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The Health Burden of E-Waste: The Impact of E-Waste Dumping Sites on Child Mortality

Stefania Lovo and Samantha Rawlings

Abstract

E-waste is one of the fastest growing global waste streams, and is frequently shipped to poorer nations illegally, leading to contamination of local environments. The impact of e-waste dumping sites on neonatal and infant mortality is investigated, focusing on two major dumpsites in Ghana and Nigeria. Using a difference-in-differences approach, outcomes are compared for children born near and far from dumpsites before and after their creation. E-waste sites increase neonatal and infant mortality for those living closer to sites. Event studies suggest that effects emerge two to three years after site openings, consistent with gradual and systematic accumulation of contaminants in the environment. There is suggestive evidence that contamination of water and of urban farming produce are among the drivers of the observed effects.

JEL classification: I10, Q53, Q56, O10

Keywords: e-waste, health, infant mortality, dumping sites, West Africa

1. Introduction

E-waste refers to waste made up of electrical and electronic equipment (EEE), and is classified as hazardous waste, due to the presence of toxic materials in many electrical components (Bakhiyi et al. 2018). It is one of the fastest growing waste streams, with 62 million metric tons of e-waste generated globally in 2022, estimated to rise to 82 million metric tons by 2030 (Baldé et al. 2024).

E-waste in developing countries originates both from domestic and international sources. Internationally, a vast share of e-waste imports comprises working or repairable electronic equipment that consumers soon discard, because although often usable, imported secondhand equipment has a short life span (Heacock et al. 2016; Davis, Akese, and Garb 2019). Indeed, many e-waste dumping sites originate from or are in the proximity of secondhand markets (Manhart et al. 2011). Evidence also indicates the existence of a non-negligible international flow of e-waste that enters developing countries illegally (Kellenberg 2010). A significant share of the international flow is also generated within regions rather than

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transferred between regions (Lepawsky and McNabb 2010). Within West Africa, Ghana and Nigeria serve as the main trade hubs for both regional and international trade in used-EEE and e-waste (Schluep et al. 2011), which primarily come from Europe (Baldé et al. 2022).

E-waste is frequently inappropriately transported, stored, or disposed of (Maphosa and Maphosa 2020). It contains significant amounts of precious metals and other valuable materials, resulting in a market for salvage, which in many countries is performed by informal sector workers. The stripping of components is done manually, and unwanted components are burned or discarded in open dumpsites (Kellenberg 2010). The mismanaged treatment and disposal of e-waste can lead to the release of up to 1,000 different chemical compounds into the environment, which are not biodegradable and pose significant health risks (Widmer et al. 2005). These include persistent organic pollutants (POPs) with long half-lives, brominated flame retardants, and heavy metals that are known to have developmental effects on children, such as lead, cadmium, arsenic, and mercury (Chen et al. 2010; Grant et al. 2013).

This paper investigates how exposure to the two major e-waste sites in Ghana and Nigeria have impacted infant and neonatal mortality, employing a difference-in-differences approach. Children are especially vulnerable to pollutants due to physiological differences from adults, including higher intakes of air, water, and food per body weight, and a lessened ability to eliminate toxins, particularly amongst infants (Pronczuk-Garbino et al. 2007). They are also subject to additional exposure routes like breastfeeding and through the placenta, as well as behaviors such as frequent hand-to-mouth activities (Grant et al. 2013).[1]

This paper exploits households' distance to the dumping site to define intensity of exposure to pollution at birth or in the womb. The identification strategy relies on the comparison of children born before and after the existence of the dumpsite, and distance from the dumpsite. To mitigate concerns about potential dump-induced in-migration, the paper focuses on non-migrant households and compares siblings born before and after the creation of the dump. This analysis, however, is limited to Ghana only due to limited migration information for Nigeria, and might lead to an underestimation of the treatment effects if e-waste affects the probability of successful pregnancies. The analysis cannot rule out the potential bias induced by out-migration, and the direction of this bias remains ambiguous. Nonetheless, the limited evidence of changes in parental characteristics before and after the creation of the sites provides some reassurance, though this concern cannot be entirely dismissed.

