Supplementary Materials

Effects of land use and water quality on greenhouse gas emissions from an urban river system in Cuenca (Ecuador)

Long Ho[1]*, Ruben Jerves-Cobo[1, 2, 3], Matti Barthel[4], Johan Six[4], Samuel Bode[5], Pascal Boeckx[5], Peter Goethals[1]

[1] *Department of Animal Sciences, Ghent University, Gent, Belgium;*

[2] *PROMAS, Universidad de Cuenca, Cuenca, Ecuador;*

[3] *BIOMATH, Department of Data Analysis and Mathematical Modelling, Ghent University, Gent, Belgium*

[4] *Department of Environmental Systems Science, ETH Zurich, Zurich, Switzerland;*

[5] *Department of Green Chemistry and Technology, ISOFYS Group, Ghent University, Gent, Belgium*

*Corresponding author. Email: Long.TuanHo@UGent.be

1. Supplementary Material S1: Details of Hack kits

Table S1. List of physicochemical variables and the associated method.

Variable	Technique	Remark(s)
Temperature	Probe	YSI V6920
Conductivity	Probe	YSI V6920
pH	Probe	YSI V6920
Dissolved oxygen	Probe	YSI V6920
Turbidity	Probe	YSI V6920
Chemical oxygen demand	Test kit code 2415815	Hach, limits: 0.7 – 40.0 mgO_2 L^{-1} Follows EPA 5220 D
Ammonia-nitrogen	Test kit code 114752	Merck, limits: 0.010 – 3.00 mgN L^{-1} Follows EPA 350.1, APHA 4500-NH3 F, ISO 7150-1 and DIN 38406-5
Nitrite-nitrogen	Test kit code 114776	Merck, limits: 0.002 – 1.00 mgN L^{-1} Follows EPA 354.1, APHA 4500-NO2- B and DIN EN 26 777
Nitrate-nitrogen	Test kit code 109713	Merck, limits: 0.1 – 25.0 mgN L^{-1} Follows DIN 38405-9
Orthophosphate-phosphorus	Test kit code 114848	Merck, limits: 0.0025 – 5.00 mgP L^{-1} Follows EPA 365.2+3, APHA 4500-P E and DIN EN ISO 6878

2. Supplementary Material S2: Sampling protocol

- Site Name:
- Time and date:
- Sample ID:
- Investigator:

Stream name/lake	
Type of watercourse	River Lake
Coordinates	
Photos of the sampling location (numbering the photos) - Downstream - Upstream - Left bank - Right bank - Substrate	
Description of sites (exceptional, weather conditions, main interruption, …)	

Land use of the bank top (Estimate at both banks for the stretch of 100m * 10m)

Type of land use	% on left bank	% on right bank
forests		
arable land		
residential areas		
road, paths		
urban area		
quarrying or mining		
orchard		
other		

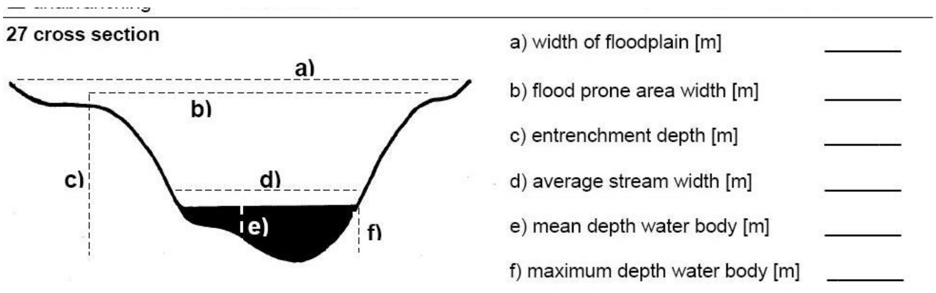
Shading

partly shaded, limited stretch <33%	
partly shaded, longer stretch 33-90%	
partly shaded, whole stretch >90%	
completely shaded, limited stretch >33%	
completely shaded, longer stretch 33-90%	
completely shaded, whole stretch >90%	

Presence of macrophytes (% of the bed covered by Macrophytes) (Estimate area cover at the littoral zone of 100m * 10m)

	Submerged aquatic macrophytes	Emerged aquatic macrophytes	Floating aquatic macrophytes
Contigous/Interrupted			
Abundant = 75-100%			
Common = 50-75%			
Frequent = 25-50%			
Occasional = 5-25%			
Rare = 1-5%			
Invisible			

River morphology



Free drawing

Bank

erosion	Absent/Limited/Abundant
curvature erosion	Absent/Limited/Abundant
width-erosion	Absent/Limited/Abundant

Stream Depth

(Measure the depth across the stream, from right bank to left bank, the measure should be done at approximately 1/6, 2/6, 3/6, 4/5 and 5/6 of the way across the stream, 5 measurements)

Section 1

M1	M2	M3	M4	M5

Section 2

M1	M2	M3	M4	M5

Section 3

M1	M2	M3	M4	M5

Variation in flow

- absent
- at human constructions
- low
- moderate
- high

Current Velocity

(Should be measured at the same location where the depth measurements were taken)

