Mines – Rivers – Yields

Downstream Mining Impacts on Agriculture in Africa

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Background

Methods and Data

Results

Mines – Curse or Blessing?

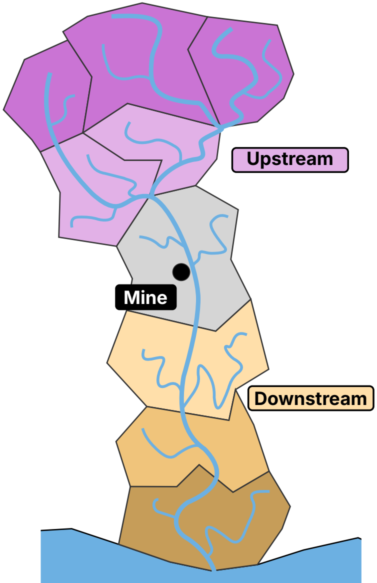
A Blessing?

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

A Curse?

- Resource extraction causes **negative externalities.**
- **Ecological effects** include:
  - Mines **use water** and produce **sediments and tailings** (Moura et al., 2022).
  - Pollutants include **mercury** and **lead** (Schwarzenbach et al., 2010).
  - Industrial pollution **harms plant growth** (Yang et al., 2021).

How to Find Affected 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**.

show schematic depiction show more on basins

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).

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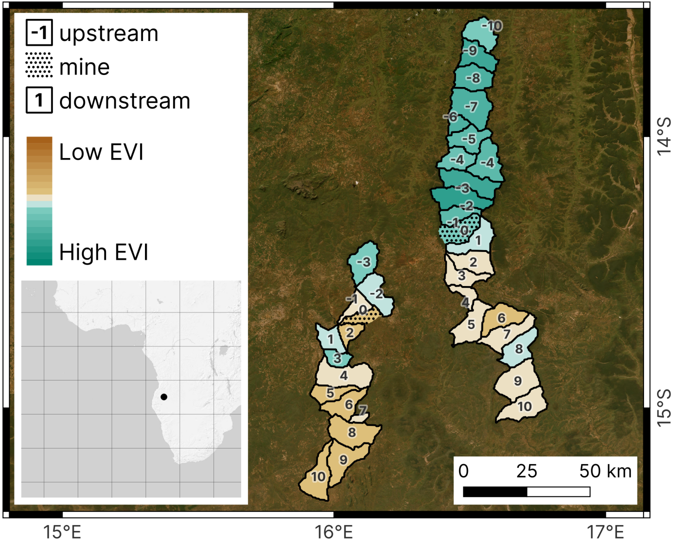
Mines

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, and
  - ranges **between −1** (water) **and 1** (dense vegetation).
- We extract the **annual maximum** on the **entire basin area**, and the maximum **only on croplands** within the basin.

Variables and Observations

A Blessing?

- We use the **Enhanced Vegetation Index (EVI)**, which
  - is **remotely sensed**, and
  - ranges **between −1** (water) **and 1** (dense vegetation).
- We extract the **annual maximum** on the
  - **entire basin area**, and
  - **only on croplands** within the basin.

A Curse?

- We observe **6,698 upstream** basins, **1,900 mine** basins, and **5,729 downstream** basins over $T = 8$ years. show order × status
- We observe **covariates** on:
  - topography,
  - soil type,
  - climate, and
  - socioeconomic characteristics.

show summary statistics show balance

Empirical Strategy (Spatial RDD), Identification

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

- 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**,
- d_{ij}: **Distance** to nearest mine (as order or river stream length).

- Parameter β_3 is identified under the assumption that there are no **other discontinuous changes** at the mine basin.
  - We check balance, include controls, conduct placebo checks.

