Mines – Rivers – Yields

Downstream Mining Impacts on Agriculture in Africa

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Snapshot

Background

Methods and Data

Results

Mines — Curse or Blessing?

A Blessing?

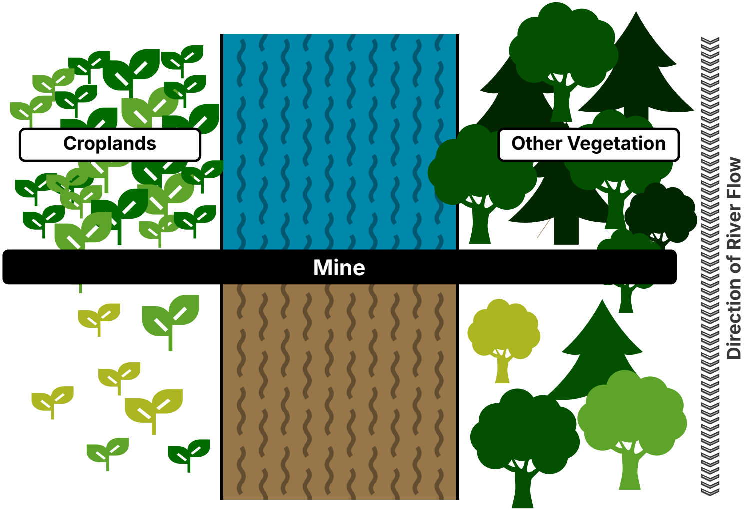
- More **minerals** are needed for the **green transition**.
- **Africa** has large reserves of some of these minerals.
- Extraction entails **local economic opportunities**.

A Curse?

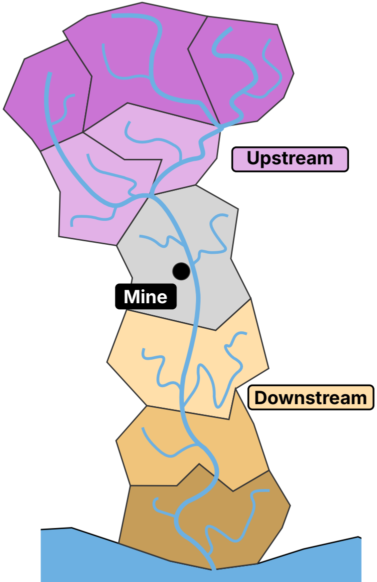
- Resource extraction causes **negative externalities.**
- **Ecological** effects are well-documented and can impact livelihoods.
- Ideally, we can inform **policy** in order to mitigate them.

How Pollution Travels

If **water pollution** from mines affects vegetation, we should observe **reduced vegetation health downstream** of a mine.



How to Find Downstream Areas



Using data on **river basins** (Lehner & Grill, 2013), we know where water flows from a given location.

Water moves from **upstream** to **downstream** of a mine.

Using a **remotely-sensed vegetation index**, we find evidence for less healthy vegetation **downstream**.

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Economic Benefits from Mines

- Demand for relevant **minerals** is projected to increase **fourfold** until 2050 (Hund et al., 2023).
- Extraction of these resources has **multiple benefits**:
  - enabling the **green transition**,
  - increasing local **incomes** (Bazillier & Girard, 2020),
  - and improving **wealth** and **asset ownership** (von der Goltz & Barnwal, 2019).

Mines' Negative Externalities

- Mines cause a flurry of **negative externalities**.
- Mines negatively impact the **institutional environment**, causing
  - **conflict** (Berman et al., 2017) and
  - **corruption** (Knutsen et al., 2016).
- An especially extensive cluster of externalities revolves around **pollution**.

Mines' Negative Externalities: Pollution

- Mines **use water** and produce **sediments and tailings** (Moura et al., 2022).
- Pollutants include **mercury** and **lead** (Schwarzenbach et al., 2010).
- 23 million people live in **polluted river basins** (Macklin et al., 2023).
- Industrial pollution **harms plant growth** (Yang et al., 2021).

Mines pollute water, this water travels, and it can harm plants.

Research Question

What is the causal effect of water pollution from mining on agricultural productivity in Africa?

- **Africa** is a particularly interesting focus because
  - it has a **booming mining industry** (ICMM, 2022),
  - with many **artisanal and small-scale mines** (ASM Inventory, 2022; Girard et al., 2022)
  - and a **lack of containment facilities** (Kossoff et al., 2014; Macklin et al., 2023).
- Negative effects are **more locally concentrated** than benefits.
- Informing this discussion enables **improved environmental governance**.

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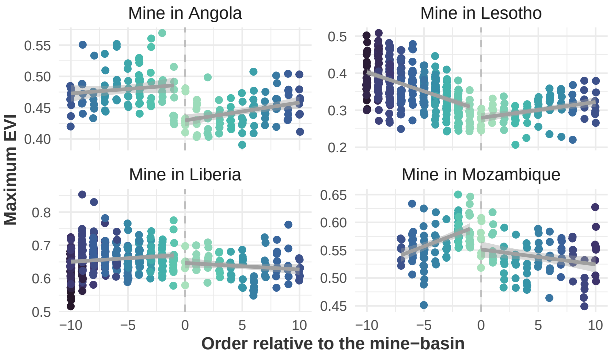
Intuition

The **four mines** depicted give an intuition for what we expect.

Following the river "flow" from left to right, we can see **discontinuities** at the **mine basin**.



show distance

Basins

Illustration from Lehner and Grill (2013)

Our **unit of observation** is the **river basin**.

