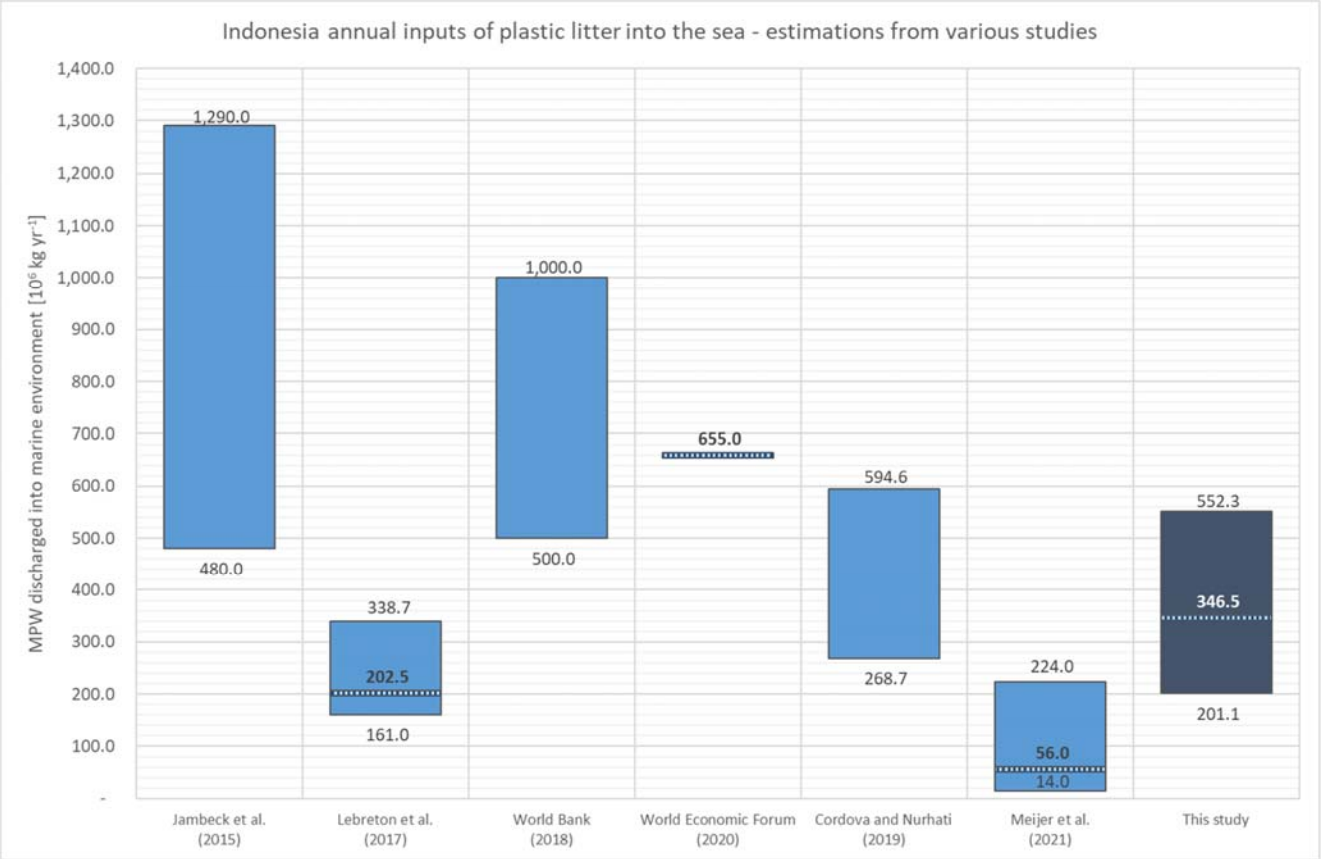
Catchment	Size (km^2)	Region	Estimated plastic discharge ($kton.year^{-1}$)			Share (%) of total across Indonesia
			low	mid	high	
DKI Jakarta rivers	1,529.7	Java	28.76	31.69	34.94	8.9
Musi	55,447.1	Sumatra	10.73	15.88	20.81	4.7
Bengawan Solo	15,538.4	Java	3.86	6.28	8.73	1.9
Brantas	12,139.8	Java	3.65	5.60	7.68	1.7
Cirarab	180.8	Java	2.47	5.40	11.72	1.6
Batanghari	44,802.4	Sumatra	2.37	4.35	7.04	1.3
Serayu	3,794.0	Java	2.86	4.32	5.84	1.3
Kapuas	17,758.9	Kalimantan	2.57	3.85	5.25	1.1
Barito	61,094.7	Kalimantan	2.86	3.70	4.60	1.1
Citanduy	3,701.7	Java	2.24	3.61	4.90	1.1



File S13. Plastic waste removed from Manggarai gate converted to tons/day (conversion rate derived from sampling composition of waste removed from waterways by the Municipal Environment Agency, DLH) (red); daily plastic discharge timeseries derived from model results (blue line). This supports the discussion **in section 3 - Results**, on the validation of the modelling results.

File S14. Estimated annual (365 day) leakages and discharges for Indonesia showing high uncertainty due to SWM input data. This supports the discussion **in section 3 – Results.**

		estimated leakage from MPW			uncertainty due to SWM data
		low [kton/year]	mid [kton/year]	high [kton/year]	
point sources		31.0	68.2	149.0	**173.0%**
diffuse sources to land		184.1	289.8	388.4	**70.5%**
diffuse sources to water		273.7	408.9	539.2	**64.9%**
discharge	dry	211.6	325.1	444.2	**71.5%**
	average	218.3	336.1	460.7	**72.1%**
	wet	229.4	354.5	489.0	**73.2%**
uncertainty due to hydrology		**8.1%**	**8.7%**	**9.7%**	



File S15. Comparison of the results with previous studies, revealing that the results from the other studies are within the range of our study. The blue bars indicate the range of the individual study results, and where available, the best estimate is provided as a dotted line. This supports the discussion **in section 4 – Discussion.**