The study finds large and statistically significant effects of proximity to e-waste sites on neonatal and infant mortality. One additional kilometer away from the dumping sites reduces neonatal mortality by 4 deaths per 1,000 births and infant mortality by 5 deaths per 1,000 births after the creation of the dumping site. Event study analysis is used to understand the dynamics of the relationship and suggests that these effects emerge two to three years after the existence of the site, suggesting that effects emerge once contaminants have had time to build up in the environment. The study investigates mechanisms through which the impacts may arise and presents suggestive evidence that the effects are at least in part explained by the contamination of local waterways (for Ghana only, where a major river runs alongside the site) and the consumption of locally sourced animal products. The study implements a battery of robustness checks to address concerns that results are spurious, or merely reflect differences in health trends over time related to geographical factors, such as urbanization, or changes in the composition of individuals residing near the dumpsites. In all cases, results suggest that other factors are unlikely to be driving results.

To our knowledge, this is the first study to quantify the causal impact of e-waste dumping sites on early childhood health. This is particularly important given the increasing generation of e-waste, and the extensive presence of e-waste sites in developing countries, including a number of African and Central Asian

1 Elevated levels of environmental toxins directly linked to e-waste have been found in breastmilk in one of the study sites investigated in this paper (Daum, Stoler, and Grant 2017; Asamoah et al. 2019).

countries and China (Forti et al. 2020). A significant body of literature within economics has investigated the short- and long-run effects of early-life exposure to poor environmental quality on health outcomes at birth, childhood, and beyond (see Currie et al. 2014 for a review), yet the consequences of waste—and in particular *e-waste*—have been understudied.[2] The closest papers to ours are Currie, Greenstone, and Moretti (2011) and Gennaioli and Narciso (2017) who investigate the impact of toxic or hazardous waste on health outcomes, and Deiana and Giua (2023) who consider mining waste. Currie, Greenstone, and Moretti (2011) investigate the impact of toxic waste dumps in the United States on infant health. They find that cleanups of hazardous waste sites reduced the incidence of congenital anomalies by roughly 20–25 percent, with no statistically significant effects on outcomes such as low birth weight, prematurity, or infant death. More recent work by Gennaioli and Narciso (2017) investigates the impact of illegal dumping of (non-specified) hazardous waste in Ethiopia on infant health. Given the absence of information on locations of illegal waste sites, the study relies on predictions based on road construction, which facilitates disposal of toxic waste. It finds that an additional road within a 5-kilometer radius is associated with an increase in infant mortality by 3 percentage points. Finally, Deiana and Giua (2023) investigate the long-run impact of decommissioning mining waste sites on (all-age) resident mortality in Italy. They find that shutting down mining waste sites decreases decadal mortality in treated municipalities by 126 deaths per 100,000 inhabitants (around 15 percent). Yet, while this existing literature focuses on mostly industrial waste which is generated locally, evidence on e-waste—a substantial and growing global waste stream, which is frequently inappropriately managed—relies mostly on observational studies.[3] Hence, this paper contributes to this scarce literature by empirically quantifying the impact of e-waste on neonatal and infant mortality.

The rest of the paper proceeds as follows. An overview of background and context regarding e-waste and the sites used in the analysis is given in the Background section. The Data section outlines the data used, the Empirical Results section outlines empirical specifications, whilst the Empirical Results section presents results and robustness checks. The paper discusses potential mechanisms underlying the results in the Underlying Mechanisms section. Finally, the Conclusions section provides a brief summary of the main findings and their implications.

2. Background

This section provides background information on transboundary movements of e-waste, and the study area used in the analysis.

2.1. International Conventions on Exporting Hazardous Waste

In response to increasing exports of hazardous waste to countries in the developing world and the resulting international outcry, the Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and their Disposal was opened for signatures on March 22, 1989, and entered into force on May 5, 1992 (Kitt 1994; Andrews 2009). The convention did not ban the export of hazardous waste, but regulated it, based on the principle of prior informed consent (PIC), in which exporting parties would

2 Studies have focused on, for example, the effect of air pollution (see for example Currie and Neidell 2005; Jayachandran 2009; Greenstone and Hanna 2014; Arceo, Hanna, and Oliva 2012; Luechinger 2014; Tanaka 2015; Currie, Neidell, and Schmieder 2009; Currie and Walker 2011), water quality (Greenstone and Hanna 2014; He and Perloff 2016), and proximity to mining operations (von der Goltz and Barnwal 2019) on health.