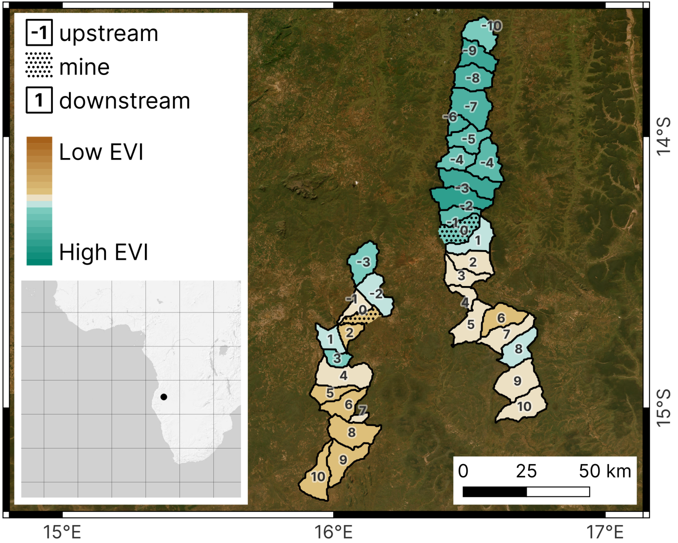
Lehner and Grill (2013) provide a nested basin collection, of which we use the **most granular level**.

If we spill a cup of water anywhere in a basin, it always ends up in the next basin **downstream**.

Mines

We use **mine locations** from Maus et al.'s (2022) dataset, which includes some ASM sites.

We then designate **mine basins** and determine 10 levels each of **upstream** and **downstream** basins.



A Remotely Sensed Outcome Measure

- We cannot use official **agricultural production statistics** due to a
  - lack of spatial **granularity** and the
  - **institutional differences** across countries.
- Instead, we use the **Enhanced Vegetation Index (EVI)**, which
  - is **remotely sensed** as the difference between red and near infrared light,
  - ranges **between –1** (water) **and 1** (dense vegetation), and
  - can be seen as a measure of **vegetation greenness**.

A Proxy for Agricultural Activity

- We get a **proxy** for **agricultural productivity** like this:

  (1) Filter out **cloud cover**.

  (2) Aggregate the **mean EVI** per basin.

  (3) Take the **annual maximum** per basin per year. **→ Max. EVI**

  (4) Apply a **cropland mask** (Digital Earth Africa, 2022). **→ Max. Cropland EVI**

- This **Peak Vegetation Index** has been shown to proxy well for crop yields (Azzari et al., 2017; Becker-Reshef et al., 2010; Bolton & Friedl, 2013; Johnson, 2016).

Observations

- We observe N = 14,327 basins over a period of T = 8 years:
  - **6,698 upstream** basins,
  - **1,900 mine** basins, and
  - **5,729 downstream** basins.

show order × up-/downstream numbers

- In addition to treatment and outcome, we observe **covariates** concerning:
  - **topography** (elevation and slope),
  - **soil type**,
  - **climate** (precipitation, temperature), and
  - **socioeconomic characteristics** (population, accessibility).

show balance

Summary Statistics

Variable	*N*	Mean	St. Dev.	Min.	Max.
Max. EVI	114,616	0.411	0.168	-0.112	0.993
Mean EVI	114,616	0.270	0.118	-0.112	0.578
Max. Cropland EVI	94,671	0.454	0.129	-0.112	0.990
Mean Cropland EVI	94,671	0.286	0.093	-0.114	0.734
Max. Temperature	114,616	33.80	4.047	20.00	45.40
Precipitation	114,616	882.3	606.3	0.555	4,375.3
Population	114,536	8,185	37,090	0.000	1,396,921
Elevation	114,616	804.6	482.0	-118.3	3,059.7
Slope	114,616	2.201	2.320	0.000	20.92
Accessibility	114,576	183.9	255.9	1.002	7,681

show balance

Empirical Strategy

We employ a **quasi-experimental regression discontinuity design (RDD):**

$$y_{ijt} = \beta_1 \, d_{ij} + \beta_2 \, d_{ij} \times \text{downstream}_j + \beta_3 \, \text{downstream}_j + \boldsymbol{\delta}' \mathbf{x}_{it} + \mu_j + \psi_t + \varepsilon_{ijt},$$

- y_{ijt}: **Outcome** of basin i near mine j in year t,
- μ_j, ψ_t: Mine and year **fixed effects**,
- $\mathbf{x}_{it}$: Basin specific **covariates:**
  - topographic, climate, soil type, socioeconomic,
- d_{ij}: **Distance** to nearest mine,
  - either the **basin's order** relative to the mine,
  - or kilometers along the **river stream**.

Identification

$$y_{ijt} = \beta_1 \, \mathrm{d}_{ij} + \beta_2 \, \mathrm{d}_{ij} \times \mathrm{downstream}_j + \beta_3 \, \mathrm{downstream}_j + \boldsymbol{\delta}' \mathbf{x}_{it} + \mu_j + \psi_t + \varepsilon_{ijt},$$

- Parameter β_3 is identified under the assumption that there are no **other discontinuous changes** at the mine basin.
- To assess the **validity** of this assumption, we
  - check **balance** of up- and downstream basins,
  - include meteorological, geographical, and socioeconomic **controls**, and
  - use plausibly unaffected covariates as **placebo** outcomes .

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Results Overview

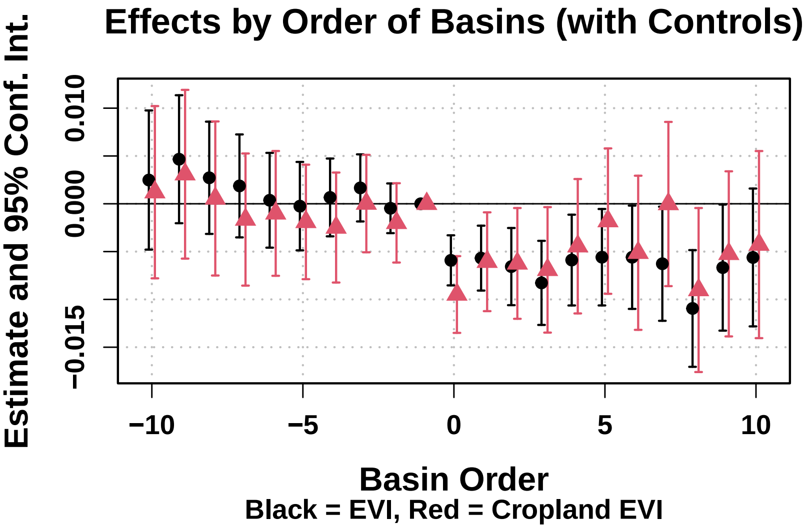
- We find a **significant reduction** in vegetation health **downstream** of mines.
- The magnitude of this effect is **greater** on **croplands**.
- Impacts **dissipate slowly** the farther we move from a mine.
- These results are **robust** to varying the sample, the outcome measurement, and the level of fixed effects.