Section 1

S1	S2	S3	S4	S5
B1	B2	B3	B4	B5

Section 2

S1	S2	S3	S4	S5
B1	B2	B3	B4	B5

Section 3

S1	S2	S3	S4	S5
B1	B2	B3	B4	B5

Pool/Riffle class

Class 1 Pool-riffle pattern is (nearly) pristine: extensive sequences of pools and riffles.	**Class 2** Pool-riffle pattern is well developed: high variety in pools and riffles.
Class 3 Pool-riffle pattern is moderately developed: variety in pools and riffles but locally.	**Class 4** Pool-riffle pattern is poorly developed: low variety in pools and riffles.
Class 5 Pool-riffle pattern is absent: uniform pool-riffle pattern.	**Class 6** Pool-riffle pattern is absent due to structural changes: uniform pool-riffle pattern due to reinforced bank and bed structures.

3. Supplementary Material S3: Prati and Oregon Indexes

The Prati-index

The researcher Prati developed a method to evaluate the degree of pollution by an index that considers different pollutants. Since different parameters have to be compared, different transformation formulas of the parameters were developed. The index is calculated by transforming the measured values. After that, the average values of the transformed measurements are considered.

Variables in the following formulas:

X: index according to PRATI

Y: measured value of the variable

- **Dissolved oxygen**

Saturation < 50 %	$X = 4.2 - 0.437*(100-Y)/5 + 0.042*((100-Y)/5)^2$
Saturation 50 – 100 %	$X = 0.08*(100-Y)$
Saturation > 100 %	$X = 0.08*(Y-100)$

- **COD** (mg/L)**: X = Y/10**
- **NH_4-N** (mg N/L): **$X = 2^{2.1*\log(12*Y)}$**

Assessment of Prati Index:

0 – 1 = good quality

1 – 2 = acceptable quality

2 – 4 = polluted

4 – 8 = heavily polluted

> 8 = very heavily polluted

The Oregon Index

The original Oregon Index was designed in the 1970s to be a simple and concise method for expressing ambient water quality information. The Oregon Index is used in analyses to compare conditions across river basins and to detect trends over time. The OWQI is calculated using index aggregation. First, six water quality parameters, i.e. water temperature, DO, BOD_5, pH, total concentration of NH_4, NO_2, NO_3, and TP concentration, are transformed by the below equation. After that, they were aggregated using the additive method to produce the final index value as follows.

$$Oregon\ Index = \sqrt{\frac{n}{\sum_{i=1}^{n} 1/SI_i^2}}$$

where n is number of subindices; SI is subindex i;

Temperature (T)

T < 11 °C	SI_T = 100
T: 11 °C-29 °C	$SI_T = 76.54 + 4.172*T - 0.1623*T^2 - 2.0557E\text{-}3*T^3$
T: > 29 °C	SI_T = 10

Dissolved Oxygen (DO)

DO saturation (DOs) ≤ 100%:

DO concentration (DO_C) < 3.3 mg/L	SI_{DO} = 10
DO_C: 3.3-10.5 mg/L	$SI_{DO} = -80.29+31.88*DO_C - 1.401*DO_C^2$
DO_C ≥ 10.5 mg/L	SI_T = 100

DOs: 100% - 275%

$SI_{DO} = 100*\exp((DO_S - 100)*-1.197E\text{-}2)$

DOs > 275%

SI_{DO} = 10

Biochemical Oxygen Demand, 5 day (BOD_5)

$BOD_5 \leq 8$ mg/L: $SI_{BOD} = 100*\exp(BOD*-0.1993)$

$BOD_5 > 8$ mg/L: SI_{BOD} = 10

pH

pH < 4	SI_{pH} = 10
pH: 4-7	SI_{pH} = 2.628*exp(pH*0.5200)
pH: 7-8	SI_{pH} = 100
pH: 8-11	SI_{pH} = 100*exp((pH-8)*-0.5188)
pH > 11	SI_{pH} = 10

Ammonia + Nitrate Nitrogen (N)

N ≤ 3 mg/L: SI_N = 100*exp(N*-0.4605)

N > 3 mg/L: SI_N = 10

Total Phosphorus (P)

P ≤ 0.25 mg/L: SI_P = 100 -299.5*P -0.1384*P^2

P > 0.25 mg/L: SI_P = 10

Assessment of Oregon Index:

