Lead Exposure and Cognitive Skills in a Developing Country

Evidence From Toxic Sites in Indonesia

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Lead-acid battery recycling risk for children's development

Lead exposure estimated to account for over **one-fifth of the learning gap** between rich and poor countries
(meta-analysis of 47 studies, Crawfurd et al. 2024).

Used Lead-Acid Battery (ULAB) recyclers are the biggest chemical polluter for poorer nations
(2016 World's Worst Pollution Problems report, Green Cross Switzerland and Pure Earth)

Problem expected to grow because of high demand for electric vehicles and energy storage

A worker hacks at at a used car battery with a machete to remove the lead cells for recycling. Image by Larry Price. Indonesia, 2016.

ULABs in Indonesia

Around **200 toxic sites** have been identified in the past two decades (Haryanto, 2016).

- Around 1900 people are at risk around each ULAB (Author's calculations, TSIP data).
- Main risk is ingestion through water or crops and livestock grown near sites.

Estimated that **8 million children** (about 10% of all children) in Indonesia have Blood Lead Levels (BLL) > 5µg/dL (UNICEF and Pure Earth, 2020).

- Near ULABs: 4.9µg/dL (Prihartono et al., 2019) to 25.8 µg/dL (Gunawan & Masloman, 2014).
- BLL > 3.5 µg/dL may be associated with decreased intelligence in children and learning problems (WHO, 2021).

How do ULABs affect children's learning outcomes?

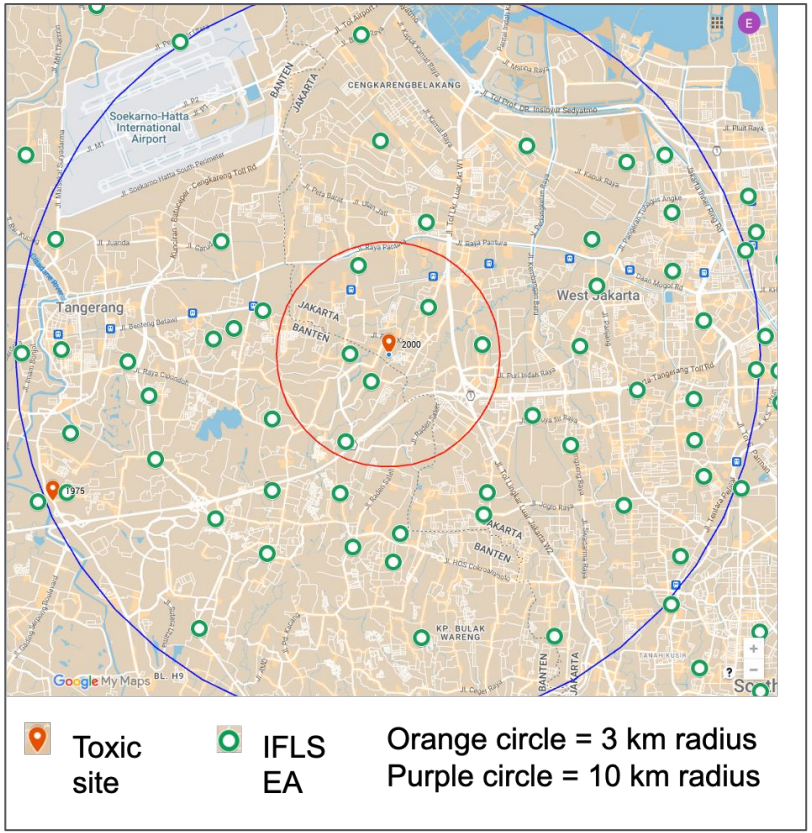
Data Combine ULAB location and IFLS data

Pure Earth Toxic Site Identification Program (TSIP)

- Coordinates of about 150 sites
- Lead measurements in soil or water

Indonesian Family Life Survey (IFLS)

- Longitudinal household survey representative of 83% of population.
- 2000, 2007 and 2014 include numeracy test: *5 multiple-choice questions covering the grade 1-5 curriculum, asked to 7-59 year old respondents.*



Data Sample selection on distance and age at exposure

Distance to a toxic site

- Negative impacts found for children within 3 kilometers from toxic sites.
  (Persico, 2022; Persico et al., 2020; Rau et al., 2015)
- Data requirement: IFLS Enumeration Areas within 3 km from ULAB

Age at first exposure

- In utero or younger children (6 or below) experience worse outcomes as through relatively higher ingestion and period of brain development.
  (Brown & Jernigan, 2012; WHO, 2021; Persico, 2022)
- Data requirement: known starting date of ULAB

Selected sample: 14 toxic sites with 6206 respondents living within 10 km from the sites.

- On average, 93 respondents lived within 3 km of each toxic site.
- Focus on 10 km radius to ensure similar socioeconomic background and a sufficient sample size.