Order Specification Results (1)

	Max. EVI		Max. Cropland EVI	
	(Plain)	(Full)	(Plain)	(Full)
Order				
Mine-basin (0^{th})	-0.0064***	**-0.0059***	-0.0093***	**-0.0095***
	(0.0014)	(0.0013)	(0.0021)	(0.0020)
Downstream (1^{st})	-0.0060***	**-0.0057***	-0.0049*	**-0.0061**
	(0.0018)	(0.0017)	(0.0026)	(0.0026)
Downstream (2^{nd})	-0.0070***	**-0.0066***	-0.0042	**-0.0062**
	(0.0021)	(0.0021)	(0.0028)	(0.0030)
Sample mean	0.412	0.412	0.454	0.454
Observations	114,616	114,496	94,671	94,604
R^2	0.912	0.924	0.780	0.786
Controls	No	Yes	No	Yes
Year F.E.	Yes	Yes	Yes	Yes
Mine F.E.	Yes	Yes	Yes	Yes

Clustered (by mine-basin) standard errors in parentheses.
*Significance levels: ***: 0.01, **: 0.05, *: 0.1.* show full results

Order Specification Results (2)



Order Specification Results (3)

- We can see that **upstream** basins are unaffected, while **downstream** basins experience a significant negative effect.
- At the sample mean, the effect for the
  - **Max. EVI** corresponds to an EVI reduction of **1.4%**.
  - **Max. Cropland EVI** corresponds to an EVI reduction of **2.1%**.
- The effect **persists** beyond the mine basin.
- At higher order basins, impacts become imprecise.

Distance Specification Results

	Max. EVI		*Max. Cropland EVI*	
	(Plain)	**(Full)**	**(Plain)**	**(Full)**
Distance				
Downstream	**-0.0065***	**-0.0058***	**-0.0086***	**-0.0087***
	(0.0023)	(0.0021)	(0.0029)	(0.0028)
Downstream × Distance	-2.0×10^{-5}	-2.0×10^{-5}	0.0003**	0.0002
	(0.0001)	(0.0001)	(0.0001)	(0.0001)
Downstream × Distance^2	-4.0×10^{-7}	-9.8×10^{-8}	-2.2×10^{-6}**	-1.9×10^{-6}*
	(9.2×10^{-7})	(7.2×10^{-7})	(1.1×10^{-6})	(1.0×10^{-6})
Sample mean	0.412	0.412	0.454	0.454
Observations	114,616	114,496	94,671	94,604
R^2	0.918	0.924	0.780	0.786
Controls	No	Yes	No	Yes
Year F.E.	Yes	Yes	Yes	Yes
Mine F.E.	Yes	Yes	Yes	Yes

Clustered (by mine-basin) standard errors in parentheses.
*Significance levels: ***: 0.01, **: 0.05, *: 0.1.* show full results

Impact Decay (1)

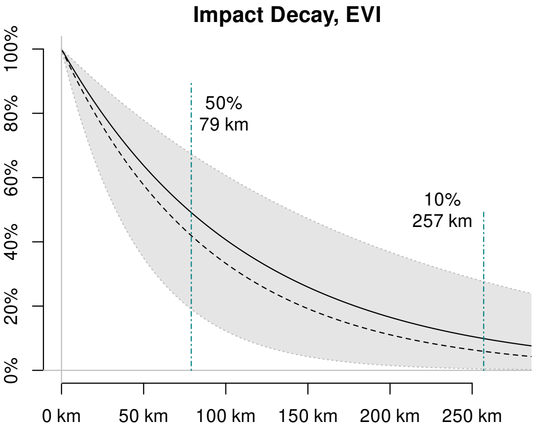
- The decay of the impact is **not accurately reflected** by linear and linear-quadratic distance operationalizations.
- Dispersal of toxic mine tailings occurs non-linearly (Macklin et al., 2023).
- We therefore re-estimate the main specification using an **exponential distance decay** function:

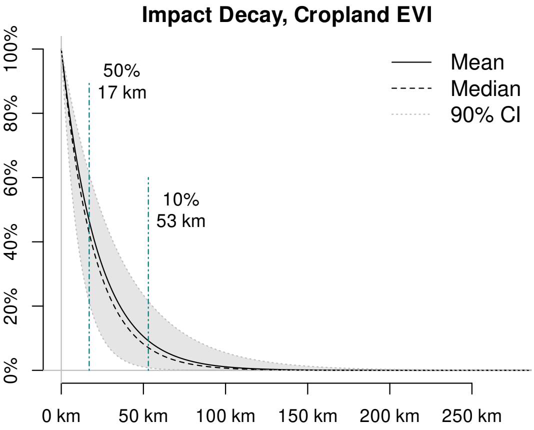
$$exp(-\delta d_{ij}),$$

where d_{ij} is the distance along the river from a mine.

show details

Impact Decay (2)