Background

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Results Overview

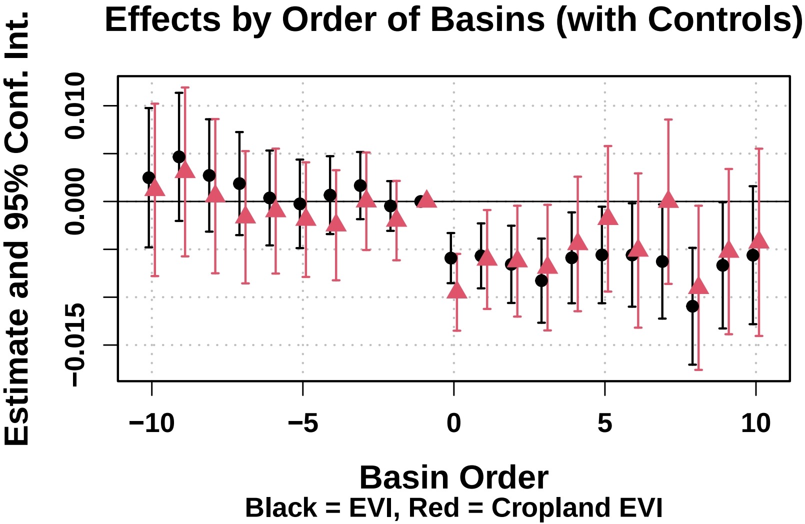
- We find a **significant reduction** in vegetation health **downstream** of mines.
- The magnitude of this effect is **greater** on **croplands**.
- Impacts **dissipate slowly** the farther we move from a mine.
- These results are **robust** to varying the sample, the outcome measurement, and the level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

Order Specification Results (2)



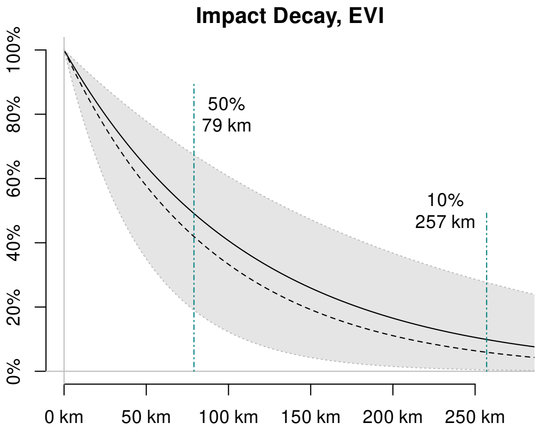
Distance Specification Results

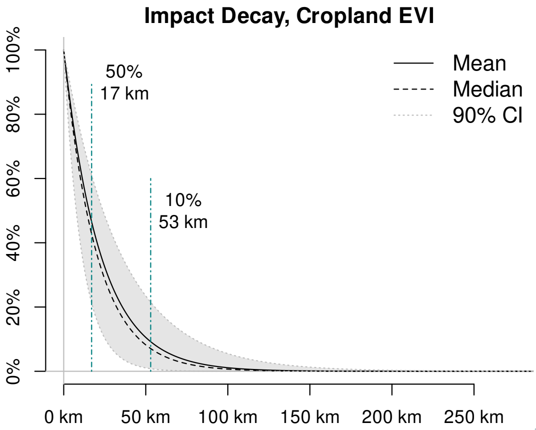
	Max. EVI		Max. Cropland EVI	
	(Plain)	(Full)	(Plain)	(Full)
Distance				
Downstream	**-0.0065*****	**-0.0058*****	**-0.0086*****	**-0.0087*****
	(0.0023)	(0.0021)	(0.0029)	(0.0028)
Downstream × Distance	-2.0×10^{-5}	-2.0×10^{-5}	0.0003**	0.0002
	(0.0001)	(0.0001)	(0.0001)	(0.0001)
Downstream × Distance^2	-4.0×10^{-7}	-9.8×10^{-8}	$-2.2 \times 10^{-6**}$	$-1.9 \times 10^{-6*}$
	(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

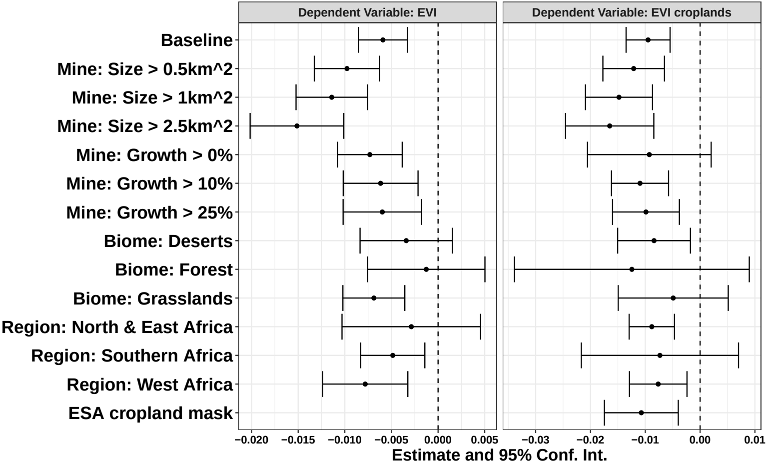
- We re-estimate the main specification using an **exponential distance decay** function, $exp(-\delta d_{ij})$, where d_{ij} is the distance along the river from a mine. details





