Tutorial: Calculating River Plastic Transport from Visual Counting

In this tutorial you will work with actual visual counting data to calculate river plastic transport in various rivers around the world. The calculation steps can also be used to work with your own data.

Learning outcomes

The learning outcomes of this practical are:

1. Calculate plastic transport from visual counting observations
2. Estimate plastic emission using a conceptual model
3. Compare the observation-based and model-based emission estimates
4. Explain the differences between observation-based and model-based estimates for various rivers.

What you need to hand in

You can write down the answers to the questions, briefly and to the point, in the provided spaces on this exercise sheet.

Getting ready

- Make sure your Excel is set in English. To do this: Set up your Excel in English: File → Option → Language → English;
- Make sure that the Delimiter set to '.', instead of ','. To do this: File → Option → Advanced → Untick "use system separators";
- For the tutorial, make sure to at least finish up to the questions in 1.1.2. If that works you're all set for the practical;
- Work in pairs.

Introduction

During this practical you will make use of the statistics program Excel. The workout and answers of the exercises will also be given.

In this practical you will estimate annual floating plastic transport in rivers and investigate the relationship between plastic transport and discharge. For this practical, you will use observation data. These are:

(a) Visual counting observations of floating plastic in the Meuse river, Netherlands;
(b) Visual counting observations of floating plastic in the Odaw river, Ghana;
(c) Visual counting observations of floating plastic in the Ciliwung river, Indonesia;
(d) Model inputs for the Meuse, Odaw and Ciliwung rivers from Lebreton et al. (2017) model;
(e) Discharge data for the Meuse river and for the Odaw river.

Part 1: Observations-based estimates of annual plastic transport

1.1 River Meuse

Open the Excel file provided and work with the first sheet called ‘Meuse_data’.

Fig. 1. Measurement locations along the Rhine, IJssel, and Meuse rivers. The large symbols represent the locations where measurements were done monthly and during the peak discharge events. The small symbols represent the locations where three measurements were done between June and December 2021. Source: van Emmerik et al. (2022).

1.1.1 Calculate hourly plastic transport (columns N to Q)

You will calculate the floating plastic transport based on visual counting observations. Observations were done at different bridge locations. At each bridge, measurements were done at various segments. First, calculate the transport flux per minute (column N) and then per hour (column O). You need to insert a formula in the first row of each column and then drag it to the rows below for it to be applied to all the data.

In the bottom right corner of the cell in which you wrote down a formula, you will see a black cross appearing. If you double click on it (or drag it down), the formula will be applied to the cells below:

L	M	N
Duration [min]	Total plastic item [n]	Plastic item flux [n/min]
5	1	=M3/L3
5	2	
5	4	
5	1	
5	2	
5	1	
5	1	
5	1	
5	1	
5	3	
5	2	
5	0	
5	0	
5	1	

Second, calculate the normalized hourly transport per segment (column P). Here you take into account the observational width (e.g.: the segment width). You can then extrapolate to the entire river width (which corresponds here to the bridge width) (column Q).

Q: Considering the values you get per bridge segment, why do you think observations are made at various segments across bridges?

Q: What would happen if observations were only made at one segment?

1.1.2 Calculate daily transport rates (columns S to W)

You will now estimate the daily transport rates per locations. For that, you need to add a column that joins the location name and date, as we are ultimately interested in having daily averages per location. You can use the following Excel formula to that scope in column S:

=TEXT(A3, "yyyy-mm-dd") & " - " & E3

This formula joins the datetime (A column) with the location name (E column). Drag down the formula in the next rows to have it applied to the entire table.

In the next column (T), select the unique sets of locations and dates across your entire dataset. You can use the ‘UNIQUE(S$3:S$1686)’ command in Excel.

You have now selected the unique dates and locations of plastic sampling. Now you will calculate the daily plastic transport averages for all these unique combinations in the next column (column W). You can use the AVERAGEIF function in Excel:

=AVERAGEIF(S:S, T3,Q:Q)

And then drag down the formula in the next rows.

This formula takes three main arguments:

- **Range (S)**: This is the range where Excel looks for values that meet a specified condition or criterion (in this case, S:S contains the dates and locations for plastic sampling).
- **Criteria (T3)**: This specifies what value to look for in the range. Here, T3 holds the unique date-location combination for which you want to calculate the average. Excel will search through S:S to find cells that match T3.
- **Average range (Q)**: This is the range of values Excel will average if they meet the criteria (i.e., if the date and location in column S match T3). Here, Q:Q contains the plastic transport values you want to average for each unique date-location combination.

Q: Write down here the range of your values (min and max values) and the average you find for the entire river Meuse. For this, use the MIN, MAX and AVERAGE functions in Excel. Compare your results with that of your neighbors.