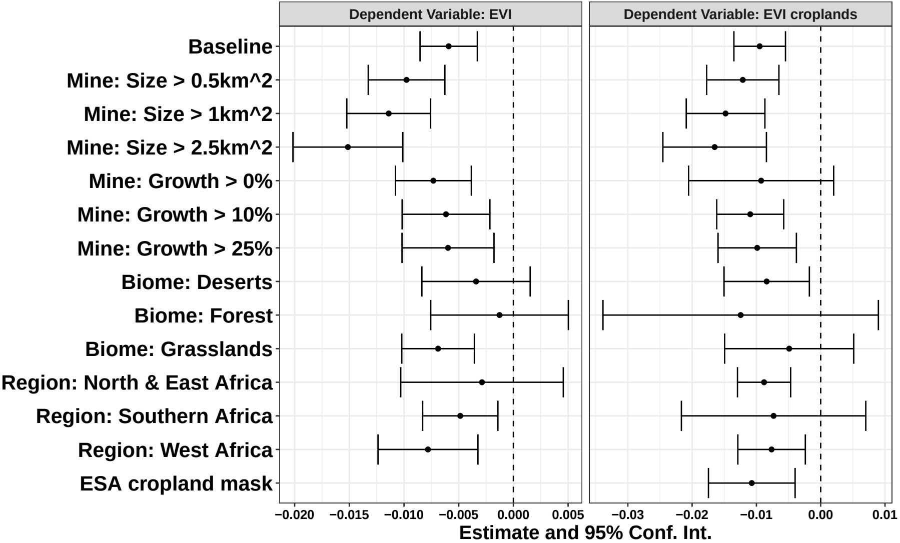




Heterogeneity (1)

- We investigate heterogeneity along three main dimensions.
  - **Characteristics of mine basin** :
    - greater effect for larger mines,
    - no differential effect for mines that grew faster over time
  - **Biome** :
    - larger effect for mines located in grasslands,
    - no significant effect in deserts and forests.
  - **Region** :
    - greater effect in West Africa,
    - smaller effect in Southern Africa,
    - no significant effect in North & East Africa.

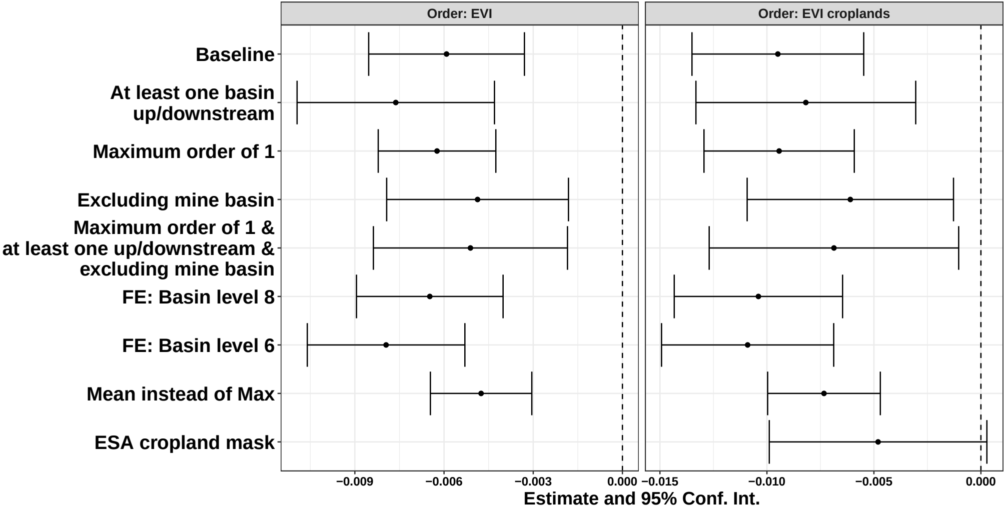
Heterogeneity (2)



Robustness Checks

- We check the robustness of our results in multiple ways.
  - **Outcome Variable**:
    - mean instead of maximum EVI, different cropland mask.
  - **Sample Definition**
  - **Level of Fixed Effects**
  - **Estimation Methods**:
    - data-driven estimation methods (Cattaneo et al., 2019),
    - inducing balance using coarsened exact matching (Iacus et al., 2012).
  - **Placebo Outcomes**:
    - temperature, elevation, slope, precipitation, accessibility, population.

Robustness



show varying sample estimates | show varying outcome/FE estimates | show placebo estimates | show automatic BW sel. estimates

Discussion

- We find **negative impacts** on vegetation health by about 1.4-2.1% at the sample mean.
- Various treatments have been found to have large effects on crop yields.
  - Land tenure reforms: +20% (Adamopoulos et al., 2024)
  - Gold mining: about -40% (Aragón & Rud, 2015)
- Studies that use remotely sensed outcome measures usually find smaller effects.
  - Institutional changes reduce crop yields by about 2% as measured through EVI (Wuepper et al., 2023)

Relevance

- Our findings inform the **discussion** about **resource extraction**,
  - particularly in countries with **weak environmental governance.**
- There is a need to
  - tackle the lack of **containment facilities** and
  - improve **environmental legislation**,
  - both for **industrial** and **informal** mines.
- This is an especially urgent issue due to its potential to endanger **food supply**.

Limitations and Future Alleys for Research

- Using **remotely sensed measures** helped us overcome data scarcity.
- However, they only represent crop yields **indirectly**.
- Our **treatment indicator** relied only on mine location.
- Differences in **waste management** are not accounted for, but may affect outcomes.
- **Adaptive behavior** by farmers is not covered and may attenuate results.

Conclusion

- We identified the **causal effects** of mining on agricultural productivity mediated by water pollution.
- Our results showed a **negative impact** on vegetation health.
- Effects were particularly **strong**
  - for larger mines,
  - on grasslands, and
  - in West Africa.
- The results were **robust** to various changes of treatment, outcome or sample definition.