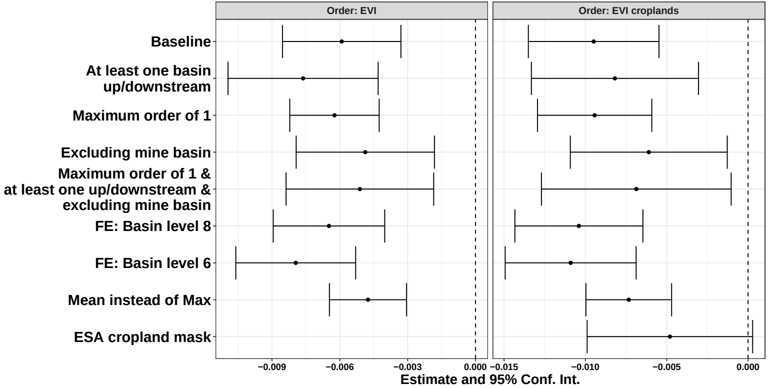
Heterogeneity

- We investigate heterogeneity re.: **mine characteristics**, **biome**, and **region**.



Robustness

- We check robustness by **varying the specification**, **estimation methods**, and checking **placebo** outcomes.



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

Discussion

Results

- We find **negative impacts** on vegetation health by about 1.4-2.1% at the sample mean.
- Our findings highlight that there is a need to
  - tackle the lack of **containment facilities** and improve environmental governance,
  - both for **industrial** and **informal** mines.

Limitations

- **Remotely sensed measures** only represent crop yields **indirectly**.
- Our **treatment indicator** relied only on mine location.
- Differences in **waste management** are not accounted for.
- **Adaptive behavior** by farmers is not covered.

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.

Results were **robust** to changes of treatment, outcome or sample definition.

References (1)

ASM Inventory. (2022). World Maps of Artisanal and Small-scale Mining. http://artisanalmining.org/Inventory/

Azzari, G., Jain, M., & Lobell, D. B. (2017). Towards fine resolution global maps of crop yields: Testing multiple methods and satellites in three countries. *Remote Sensing of Environment*, *202*, 129–141. https://doi.org/10.1016/j.rse.2017.04.014

Bazillier, R., & Girard, V. (2020). The gold digger and the machine. Evidence on the distributive effect of the artisanal and industrial gold rushes in Burkina Faso. *Journal of Development Economics*, *143*, 102411. https://doi.org/10.1016/j.jdeveco.2019.102411

Becker-Reshef, I., Vermote, E., Lindeman, M., & Justice, C. (2010). A generalized regression-based model for forecasting winter wheat yields in Kansas and Ukraine using MODIS data. *Remote Sensing of Environment*, *114*(6), 1312–1323. https://doi.org/10.1016/j.rse.2010.01.010

Bolton, D. K., & Friedl, M. A. (2013). Forecasting crop yield using remotely sensed vegetation indices and crop phenology metrics. *Agricultural and Forest Meteorology*, *173*, 74–84. https://doi.org/10.1016/j.agrformet.2013.01.007

References (2)

Cattaneo, M. D., Idrobo, N., & Titiunik, R. (2019, November). *A practical introduction to regression discontinuity designs: Foundations*. Cambridge University Press. https://doi.org/10.1017/9781108684606

Digital Earth Africa. (2022). *Cropland extent maps for Africa* (tech. rep.). (Dataset). DE Africa Services. https://docs.digitalearthafrica.org/en/latest/data_specs/Cropland_extent_specs.html

Girard, V., Molina-Millán, T., Vic, G., et al. (2022). Artisanal mining in Africa. In *Working Paper Series No. 2201*. Novafrica.