Identification strategy Staggered Differences-in-Differences

Start of toxic site:	**A**ge at start of site:	**D**istance from site:	Age at numeracy test:
Between **1975 and 2012**	0-6 years	0-3 km	**7-59 years old** in 2000, 2007 or 2014
		3-6 km	
	7+ years	6-10 km	

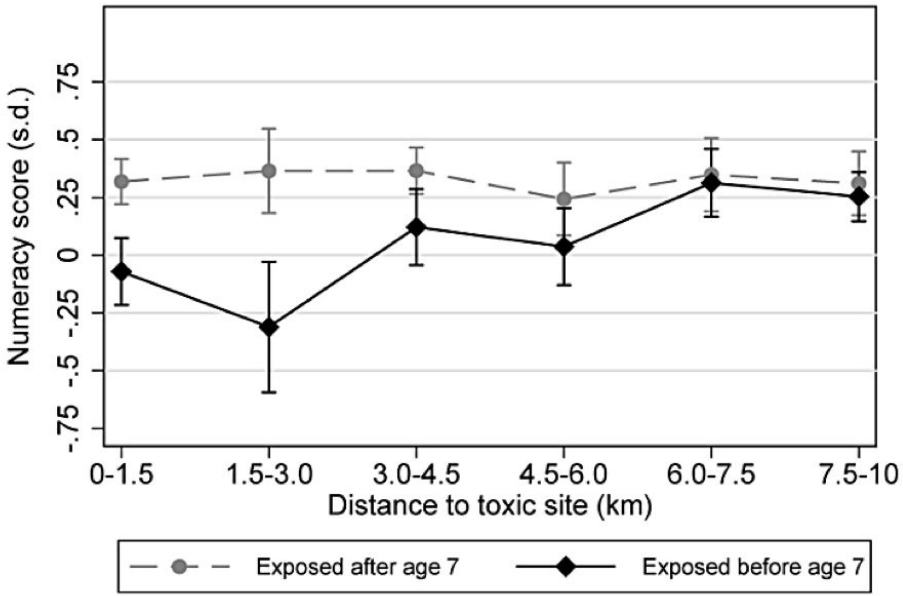
$$Score_i = \beta_1 D_i \times A_i + \beta_2 D_i + \beta_3 A_i + \beta_4 X_i + \gamma_s + \alpha_a + \varepsilon_i$$

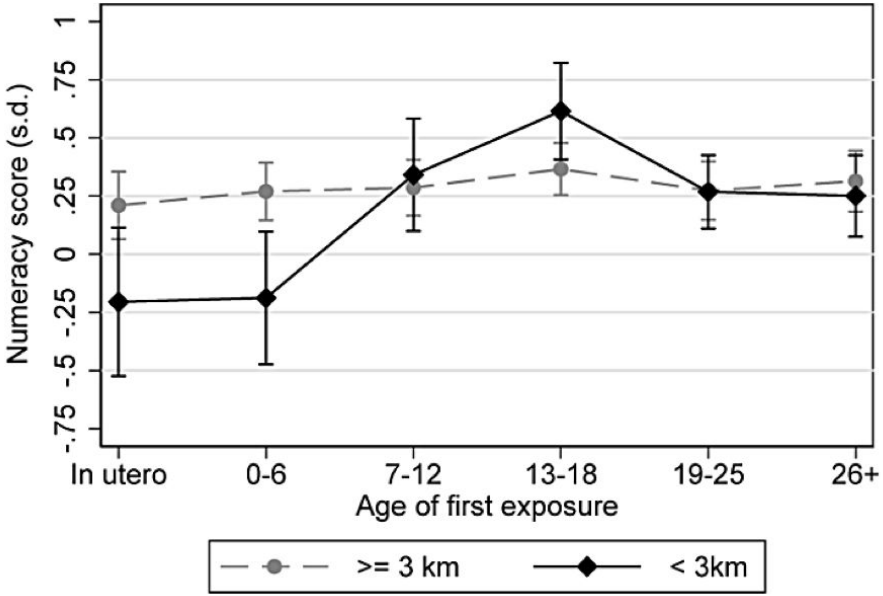
Controls (X): IFLS wave, urban status, sex, parents' education.
Standard errors: Corrected for clustering at Enumeration Area level.

Correct for Staggered DID issues in case of heterogeneous effects (Gardner et al., 2024; Borusyak et al., 2022; Liu et al., 2022)**:**

1. Estimate all fixed effects using the untreated cohort
2. Compare treatment and control cohorts after removing the fixed effects

Identification strategy Parallel trend assumption





Results Lower scores for early exposed, nearby respondents

	(1)	(2)	(3)	(4)
Early exposure	-0.18*	-0.44***	-0.35**	0.25**
	(0.10)	(0.13)	(0.15)	(0.11)
ln(Distance)	0.08**	0.01**	0.00	
	(0.04)	(0.00)	(0.00)	
Early exposure *ln(Distance)	0.15**	0.30***	0.28***	
	(0.06)	(0.09)	(0.10)	
Within 3 km				-0.04
				(0.03)
Within 3 to 6 km				-0.01
				(0.02)
Early exposure* Within 3 km				-0.48***
				(0.15)
Early exposure* Within 3 to 6 km				-0.24*
				(0.12)
Controls	No	No	Yes	Yes
TWFE correction	No	Yes	Yes	Yes
Observations	6206	6206	6206	6206

Note: The dependent variable is standardized numeracy score. The omitted category in column 4 is "within 6 to 10 km". Standard errors in parentheses and corrected for clustering at the EA level. * p < .10, ** p < .05, *** p < .01

Equivalent to losing **2.9 years** of basic education on the IFLS numeracy test

(Beatty et al., 2021)

Early childhood exposure to ULAB sites harms learning

Exposure before age 7 to ULAB sites leads to learning losses equivalent to **3 years of schooling** within 3 km, and 1.5 years within 3–6 km.

Investing in lead cleanup and prevention could substantially improve learning:

- Reversing the -0.48 s.d. learning loss would yield gains comparable to the top 10% most effective education interventions (Evans & Yuan, 2022).
- Particularly for the 10% children with elevated blood lead levels

Stronger regulation and more rigorous enforcement around ULAB sites are urgently needed.