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Appendix

Appendix Impact Decay Assessment

- We re-estimate our main specification using an **exponential decay** function $\exp\{-\delta d_{ij}\}$.
- **Hydrological studies** on dispersion patterns suggest using an exponential decay function.
- Since the **decay parameter** is not known, we conduct a grid search for $\delta \in [0.001, 2]$.
- We then use a **Bayesian model averaging** approach with BIC as marginal likelihood approximation.
- Finally, we compute the **mean effect decay** at increasing distances.

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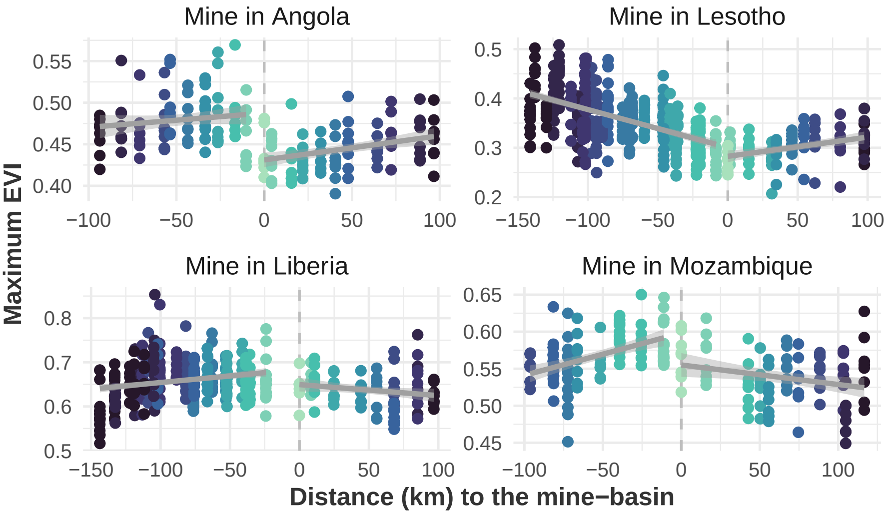
Four Selected Mines, Distance



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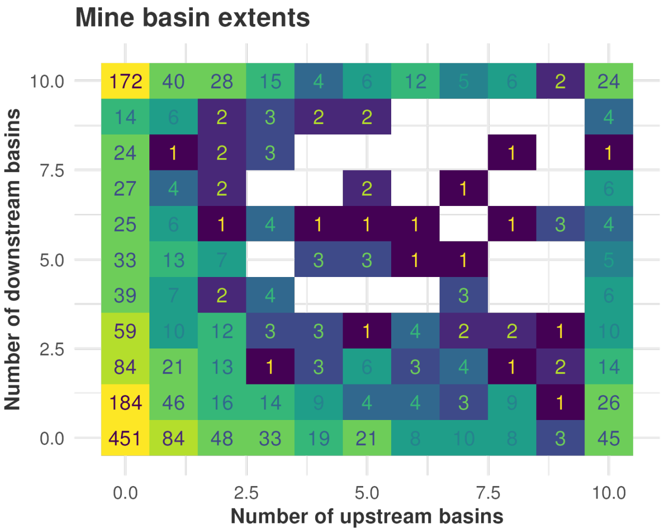

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Appendix Basins by Order

Order	Downstream		Upstream	
	N	Distance (km)	*N*	Distance (km)
0	1900	0.0	-	-
1	1162	10.7	987	14.5
2	841	22.2	865	24.2
3	695	32.9	778	34.7
4	591	43.7	738	44.7
5	531	54.4	681	55.1
6	462	64.8	593	65.9
7	418	74.3	575	75.6
8	376	85.1	530	86.6
9	343	95.9	499	95.7
10	310	106.1	452	104.2

go back to observations overview

Appendix Summary Statistics for Upstream Basins

	Upstream Basins				
Variable	*N*	Mean	St. Dev.	Min.	Max.
Max. EVI	53,584	0.417	0.169	0.021	0.983
Mean EVI	53,584	0.276	0.120	0.020	0.578
Max. Cropland EVI	44,389	0.459	0.127	0.057	0.990
Mean Cropland EVI	44,389	0.291	0.093	-0.002	0.637
Max. Temperature	53,584	33.83	4.003	20.00	45.10
Precipitation	53,584	905.4	606.5	0.851	3,976.0
Population	53,584	6,693.8	27,878.2	0.000	1,396,921.0
Elevation	53,584	840.5	471.2	10.53	3,059.7
Slope	53,584	2.295	2.256	0.086	20.91
Accessibility	53,584	192.0	242.3	3.000	7,542.8

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Appendix Summary Statistics for Downstream Basins

Downstream Basins (incl. Mine Basins)					
Variable	*N*	Mean	St. Dev.	Min.	Max.
Max. EVI	61,032	0.406	0.167	−0.112	0.993
Mean EVI	61,032	0.264	0.116	−0.112	0.563
Max. Cropland EVI	50,282	0.450	0.130	−0.112	0.981
Mean Cropland EVI	50,282	0.283	0.093	−0.114	0.734
Max. Temperature	61,032	33.78	4.085	20.00	45.40
Precipitation	61,032	862.0	605.4	0.555	4,375.3
Population	60,952	9,497.1	43,568.1	0.000	1,244,492.0
Elevation	61,032	773.1	489.1	−118.3	3,047.1
Slope	61,032	2.119	2.371	0.000	20.456
Accessibility	60,992	176.9	267.1	1.002	7,681.8

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Appendix Full Order Specification Results