90 – 100 = Excellent

85 – 89 = Good

80 – 84 = Fair

60 – 79 = Poor

10 – 59 = Very Poor

4. Supplementary Material S4: Cleveland plots

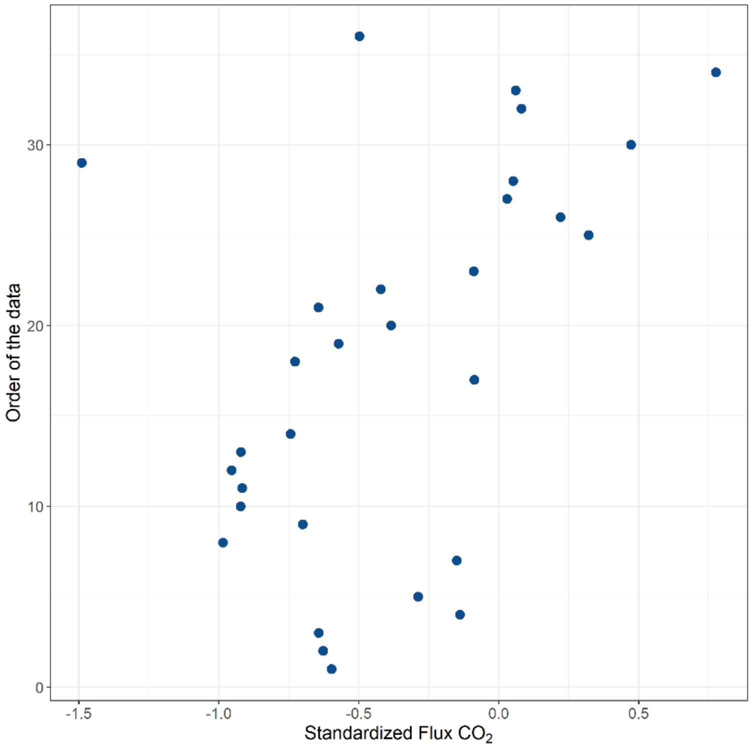


Figure S4.1. Cleveland plots of CO_2 emissions

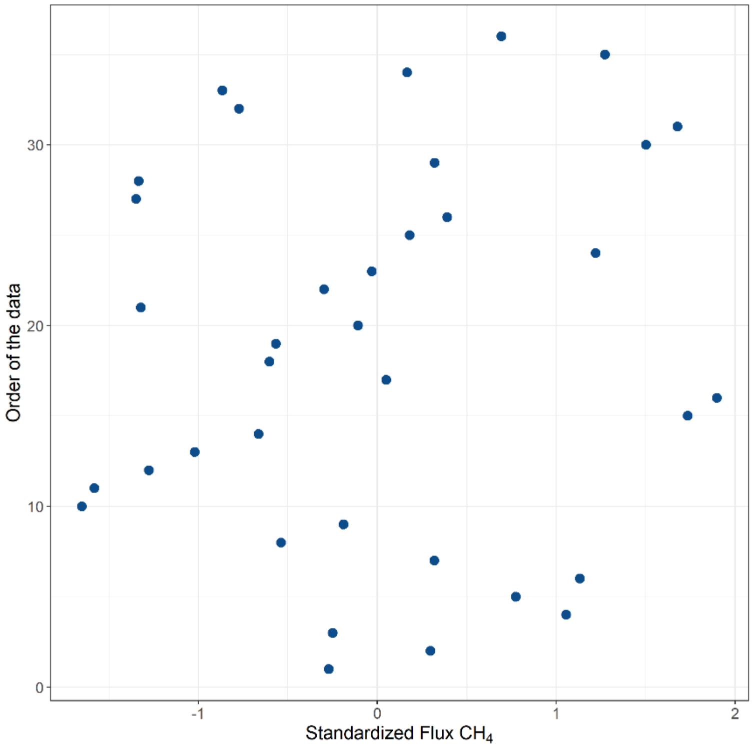


Figure S4.2. Cleveland plots of CH_4 emissions

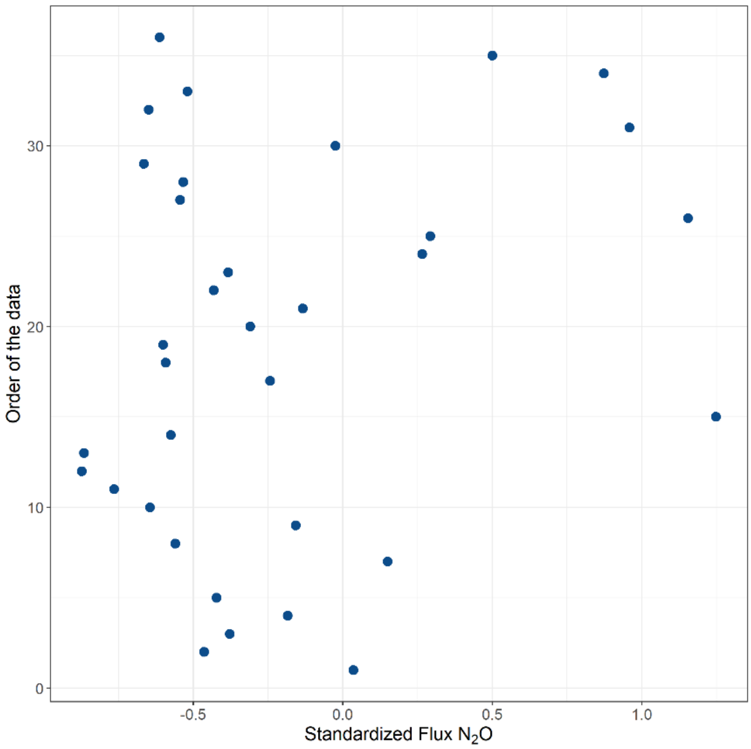