Min: Max: Mean:

Q: What do you think a negative value means?

Q: How many orders of magnitude do you have in your range of values? NB: An "order of magnitude" is a way to describe the scale or size of something, usually using powers of ten. When something differs by an order of magnitude, it means it's roughly ten times larger or smaller than something else.

1.1.3 Spatial variability along the Meuse river (columns Z to AA)

Column Z lists unique locations along the Meuse, ordered from upstream (near Belgium) to downstream (near the river mouth). Estimate the average annual transport rates for these locations using the AVERAGEIF function.

Q: Plot the data per location. Do you see any considerable differences between the locations?

Q: What could be the cause of that the large differences between Maastricht and the other locations? Remove temporarily Maastricht data in column U for the month of July and report what changes in your plot.

1.1.4 Annual time-series for two locations along the Meuse river (columns AC to AH)

For two locations – Ravenstein and Moerdijkbrug – observations were conducted each month, which is not the case for other locations. This is why we will now focus on the data from these two locations specifically.

Extract the average transport rates for both these locations over the entire time-series. Plot the monthly time-series for these two locations. You can use the Filter option on column V to only see the values for Ravenstein and Moerdijkbrug, and then copy paste them, along with the corresponding dates, in columns AC, AD, AG, AH. Plots can be added from the 'Insert' menu and then by selecting 'Scatter' from the Chart submenu.

Q: At which location is the transport rate higher? Provide some hypotheses that could explain these results. Tip: look where these two locations are along the Meuse.

Q: Are there clear peaks and trends in the time-series?

1.1.5 Annual plastic emissions into the ocean (columns AJ to AK)

Estimate the mean annual transport rates for Moerdijkbrug, the most downstream location. Given that this location is close to the Meuse river mouth, we consider that this is equivalent to emissions into the ocean. Provide your estimates in both millions of items/year and tons/year. For the mass transport estimate, consider that the average mass of plastic items is 10 g/item.

Q: Report your values below.

Q: What are the sources of uncertainties in these estimates?

Q: Express your values also as per capita values (g/year/person and items/year/person). The Meuse river catchment has approximately 9 million inhabitants. Report these values below:

1.2 Ciliwung and Odaw rivers

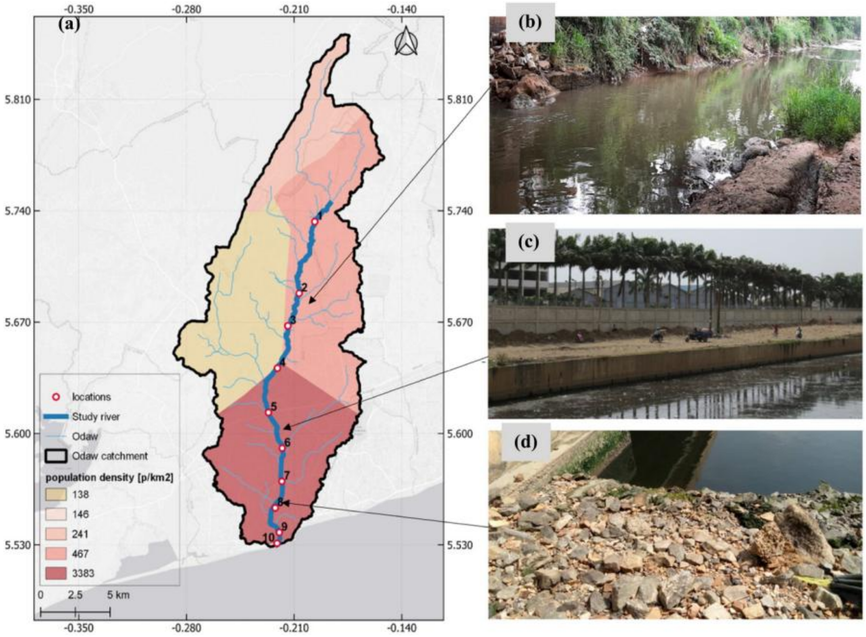

Fig.2. Map of the Odaw catchment with the 10 sampling locations indicated (Source: ESRI Gray) and riverbank characteristics in the (b) non-urban riverine zone (locations 1–4) (c) urban riverine zone (locations 5–7) (d) urban tidal zone (locations 8–10). (picture credit: Rose Pinto 2021). Source: Pinto et al., 2024.