Dependent Variables:	Maximum EVI			Maximum Cropland EVI		
Model:	(1)	(2)	(3)	(4)	(5)	(6)
Variables						
Downstream x Order = 0	-0.0064***	-0.0063***	-0.0059***	-0.0093***	-0.0097***	-0.0095***
	(0.0014)	(0.0014)	(0.0013)	(0.0021)	(0.0021)	(0.0020)
Downstream x Order = 1	-0.0060***	-0.0048***	-0.0057***	-0.0049*	-0.0050*	-0.0061**
	(0.0018)	(0.0018)	(0.0017)	(0.0026)	(0.0027)	(0.0026)
Downstream x Order = 2	-0.0070***	-0.0053**	-0.0066***	-0.0042	-0.0046	-0.0062**
	(0.0021)	(0.0021)	(0.0021)	(0.0028)	(0.0029)	(0.0030)
Downstream x Order = 3	-0.0094***	-0.0069***	-0.0083***	-0.0049	-0.0049	-0.0069**
	(0.0023)	(0.0023)	(0.0022)	(0.0032)	(0.0033)	(0.0033)
Downstream x Order = 4	-0.0071***	-0.0053**	-0.0059**	-0.0027	-0.0036	-0.0044
	(0.0025)	(0.0024)	(0.0024)	(0.0034)	(0.0036)	(0.0036)
Downstream x Order = 5	-0.0077***	-0.0052**	-0.0056**	-0.0009	-0.0013	-0.0018
	(0.0028)	(0.0026)	(0.0026)	(0.0037)	(0.0038)	(0.0039)
Downstream x Order = 6	-0.0084***	-0.0054*	-0.0056**	-0.0042	-0.0044	-0.0051
	(0.0031)	(0.0028)	(0.0028)	(0.0039)	(0.0041)	(0.0041)
Downstream x Order = 7	-0.0093***	-0.0063**	-0.0063**	0.0008	0.0003	-2.53×10^{-5}
	(0.0033)	(0.0031)	(0.0030)	(0.0041)	(0.0043)	(0.0044)
Downstream x Order = 8	-0.0140***	-0.0110***	-0.0109***	-0.0074*	-0.0085**	-0.0090**
	(0.0033)	(0.0031)	(0.0031)	(0.0041)	(0.0043)	(0.0044)
Downstream x Order = 9	-0.0103***	-0.0065*	-0.0067**	-0.0042	-0.0045	-0.0052
	(0.0035)	(0.0034)	(0.0034)	(0.0039)	(0.0043)	(0.0044)
Downstream x Order = 10	-0.0107***	-0.0056	-0.0056	-0.0038	-0.0038	-0.0043
	(0.0037)	(0.0037)	(0.0037)	(0.0045)	(0.0049)	(0.0050)
Elevation		-7.77×10^{-6}	$-2.3 \times 10^{-5***}$		$-1.59 \times 10^{-5**}$	$-3.86 \times 10^{-5***}$
		(6.08×10^{-6})	(6.29×10^{-6})		(7.19×10^{-6})	(7.35×10^{-6})
Slope		0.0034***	0.0033***		0.0023***	0.0023***
		(0.0005)	(0.0005)		(0.0006)	(0.0006)
Yearly Max. Temperature			-0.0053***			-0.0071***
			(0.0007)			(0.0007)
Yearly Precipitation			$3.33 \times 10^{-5***}$			$2.86 \times 10^{-5***}$
			(3.61×10^{-6})			(3.95×10^{-6})
Accessibility in 2015			$-9.97 \times 10^{-6*}$			-3.78×10^{-6}
			(5.28×10^{-6})			(1.18×10^{-5})
Population in 2015			$-1.51 \times 10^{-7***}$			$-1.06 \times 10^{-7***}$
			(2.75×10^{-8})			(2.04×10^{-8})
Sample Mean Effect	-1.567	-1.531	-1.438	-2.042	-2.127	-2.089
Fixed-effects						
Year	Yes	Yes	Yes	Yes	Yes	Yes
Mine	Yes	Yes	Yes	Yes	Yes	Yes
Fit statistics						
Observations	114,616	114,616	114,496	94,671	94,671	94,604
R^2	0.91808	0.92156	0.92395	0.77981	0.78184	0.78597
Within R^2	0.00393	0.04627	0.05582	0.00180	0.01099	0.02531

Clustered (Mine) standard-errors in parentheses
*Signif. Codes: ***: 0.01, **: 0.05, *: 0.1*

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Appendix Full Distance Specification Results

Dependent Variables:	Maximum EVI			Maximum Cropland EVI		
Model:	(1)	(2)	(3)	(4)	(5)	(6)
Variables						
Downstream	-0.0065***	-0.0060***	-0.0058***	-0.0086***	-0.0088***	-0.0087***
	(0.0023)	(0.0021)	(0.0021)	(0.0029)	(0.0029)	(0.0028)
Downstream × Distance	-2.02×10^{-5}	1.05×10^{-5}	-2.02×10^{-5}	0.0003**	0.0002*	0.0002
	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0001)
Downstream × Distance^2	-3.98×10^{-7}	-4.37×10^{-7}	-9.8×10^{-8}	-2.15×10^{-6}**	-2.34×10^{-6}**	-1.94×10^{-6}*
	(9.17×10^{-7})	(7.35×10^{-7})	(7.19×10^{-7})	(1.06×10^{-6})	(1.03×10^{-6})	(1.03×10^{-6})
Distance	4.05×10^{-5}	2.98×10^{-5}	2.56×10^{-5}	-7.01×10^{-5}	-5.62×10^{-5}	-4.6×10^{-5}
	(9.03×10^{-5})	(8.4×10^{-5})	(8.19×10^{-5})	(0.0001)	(0.0001)	(0.0001)
Distance^2	-1.87×10^{-7}	-9.18×10^{-9}	2.1×10^{-8}	6.93×10^{-7}	8×10^{-7}	6.06×10^{-7}
	(6.27×10^{-7})	(5.68×10^{-7})	(5.56×10^{-7})	(8.38×10^{-7})	(8.23×10^{-7})	(8.22×10^{-7})
Elevation		-7.45×10^{-6}	-2.22×10^{-5}***		-1.83×10^{-5}**	-4.03×10^{-5}***
		(6.56×10^{-6})	(6.71×10^{-6})		(7.55×10^{-6})	(7.61×10^{-6})
Slope		0.0034***	0.0032***		0.0023***	0.0023***
		(0.0005)	(0.0005)		(0.0006)	(0.0006)
Yearly Max. Temperature			-0.0053***			-0.0070***
			(0.0007)			(0.0007)
Yearly Precipitation			3.33×10^{-5}***			2.88×10^{-5}***
			(3.6×10^{-6})			(3.94×10^{-6})
Accessibility in 2015			-1.01×10^{-5}*			-4.03×10^{-6}
			(5.31×10^{-6})			(1.19×10^{-5})
Population in 2015			-1.51×10^{-7}***			-1.06×10^{-7}***
			(2.77×10^{-8})			(2.03×10^{-8})
Fixed-effects						
Year	Yes	Yes	Yes	Yes	Yes	Yes
Mine	Yes	Yes	Yes	Yes	Yes	Yes
Fit statistics						
Observations	114,616	114,616	114,496	94,671	94,671	94,604
R^2	0.91804	0.92152	0.92390	0.77971	0.78175	0.78587
Within R^2	0.00346	0.04573	0.05524	0.00138	0.01060	0.02485