Figure S4.3. Cleveland plots of N_2O emissions

5. Supplementary Material S5: Residuals of the fitted model

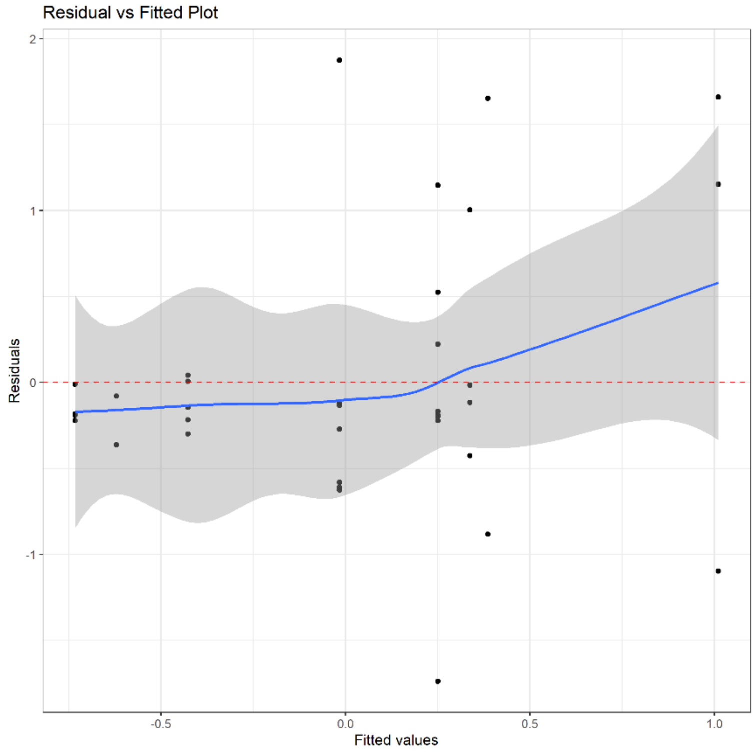


Figure S5.1. Residual vs Fitted values plot for CO_2 mixed model

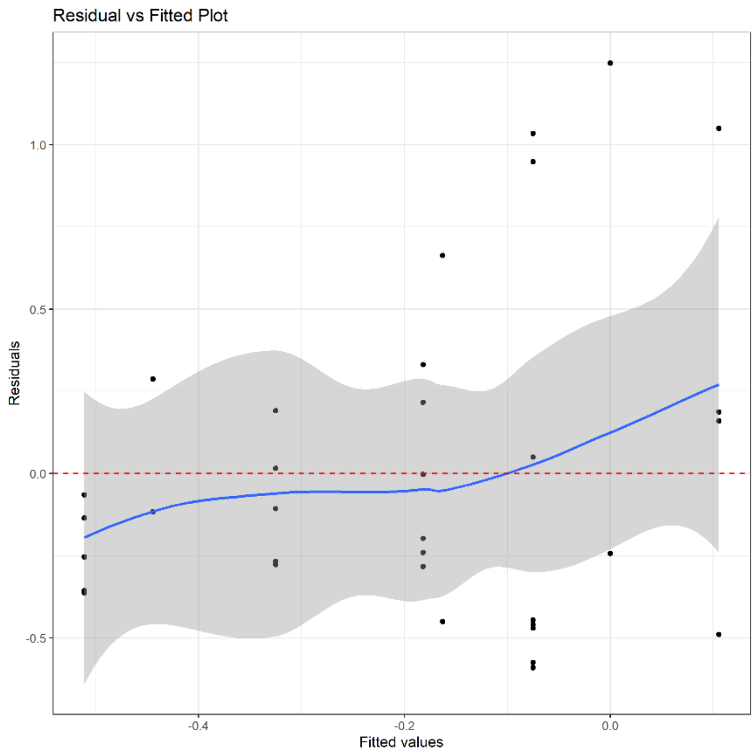


Figure S5.2. Residual vs Fitted values plot for CH_4 mixed model