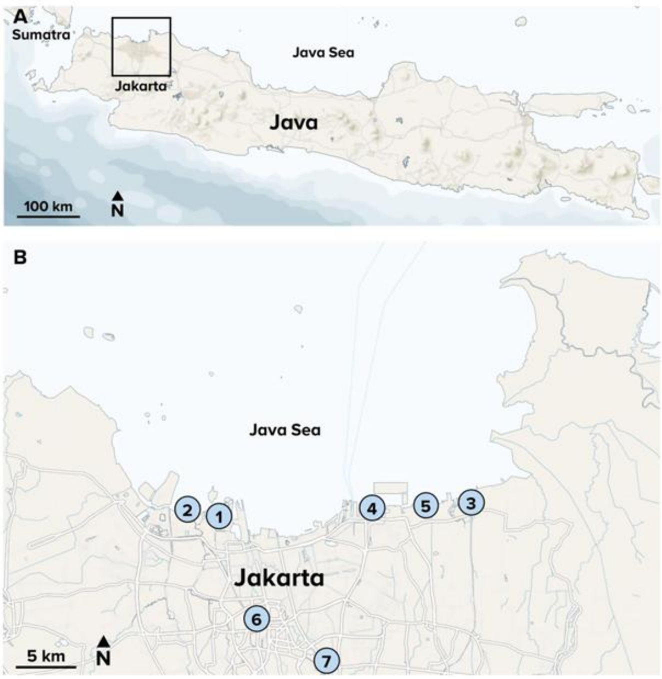

Fig.3. (A) Java, Jakarta and the Java Sea. (B) Overview of monitoring locations and hydrodynamic data locations in Jakarta, Indonesia. (1) BKB-Angke (Ciliwung), (2) Cengkareng Kapuk (Pesanggrahan), (3) BKT (various), (4) Sunter mouth (Sunter), (5) Cakung mouth (Cakung), (6) BKB-Grogol (Ciliwung), and (7) Haryono (Ciliwung). Source: van Emmerik et al., 2019.

You will now work with the sheets called 'Ciliwung_data' and 'Odaw_data'. You will reproduce the calculations made for the river Meuse for sections 1.1.1, 1.1.2 and 1.1.5. If you lack time, select just one of these two rivers. You can ask your classmates what values they found for the other river. The Ciliwung catchment has about 5 million inhabitants and the Odaw catchment about 3.4 million inhabitants.

1.2.1 Ciliwung river (Jakarta, Indonesia)

Calculate your estimates for annual transport [in millions of items/year and tons/year and per capita] for the two given locations of the Ciliwung river (Cenkareng and BKB Angke). We consider that the transport for these two downstream locations correspond to plastic emissions into the ocean.

	Annual transport at Cenkareng	**Annual transport at Angke**
items/hour		
Items/year		
millions items/year		
tonnes/year		
g/year/person		
items/year/person		

Q: How do your values compare to those of the Meuse river? Consider also the number of inhabitants and the size of the river system.

1.2.2 Odaw river (Accra, Ghana)

Q: Do the same calculations for the Odaw river. Report below the range of values you get for daily transport, as well as the average transport. What do these values tell you about the system?

Min:

Max:

Mean:

Q: Now use only the data for the most downstream location for your emission estimates (Winneba). Provide the values you find for the annual emission estimates, in items and mass transport. Reflect on how these compare with the Meuse and Ciliwung catchments.

	Annual transport at Winneba
items/hour	
Items/year	
millions items/year	
tonnes/year	
g/year/person	
items/year/person	

Part 2: Model-based estimates of annual plastic emissions

In this part of the practical, you will estimate annual plastic emissions using a simple conceptual model, from Lebreton et al. (2017). We lack observations for most rivers, therefore model can be useful to provide first-order estimates of transport rates for ungauged rivers.

2.1 First model output calculation

Open the "Lebreton_model" sheet. The sheet provides monthly data on surface runoff and mismanaged plastic waste estimates for the three catchments of interest. Those are your input data for estimated annual plastic emissions. Use the formula given in the tutorial lecture to estimate annual plastic emissions.

$$M_{out} = (k * R * MPW)^a$$

Where *R* stands for surface runoff, *MPW* for mismanaged plastic waste, and *a* and *k* the two model parameters. Note that these parameters have no direct physical meaning. However, in general *k* represents the fraction of mismanaged plastic waste entering the environment, and *a* represents the non-linearity in the response of plastic transport to discharge. The first step is to estimate the average surface runoff, using the provided monthly values. Ultimately, you want to estimate your output in tons/year, so bear in mind the units in your calculation. We provide you with initials *k* and *a* values, where k = 0.00001 and a = 1.52.

Q: What initial annual plastic emissions values do you get for the three rivers? Report those.

Q: How do these values compare to the your observation-based estimates (part 1 of the practical)?

Q: What factors can explain the diverging values that you find between the modelled values and the observed values?