Clustered (Mine) standard-errors in parentheses
*Signif. Codes: ***: 0.01, **: 0.05, *: 0.1*

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Varying Sample Definition

Dependent Variables:			Maximum EVI					Maximum Cropland EVI		
Model:	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Variables										
Downstream x Order = 0	-0.0059***	-0.0076***	-0.0062***			-0.0095***	-0.0082***	-0.0094***		
	(0.0013)	(0.0014)	(0.0012)			(0.0020)	(0.0024)	(0.0022)		
Downstream x Order = 1	-0.0057***	-0.0053***	-0.0053***	-0.0049**	-0.0051**	-0.0061**	-0.0049	-0.0051*	-0.0061**	-0.0069*
	(0.0017)	(0.0020)	(0.0017)	(0.0020)	(0.0021)	(0.0026)	(0.0032)	(0.0030)	(0.0030)	(0.0039)
Downstream x Order = 2	-0.0066***	-0.0054**		-0.0056**		-0.0062**	-0.0057		-0.0062*	
	(0.0021)	(0.0026)		(0.0023)		(0.0030)	(0.0037)		(0.0033)	
Fixed-effects										
Year	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Mine	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Fit statistics										
Observations	114,496	61,712	32,360	99,320	9,168	94,604	50,914	27,589	81,278	7,623
R^2	0.92395	0.91566	0.93993	0.92392	0.93378	0.78597	0.76613	0.84032	0.78332	0.81766
Within R^2	0.05582	0.05702	0.05650	0.05511	0.07364	0.02531	0.02382	0.03446	0.02322	0.03884

Clustered (Mine) standard-errors in parentheses
*Signif. Codes: ***: 0.01, **: 0.05, *: 0.1*

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Appendix Varying Outcome / Fixed Effects

Dependent Variables:	Maximum EVI			Mean EVI	Maximum Cropland EVI			Mean C EVI	ESA C EVI
Model:	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Variables									
Downstream x Order = 0	-0.0059***	-0.0065***	-0.0079***	-0.0048***	-0.0095***	-0.0104***	-0.0109***	-0.0073***	-0.0048*
	(0.0013)	(0.0013)	(0.0014)	(0.0009)	(0.0020)	(0.0020)	(0.0021)	(0.0013)	(0.0026)
Downstream x Order = 1	-0.0057***	-0.0060***	-0.0066***	-0.0035***	-0.0061**	-0.0062**	-0.0064***	-0.0043**	-0.0035
	(0.0017)	(0.0016)	(0.0017)	(0.0011)	(0.0026)	(0.0025)	(0.0025)	(0.0017)	(0.0032)
Downstream x Order = 2	-0.0066***	-0.0064***	-0.0067***	-0.0038***	-0.0062**	-0.0058**	-0.0064**	-0.0055***	-0.0015
	(0.0021)	(0.0020)	(0.0020)	(0.0013)	(0.0030)	(0.0029)	(0.0028)	(0.0019)	(0.0035)
Fixed-effects									
Year	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Mine	Yes			Yes	Yes			Yes	Yes
Pfaffstetter basin level 8		Yes				Yes			
Pfaffstetter basin level 6			Yes				Yes		
Fit statistics									
Observations	114,496	114,496	114,496	114,496	94,604	94,604	94,604	94,604	67,649
R^2	0.92395	0.91954	0.90419	0.95707	0.78597	0.77061	0.74193	0.88641	0.80154
Within R^2	0.05582	0.06500	0.08647	0.11783	0.02531	0.02957	0.04285	0.04478	0.02553

Clustered (Mine) standard-errors in parentheses
*Signif. Codes: ***: 0.01, **: 0.05, *: 0.1*

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Appendix Placebo Outcomes

Dependent Variables:	Elevation	Slope	Max. Temp	Precipitation	Accessibility in 2015	Population in 2015
Model:	(1)	(2)	(3)	(4)	(5)	(6)
Variables						
Downstream	-6.852	-0.0538	-0.0137	0.6025	-5.427	2,125.7
	(8.509)	(0.0912)	(0.0567)	(3.934)	(5.531)	(1,589.8)
Distance × Downstream	-5.008***	-0.0060	0.0135***	-0.1942	0.0839	-182.9***
	(0.4814)	(0.0044)	(0.0036)	(0.2860)	(0.3278)	(55.80)
Distance^2 × Downstream	0.0043	-8.25×10^{-6}	2.12×10^{-6}	0.0003	0.0004	1.081***
	(0.0039)	(4.01×10^{-5})	(3.36×10^{-5})	(0.0020)	(0.0028)	(0.3463)
Distance	2.326***	0.0025	-0.0067**	0.0879	0.7557***	-54.72
	(0.4215)	(0.0039)	(0.0032)	(0.2129)	(0.2587)	(45.17)
Distance^2	0.0005	1.12×10^{-6}	-5.34×10^{-6}	-0.0005	-0.0013	0.3439
	(0.0033)	(3.49×10^{-5})	(3.1×10^{-5})	(0.0015)	(0.0021)	(0.2724)
Fixed-effects						
Year	Yes	Yes	Yes	Yes	Yes	Yes
Mine	Yes	Yes	Yes	Yes	Yes	Yes
Fit statistics						
Observations	114,616	114,616	114,616	114,616	114,576	114,536
R^2	0.95627	0.70192	0.95579	0.96187	0.88768	0.59121
Within R^2	0.41042	0.01108	0.07605	0.00070	0.04659	0.00851