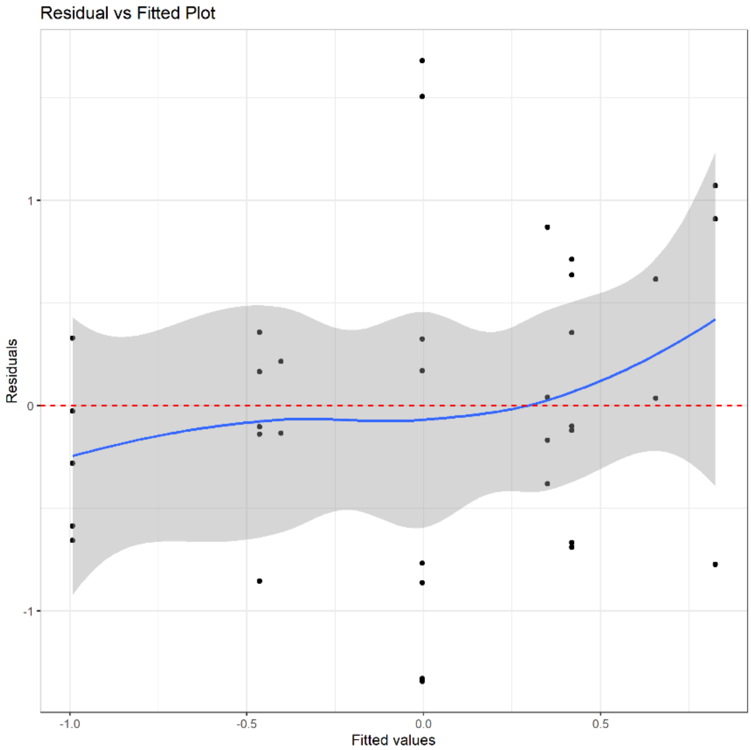


Figure S5.3. Residual vs Fitted values plot for N_2O mixed model

6. Supplementary Material S6: Mosaic plots for categorical variables

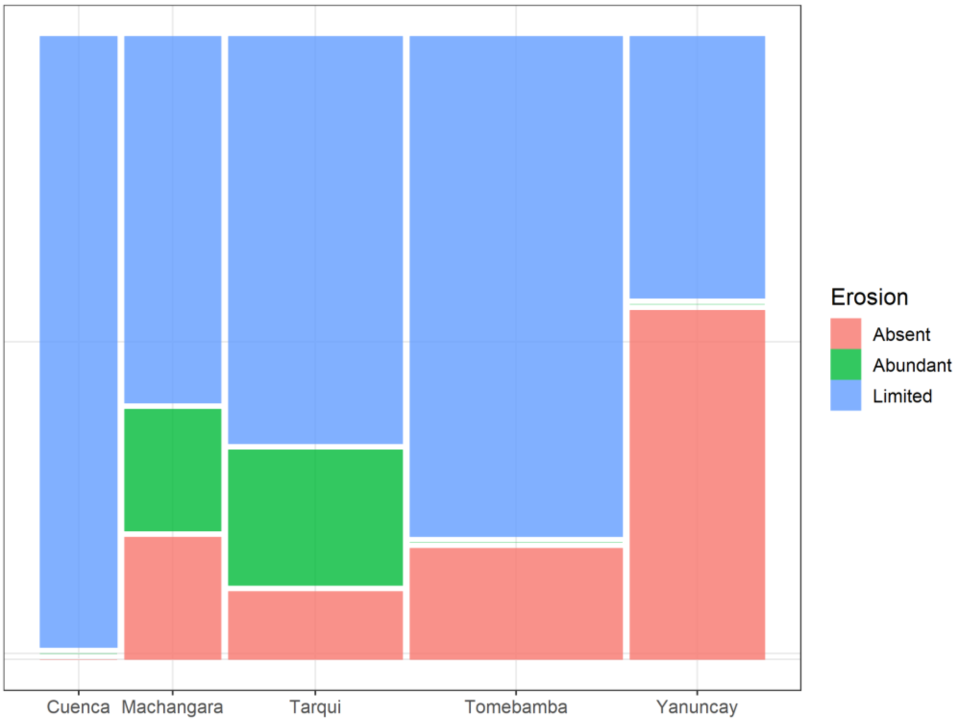


Figure S6.1. Mosaic plot of erosion level in Cuenca urban river system

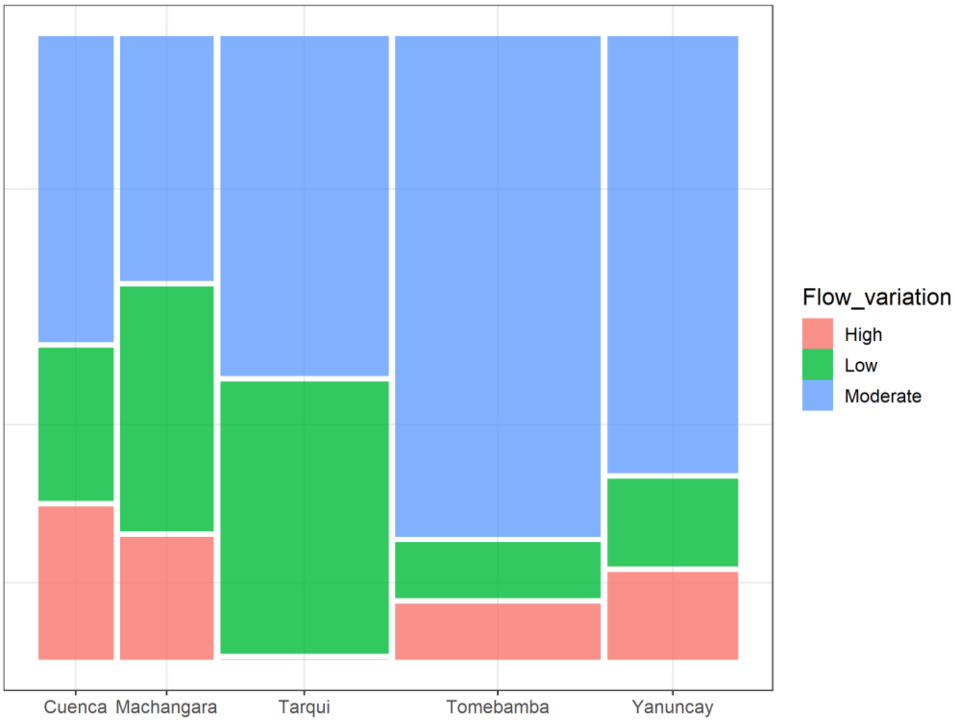