2.2 Model calibration

Adjust the coefficients *k* and *a* in your model to bring its outputs closer to the observation-based values that you found in Part 1 of the practical. Report the optimized values you obtain for *k* and *a*. Aim to approximate the observed values without spending too much time on fine-tuning; an exact match is not necessary.

River	Odaw	Meuse	Ciliwung
k			
a			

Q: This results in notably different coefficients, particularly exponents, across the three river systems. Aim to identify unique values for *k* and *a* that optimize the model for all three systems, and report the resulting values for these coefficients. Again, aim to approximate the observed values without spending too much time on fine-tuning; an exact match is not necessary.

k: *a*:

Q: Reflect on the choice of input variables in the model. Do you think the model assumptions are correct?

Q: What other factors could you consider to estimate plastic emissions into the ocean?

Part 3 Relationship between river discharge and plastic transport rates

3.1 Discharge and plastic transport for the Meuse river

In this part of the practical, you will focus again on the Meuse plastic data. In addition to the plastic data, we provide river discharge estimates, extracted from Water Info (https://waterinfo.rws.nl/). We coupled the discharge and plastic transport estimates at a daily time-scale. Open the sheet called "Meuse_plastic_discharge". The scope of this part of the practical is to formulate your own model for estimating plastic transport using discharge as the input value. You can try to do this without further instructions or you can follow the step-by-step approach that we provide.

Q: Plot for the two given locations the river discharge values against the plastic transport rates. How do the plot look like? What do they suggest?

Display on each plots the linear equations that you get for the two locations. It should be in the form of:

$$P = \beta + \alpha \cdot Q$$

Where *P* is the plastic transport rate, *Q* the discharge, *β* the intercept and *α* the slope. The intercept represents the "base plastic transport" when the discharge is 0, and the slope represents the additional plastic transport for a given increase in discharge.

Q: What intercept values do you get? Do they make sense?

Force the intercept to be set to zero. For that, click on the scatter plot, "Trendline> More options" and check the box "Set intercept".

Q: Do you get the same slope (*α)* values for the two locations?

Q: Add a new column to calculate the correlation coefficient (R^2) between discharge and observed plastic transport. An R^2 value closer to 1 indicates a better fit between the two variables. Use Excel's RSQ function for this calculation. What scores do you get?

Add a new column for which you will model plastic transport based on discharge and the α slope value that you found for each system. Additionally, include the R^2 value to indicate the goodness of fit between the predicted and observed values.

Q: What do you observe when comparing your modelled values with the observed plastic transport values?

Add a new column to propose a new model based on a power-law function. This takes the form of:

$$M_{out} = (k * Q)^a$$

Where *Q* is river discharge, *k* is a coefficient and *a* the exponent.

Q: Identify the values of *k* and *a* that provide a good fit with the observed plastic transport values. Keep in mind that relying solely on R^2 can be misleading, as it often emphasizes fit at the extreme values.

3.2 Discharge and plastic transport for the Odaw river

For some measurement days, flow velocity and water depth were measured during the plastic sampling. That enables to estimate river discharge. Use the “Odaw_river_discharge” sheet.

Q: Plot the river discharge values against the plastic transport rates for a few locations. What do you notice?

Q: Why do you think that is the case?

Q: Based on the previous section and this section of the practical, do you think river discharge is a good predictor for floating macroplastic transport?

Part 4 Riverbank plastic

4.1 Riverbank concentration

Open the file “06_Example_riverbank.xlsx”. This file contains measurements of riverbank plastic, and other litter, sampled along the Odaw river in Ghana. Below the data entries you can find on overview of the locations. You can do your calculations here.

Q: What are the total sampled mass and items per location? Calculate the mean item concentration, plastic item concentration, and mass concentration for each location. Plot the plastic concentration (y-axis) per location (x-axis). Do you see a trend? Can you explain your results?

4.2 Top items on riverbanks

You can also look at the item distribution, to identify most abundant items per location and in total.

Q: What are the 10 most abundant items in the Odaw? And per location? Can you explain the results?

References

Lebreton, L. C., Van Der Zwet, J., Damsteeg, J. W., Slat, B., Andrady, A., & Reisser, J. (2017). River plastic emissions to the world's oceans. *Nature communications*, 8(1), 15611.

Pinto, R. B., Bogerd, L., van der Ploeg, M., Duah, K., Uijlenhoet, R., & van Emmerik, T. H. (2024). Catchment scale assessment of macroplastic pollution in the Odaw river, Ghana. *Marine Pollution Bulletin*, 198, 115813.

Van Emmerik, T., Loozen, M., Van Oeveren, K., Buschman, F., & Prinsen, G. (2019). Riverine plastic emission from Jakarta into the ocean. *Environmental Research Letters*, 14(8), 084033.