3 For example, a number of small-sample observational studies in China suggest negative associations between exposure to e-waste and health outcomes. Children born near e-waste sites have reduced birth weights, while higher chemical pollutants are found in the cord blood of pregnant women residing near such sites, and increases in pregnancy miscarriage and premature births are observed, compared to women and children in control areas (see Grant et al. 2013, and references therein).

need to have explicit consent from a competent authority in the importing state for the trade to occur (Krueger 1998). The intention was to strike a balance between free trade and environmental protection (Lucier and Gareau 2016). The convention did not classify e-waste as hazardous waste under the Basel Convention until 1998. A weakness of the 1989 convention was that it defined waste only as objects for disposal i.e. "scrap," leading to the so-called recycling loophole which allowed for the stated intention of exports to be recycling of raw materials when in effect waste was either dumped, burned, or recycled in such a way as to pose a risk to local inhabitants (Andrews 2009). A 1995 Basel Ban Amendment attempted to address this, by extending the ban to include export of hazardous waste that was intended for recycling, but this was not ratified into international law until 2019. Despite these attempts to regulate e-waste trade, large amounts of e-waste have continued to be shipped illegally, in part due to the complex and fragmentary regulatory environments which have hindered enforcement of international and national law (UNEP et al. 2019).

In addition, the export of electronic equipment labeled as "for re-use" is still permitted (UNEP 1989). This has led to significant levels of imported used EEE into African countries which ultimately ended up discarded, either because of a short lifespan, or for being illegally labeled as for re-use while effectively being end-of-life equipment (Heacock et al. 2016; Kellenberg 2010).[4]

2.2. Study Area

The study focuses on two major e-waste sites in West Africa: Agbogbloshie in Ghana and Soluos (2) in Nigeria. The choice of these two sites was determined by the following criteria: The site predominantly deals with e-waste, it was established after e-waste became a significant waste flow in the late 1990s (Grant and Oteng-Ababio 2012; Forti, Baldé, and Kuehr 2018)n, and there is availability of sufficient data on birth outcomes (see Data section for details on the data used). The search for sites was guided by the 2014 Waste Atlas Report on the world's 50 biggest dumpsites (Waste Atlas Partnership 2014). Of the 50 sites in the Waste Atlas Report, 18 are in Africa, and 6 deal with e-waste (see supplementary online appendix table S1.1), 5 of which are in Africa. The study excluded two sites (Kibarani in Kenya, and Olusosun in Nigeria) due to their opening date pre-dating the influx of e-waste so that date of treatment was uncertain, and two more recent sites (Tibar in Timor-Leste, and Pugu-Kinyamwezi in Tanzania) because they deal extensively in other types of waste (e.g. medical/toxic) rather than predominantly e-waste, and/or because of limited household survey data.

Agbogbloshie is a dumping site established in 2001 in Accra, Ghana, that deals exclusively with e-waste; in 2014 it was estimated to have a size of 10.6 hectares, and to receive 192 kilotons of e-waste every year (Waste Atlas Partnership 2014). In 2004, the Government of Ghana reduced the import duty on used computers to zero, leading to a large increase in shipments to Ghana (Grant and Oteng-Ababio 2012). A recent estimate suggested that approximately 39 percent of e-waste generation in Ghana is treated in Agbogbloshie (Owusu-Sekyere et al. 2022). It is the second largest e-waste processing site in West Africa (Bernhardt and Gysi 2013), and is situated in a densely populated area, with an estimated population within 10 km of the site of 2.3 million (Waste Atlas Partnership 2014). Extensive evidence has documented dumpsite-induced poisoning of the local area and food chain (e.g. Daum, Stoler, and Grant 2017; IPEN and BAN 2019).