Figure S6.2. Mosaic plot of flow variation in Cuenca urban river system

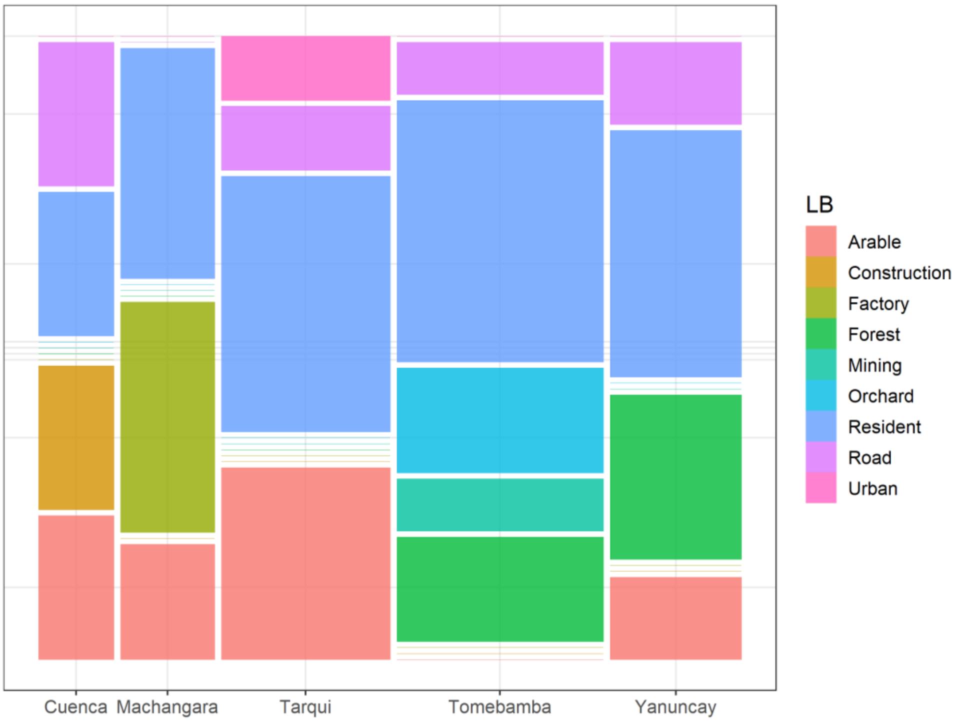


Figure S6.3. Mosaic plot of land-use categories in left bank in Cuenca urban river system. LB: Left Bank

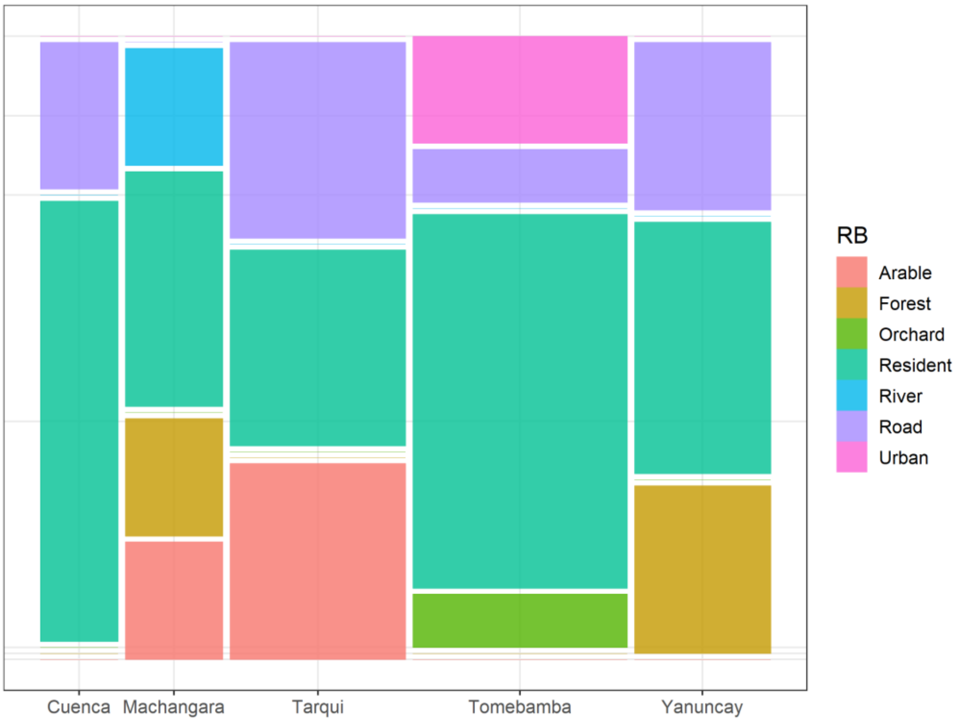


Figure S6.4. Mosaic plot of land-use categories in right bank in Cuenca urban river system. RB: Right Bank