Hund, K., La Porta, D., Fabregas, T. P., Laing, T., & Drexhage, J. (2023). *Minerals for climate action: The mineral intensity of the clean energy transition* (tech. rep.). World Bank Group. Washington DC, United States. https://pubdocs.worldbank.org/en/961711588875536384/Minerals-for-Climate-Action-The-Mineral-Intensity-of-the-Clean-Energy-Transition.pdf

References (3)

ICMM. (2022). Mining Contribution Index (MCI) (6th Edition). https://www.icmm.com/website/publications/pdfs/social-performance/2022/research_mci-6-ed.pdf?cb=16134

Johnson, D. M. (2016).A comprehensive assessment of the correlations between field crop yields and commonly used MODIS products. *International Journal of Applied Earth Observation and Geoinformation*, *52*, 65–81. https://doi.org/10.1016/j.jag.2016.05.010

Kolesár, M., & Rothe, C. (2018).Inference in regression discontinuity designs with a discrete running variable. *American Economic Review*, *108*(8), 2277–2304. https://doi.org/10.1257/aer.20160945

Kossoff, D., Dubbin, W. E., Alfredsson, M., Edwards, S. J., Macklin, M. G., & Hudson-Edwards, K. A. (2014).Mine tailings dams: Characteristics, failure, environmental impacts, and remediation. *Applied Geochemistry*, *51*, 229–245. https://doi.org/10.1016/j.apgeochem.2014.09.010

References (4)

Lehner, B., & Grill, G. (2013). Global river hydrography and network routing: Baseline data and new approaches to study the world's large river systems. *Hydrological Processes*, *27*(15), 2171–2186. https://doi.org/10.1002/hyp.9740

Macklin, M. G., Thomas, C. J., Mudbhatkal, A., Brewer, P. A., Hudson-Edwards, K. A., Lewin, J., Scussolini, P., Eilander, D., Lechner, A., Owen, J., Bird, G., Kemp, D., & Mangalaa, K. R. (2023). Impacts of metal mining on river systems: A global assessment. *Science*, *381*(6664), 1345–1350. https://doi.org/10.1126/science.adg6704

Maus, V., Giljum, S., da Silva, D. M., Gutschlhofer, J., da Rosa, R. P., Luckeneder, S., Gass, S. L., Lieber, M., & McCallum, I. (2022). An update on global mining land use. *Scientific data*, *9*(1), 1–11.

Moura, A., Lutter, S., Siefert, C. A. C., Netto, N. D., Nascimento, J. A. S., & Castro, F. (2022). Estimating water input in the mining industry in Brazil: A methodological proposal in a data-scarce context. *Extractive Industries and Society*, *9*, 101015. https://doi.org/10.1016/j.exis.2021.101015

References (5)

Schwarzenbach, R. P., Egli, T., Hofstetter, T. B., von Gunten, U., & Wehrli, B. (2010). Global water pollution and human health. *Annual Review of Environment and Resources*, (Volume 35, 2010), 109–136. https://doi.org/10.1146/annurev-environ-100809-125342

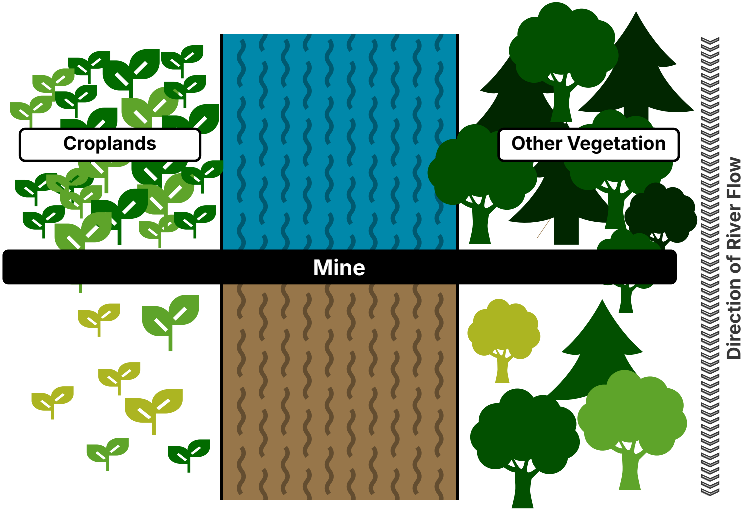
von der Goltz, J., & Barnwal, P. (2019). Mines: The local wealth and health effects of mineral mining in developing countries. *Journal of Development Economics*, *139*, 1–16. https://doi.org/10.1016/j.jdeveco.2018.05.005

Yang, J., Sun, H., Qin, J., Wang, X., & Chen, W. (2021). Impacts of Cd on Temporal Dynamics of Nutrient Distribution Pattern of Bletilla striata, a Traditional Chinese Medicine Plant. *Agriculture*, *11*(7), 594. https://doi.org/10.3390/agriculture11070594

Appendix

Appendix How Pollution Travels

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



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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**.