Soluos (2) is a dumping site established in 2006 in Lagos, Nigeria, receiving a large amount of waste, both municipal and e-waste.[5] An estimated 4 million people live within 10 km of the site, and the nearest settlement to the site is 200 m away (Waste Atlas Partnership 2014). In addition, a road runs through the

4 In 2012, the Basel Secretariat, acknowledging difficulties associated with identification of genuine export of electrical equipment from e-waste intended for scrap, issued guidance on transboundary movements of e-waste in an attempt to aid in the distinction between waste and non-waste (Ogunseitan 2013).

5 There are no estimates separately for e-waste vs. municipal waste, but estimates suggest that it received 428,728 metric tonnes of waste in the first two quarters of 2009 (Balogun and Adegun 2016).

middle of the site, establishing it as a trade route and business center (Ife-Adediran and Isabota 2018). Evidence suggests that the Soluos (2) site has contributed to significant contamination of groundwater with excessively high levels of various heavy metals (Ofudje et al. 2014). These metals include cadmium, which has been linked to adverse perinatal and neonatal outcomes (Grant et al. 2013). Lagos is a high water-table area, which increases the specific risk of contamination of water from the dumpsite (Osibanjo, Adeyi, and Majolagbe 2017); this has led to nearby water that is unfit for human consumption (Adegun 2013).

A complication of the inclusion of this site into the study is the existence of an older, large dumpsite 14 km away, known as the Olusosun (also known as Olushosun) waste site. The Olusosun site also deals with e-waste, but was established as an ordinary waste site in 1992 before e-waste flows were a significant problem. This precludes the study from having a clean "before" and "after" period of exposure to e-waste, and is, therefore, not included in the main analysis.[6] In analyzing the Soluos site, the main analysis excludes all households living within a 5 km distance of Olusosun (further details are discussed in the Data section).

3. Data

The study uses data from the Demographic Health Surveys (DHS) for Ghana (1998, 2003, 2008) and Nigeria (2003, 2008, 2013). These are nationally representative surveys, using standardized questionnaires that are comparable across countries.[7] The DHS collects complete fertility histories from women aged 18–49, including information on all births and any deaths of children respondents have ever had. Women are also asked a range of questions on health and socioeconomic status, and a household questionnaire collects information on characteristics of the household. The DHS also contains GPS coordinates of the cluster within which the household is placed.[8]

To increase sample size, the study supplements the analysis with data from the Malaria Indicator Surveys for Nigeria (2010, 2015) which are also administered by the DHS programme. These use identical questionnaires to the DHS, but collect information on a narrower range of outcomes, for children born in the last five years. Crucially, they still collect data on births, deaths, individual and households characteristics needed for the analysis, as well as GPS coordinates of cluster location. Figure 1 shows the location of the two dumping sites and the distribution of survey clusters in the surrounding area of the site within the 20 km buffer zone.[9]

6 Given the lack of a clean research design for this site, the study omits Olusosun from the analysis. Nonetheless, the study conducted a separate analysis for Olusosun. In particular, the study argues, based on e-waste trade data, that the dumping of e-waste started around 1998. Based on this assumption, the study found results consistent with the main findings, but more imprecise. See supplementary online appendix S2.1.