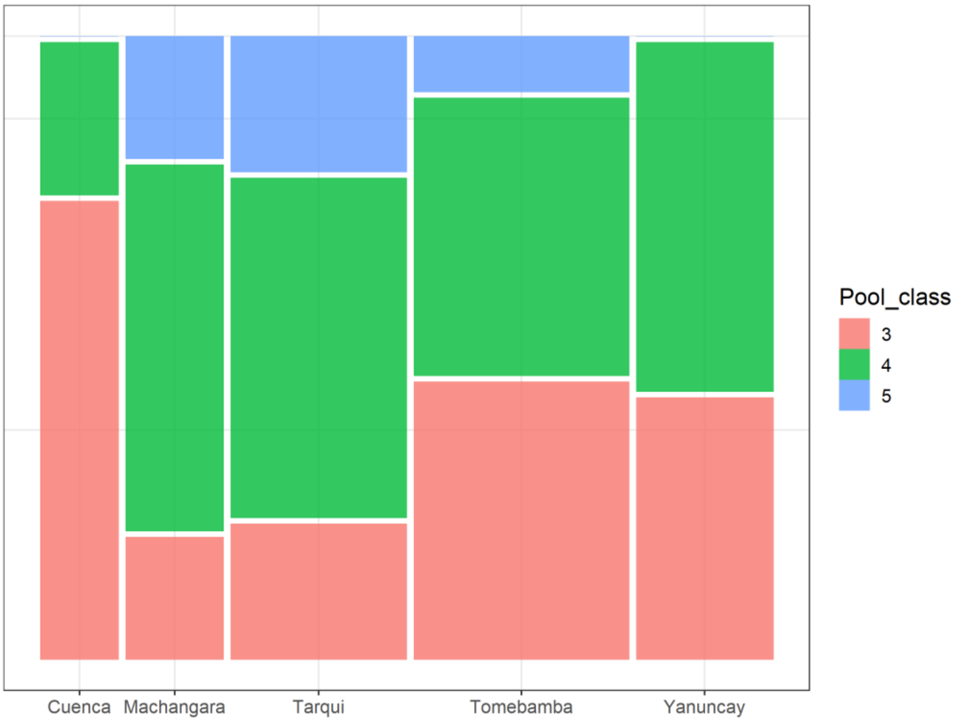


Figure S6.5. Mosaic plot of pool-riffle classes in Cuenca urban river system

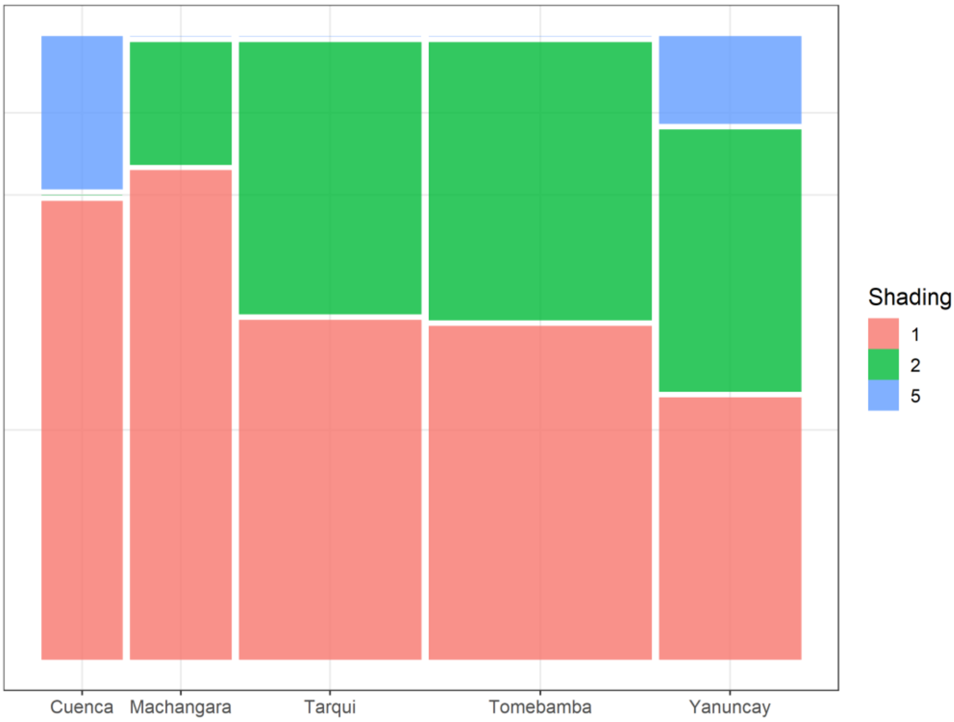


Figure S6.6. Mosaic plot of shading levels in Cuenca urban river system

7. Supplementary Material S7: Source of the GHG emissions

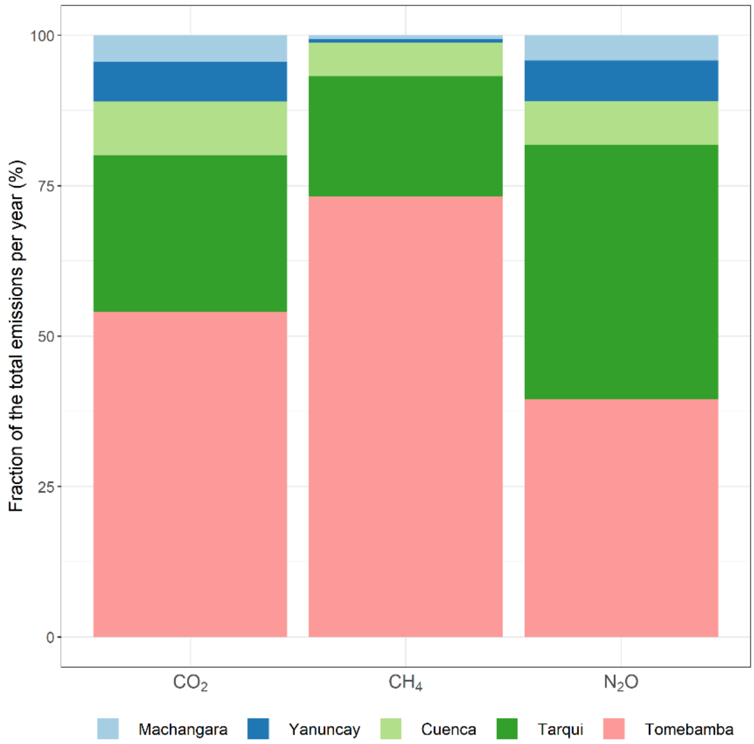