Clustered (Mine) standard-errors in parentheses
*Signif. Codes: ***: 0.01, **: 0.05, *: 0.1*

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Dist. Spec. w/ Aut. Bandwith Selection (No Controls)

	Max EVI		Max C EVI	
	Conv.	Bias-Corr.	Conv.	Bias-Corr.
No Controls				
Conventional	-0.0050***	-0.0056***	-0.0112***	-0.0116***
	(0.0015)	(0.0015)	(0.0020)	(0.0025)
Observations	37,880	37,880	32,813	32,813
Bandwidth (Conv)	20.3	20.3	20.7	20.7
Bandwidth (Bias)	46.4	46.4	47.4	47.4

Note: Table shows results for estimation of 20, with distance as measured in kilometer along the river network used as the running variable, using practices suggested in Cattaneo et al., 2019 for automatic bandwidth selection using a triangular Kernel and the mean squared error distance as selection criterion, and bias correction. Models in the upper panel include no covariates, models in the lower panel include the full set of controls. Models in columns (1) and (2) report results using the overall EVI as outcome, models in columns (3) and (4) for the cropland-specific EVI. Models (1) and (3) fit a linear polynomial of the distance measure at each side of the cutoff, models in columns (2) and (4) a quadratic polynomial. All specifications include mine and year fixed effects. Standard errors are clustered at the mine basin system level.

Significance Codes: *** p<0.01, ** p<0.05, * p<0.1 · Clustered (Mine) standard errors in parentheses.

Appendix Dist. Spec. w/ Aut. Bandwith Selection (Full Controls)

	Max EVI		Max C EVI	
	Conv.	**Bias-Corr.**	**Conv.**	**Bias-Corr.**
	With Full Controls			
Conventional	-0.0045*** (0.0015)	-0.0049*** (0.0015)	-0.0100*** (0.0020)	-0.0118*** (0.0026)
Observations	38,200	38,200	32,629	32,629
Bandwidth (Conv)	20.6	20.6	20.5	20.5
Bandwidth (Bias)	43.4	43.4	45.4	45.4

Note: Table shows results for estimation of 20, with distance as measured in kilometer along the river network used as the running variable, using practices suggested in Cattaneo et al., 2019 for automatic bandwidth selection using a triangular Kernel and the mean squared error distance as selection criterion, and bias correction. Models in the upper panel include no covariates, models in the lower panel include the full set of controls. Models in columns (1) and (2) report results using the overall EVI as outcome, models in columns (3) and (4) for the cropland-specific EVI. Models (1) and (3) fit a linear polynomial of the distance measure at each side of the cutoff, models in columns (2) and (4) a quadratic polynomial. All specifications include mine and year fixed effects. Standard errors are clustered at the mine basin system level.

Significance Codes: *** p<0.01, ** p<0.05, * p<0.1 · Clustered (Mine) standard errors in parentheses.

Appendix Ord. Spec. w/ Aut. Bandwith Selection (Full Controls)

	Max EVI		Max C EVI	
	No Cluster	Cluster (Mine Basin)	No Cluster	Cluster (Mine Basin)
		No Controls		
I(order>0)	-0.0048	-0.0048	-0.0090***	-0.0090**
	(0.0013)	(0.0019)	(0.0018)	(0.0030)
Observations	45,613	45,613	38,537	38,537
Bandwidth	2	2	2	2

Note: Table shows results for estimation of 20, with distance as measured by the ordering of basins with respect to the mine basin as the running variable, using practices suggested in Kolesár and Rothe, 2018 for automatic bandwidth selection using a triangular Kernel and the mean squared error distance as selection criterion. Models in the upper panel include no covariates, models in the lower panel include the full set of controls. Models in columns (1) and (2) report results using the overall EVI as outcome, models in columns (3) and (4) for the cropland-specific EVI. Models (1) and (3) do no cluster standard errors, models in columns (2) and (4) cluster standard errors are at the mine basin system level. All specifications include mine and year fixed effects.
Significance Codes: *** p<0.01, ** p<0.05, * p<0.1

Ord. Spec. w/ Aut. Bandwith Selection (Full Controls)

	Max EVI		**Max C EVI**	
	No Cluster	**Cluster (Mine Basin)**	**No Cluster**	**Cluster (Mine Basin)**
		With Full Controls		
I(order>0)	-0.0048** (0.0012)	-0.0048 (0.0018)	-0.0090*** (0.0017)	-0.0090*** (0.0029)
Observations	45,580	45,580	38,504	38,504
Bandwidth	2	2	2	2

Note: Table shows results for estimation of 20, with distance as measured by the ordering of basins with respect to the mine basin as the running variable, using practices suggested in Kolesár and Rothe, 2018 for automatic bandwidth selection using a triangular Kernel and the mean squared error distance as selection criterion. Models in the upper panel include no covariates, models in the lower panel include the full set of controls. Models in columns (1) and (2) report results using the overall EVI as outcome, models in columns (3) and (4) for the cropland-specific EVI. Models (1) and (3) do no cluster standard errors, models in columns (2) and (4) cluster standard errors are at the mine basin system level. All specifications include mine and year fixed effects.

Significance Codes: *** p<0.01, ** p<0.05, * p<0.1

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