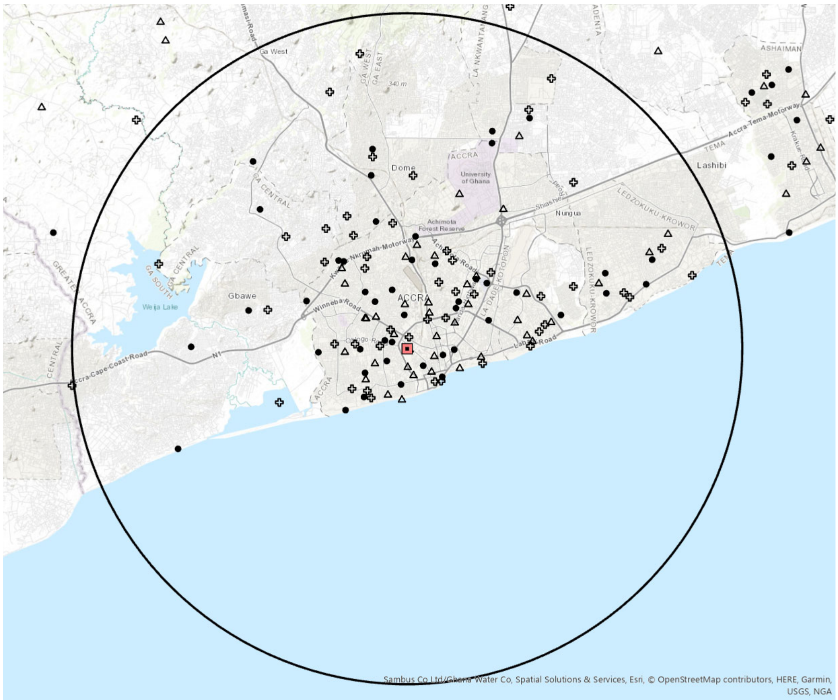
7 Although the DHS surveys are nationally and regionally representative, the analysis focuses specifically on populations residing near e-waste sites, and as such, the results may not be generalizable to other areas of the country.

8 Cluster sizes are small, with approximately 25–30 houses per cluster. For privacy reasons, the locations of DHS clusters are randomly displaced by up to 2 km in urban areas and up to 5 km in rural areas. The majority of the sample clusters are urban (96 percent in Ghana and 97 percent in Nigeria), and results are robust to exclusion of rural clusters that may have been displaced by larger amounts (supplementary online appendix S2.2). Displacement of location is random, and there is no reason to believe that displacement varies systemically with either distance from the sites or over time. The result is that the resulting noise may lead to downward-biased estimates so that, if anything, this displacement will make it harder to identify an effect.

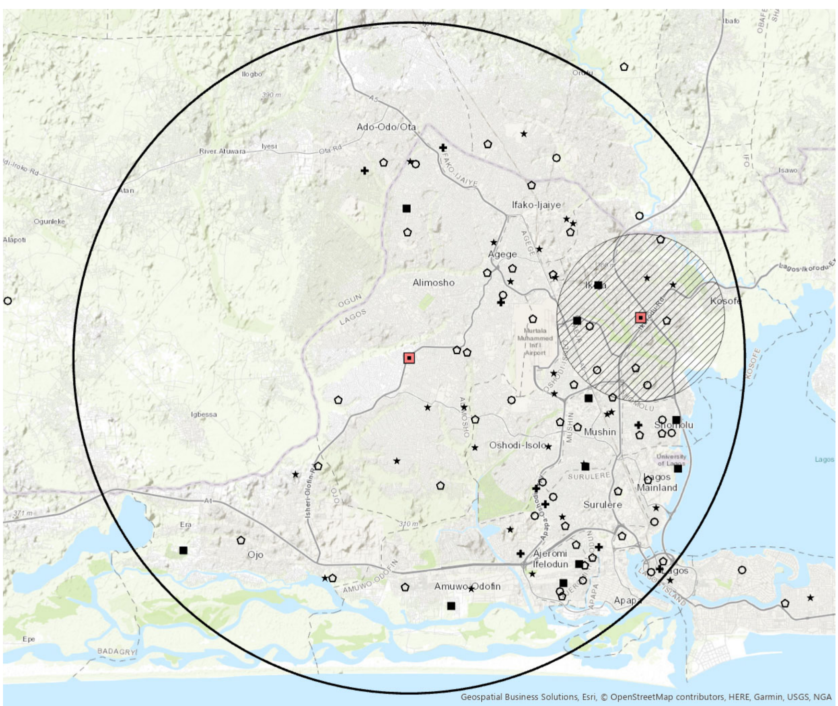
9 For Nigeria, the figure also shows the location of the earlier established dumpsite, Olusosun, which is not included in the main analysis for reasons discussed in the Data section. It also shows the 5 km radius around Olusosun, to show which clusters are excluded from the analysis of the Soluos dumpsite since they may also have been exposed to the Olusosun site.