Figure S7.1. Fraction of the total emissions per year from the five tributaries of the Cuenca urban river system.

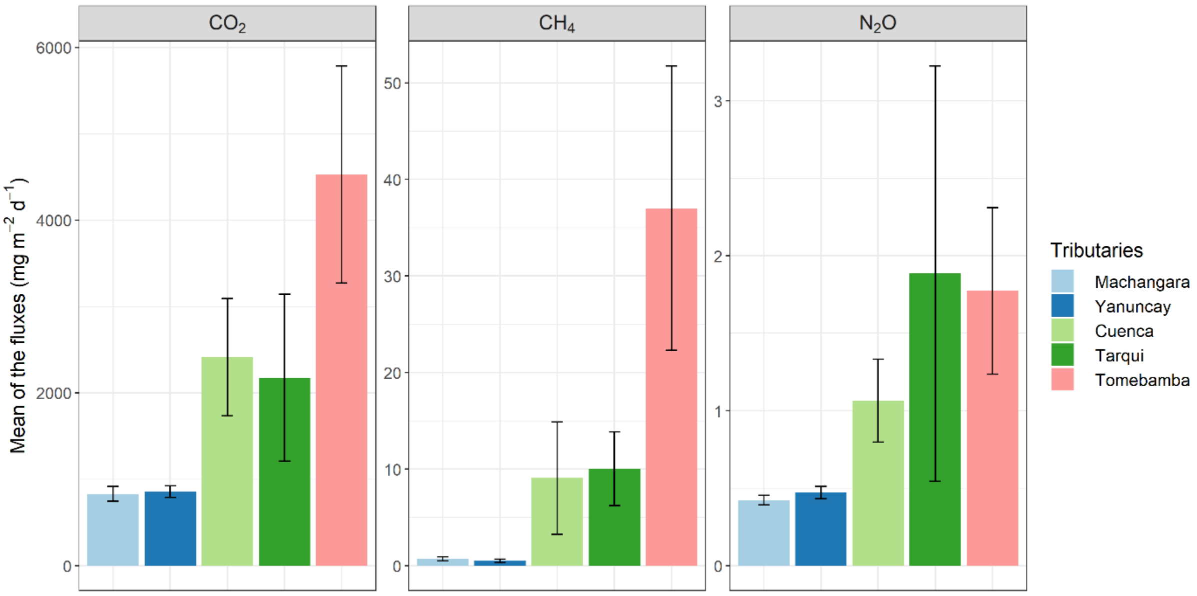


Figure S7.2. Mean of the fluxes from the five tributaries of the Cuenca urban river system. Error bars represent the standard error of the mean of the sample.