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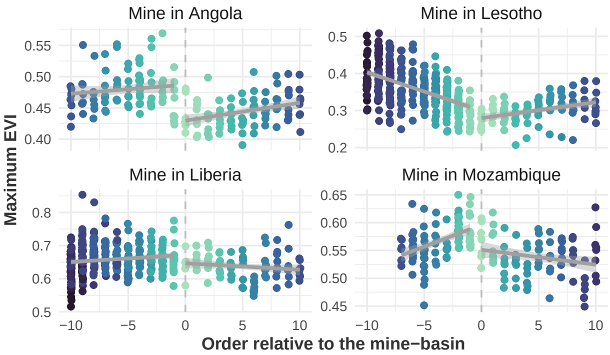
Illustration from Lehner and Grill (2013)

Appendix 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

Appendix 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).

Appendix 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

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Appendix Order Specification Results

- 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.

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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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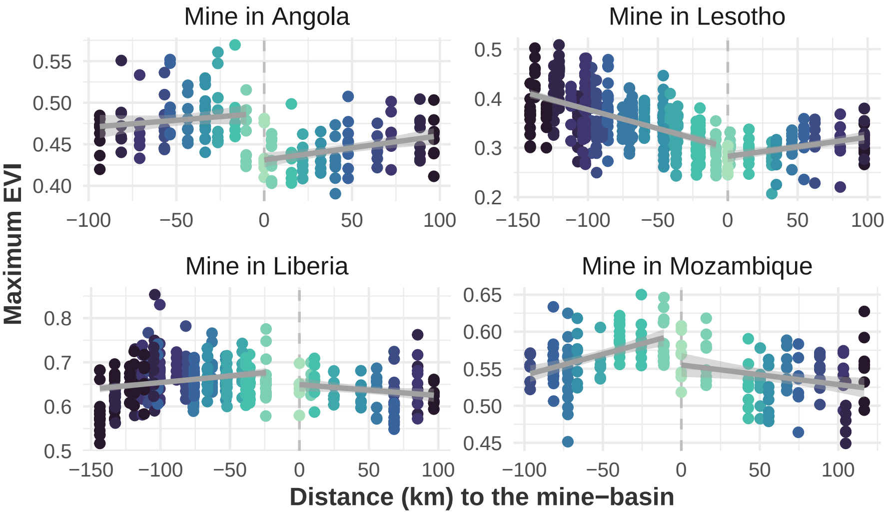
Appendix Four Selected Mines, Distance



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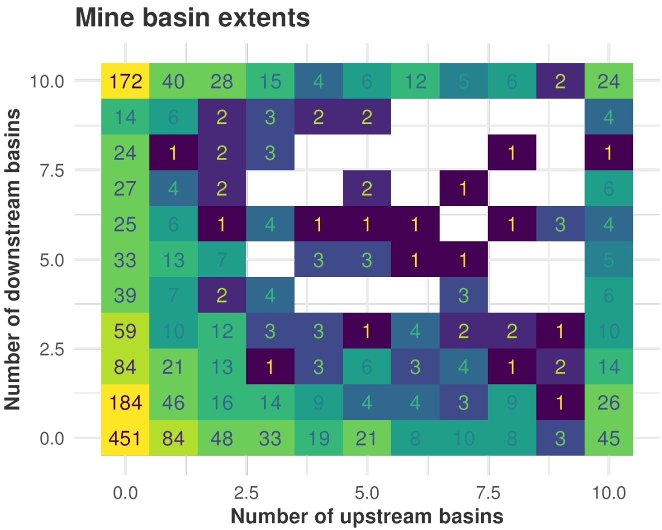
Appendix Basin Numbers



go back to observations overview

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

go back to covariate overview go back to summary statistics

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}	-2.3×10^{-5}***		-1.59×10^{-5}**	-3.86×10^{-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			3.33×10^{-5}***			2.86×10^{-5}***
			(3.61×10^{-6})			(3.95×10^{-6})
Accessibility in 2015			-9.97×10^{-6}*			-3.78×10^{-6}
			(5.28×10^{-6})			(1.18×10^{-5})
Population in 2015			-1.51×10^{-7}***			-1.06×10^{-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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Appendix 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 10, 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 10, 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 10, 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**	-0.0048	-0.0090***	-0.0090***
	(0.0012)	(0.0018)	(0.0017)	(0.0029)
Observations	45,580	45,580	38,504	38,504
Bandwidth	2	2	2	2

Note: Table shows results for estimation of 10, 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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