Figure 1. Dumping Sites and Household Locations

(a) Ghana



(b) Nigeria



Source: Authors' analysis based on data from the DHS for Ghana and Nigeria.

Note: Hollow triangles, hollow crosses, and solid circles represent DHS clusters in Ghana for survey years 1998, 2003, and 2008, respectively. Hollow circles, solid stars, solid squares, hollow pentagons, and solid crosses represent DHS clusters in Nigeria for survey years 2003, 2008, 2010, 2013, and 2015, respectively. Dumpsite locations are given by the squared points. The black buffer represents 20 km from the sites and inclusion into the analysis sample. The hatched buffer area in Nigeria shows the existence of the older dumpsite known as Olusosun, not included in the analysis, and all clusters within this 5 km buffer are excluded from the analysis.

The main analysis utilizes the birth recode in the DHS. All women interviewed are asked for the date of birth of each child and, if the child has died, their age at death.[10] Newborn and infant health is captured by measures of mortality in the first month (neonatal) and first year (infant) of life.[11] The study constructs dummy variables for neonatal and infant mortality that are equal to 1 if the child died before 30 days, or before 1 year, respectively.[12] Children who have not been fully exposed to the measure of mortality under study are dropped from the estimating sample.[13] The sample includes children born within 20 km of the vicinity of the dumps, five years before and after its establishment, leaving the study with a sample of 3,359 (3,094) births in the neonatal (infant) mortality regressions, born to 1,868 (1,743) mothers. The advantage of using mortality as the outcome of interest is that, unlike anthropometric measures such as height and weight, these are observed for all children born to a woman and observation of these variables is not conditional on survival to interview, which would lead to a selectively healthier sample.[14] In addition, children born prior to the dumpsite, but observed and measured *after* the dumpsites, are affected by the dumpsite, but only partially, so that defining treatment and exposure is less straightforward.[15]

Table 1 shows summary statistics for the births in the sample, showing data for the pooled sample, and by country (dump). Average neonatal (infant) mortality is 3.6 percent (5.7 percent), and these rates are broadly similar in Ghana and Nigeria. Most individuals (around 60 percent) have secondary education, and the overall level of schooling is only slightly higher among spouses.

Figure 2 plots average mortality rates, before and after the creation of the e-waste sites, for households in the proximity of the sites (< 5 km) and those farther away (5–20 km). Before the sites were established, neonatal and infant mortality rates were similar for those living near the sites and those farther away. After the sites were established, mortality rates significantly increased for those living near the e-waste sites. The average of neonatal (infant) mortality within the vicinity of the sites rises from 25 (53) deaths per 1,000 children before the creation of the site to about 57 (78) deaths per 1,000 children in the post-site period—an almost two-fold increase in mortality over the period. Although the fact that the small differences in mortality rates in the pre-dump period are not statistically significant is reassuring, appropriate testing for pre-trends will be provided. In contrast to mortality, when comparing characteristics of children born in the proximity of a e-waste site (< 5 km) and those farther away, before and after e-waste sites were established, there is limited evidence that compositions of births differed between areas near vs. far or that differences changed over time (supplementary online appendix Table S1.2).

10 This is reported as age in days if less than one month old at death, or age in months if older than one month at the time of death.

11 Evidence from developed nations commonly uses birth weight as a measure of newborn/in utero health (e.g. Currie, Greenstone, and Moretti 2011); however, birth weight is often poorly recorded in the DHS surveys, and this is particularly the case in these surveys. Between 70 and 80 percent of observations are missing information on both reported weight at birth and a subjective measure of size at birth (i.e. whether the baby was small or large).

12 Due to age heaping, the 30th day and 13th month are included in the definitions of neonatal and infant mortality.

13 For example, if a child is only 2 months old at the date of the interview, they are not included in the infant mortality regressions since infant mortality is right censored for these individuals.

14 One concern might be that the sample is selectively healthy if exposure to the dumpsite affects fertility itself or pregnancy loss. Analysis in supplementary online appendix S2.3 shows that there is no evidence this is the case.

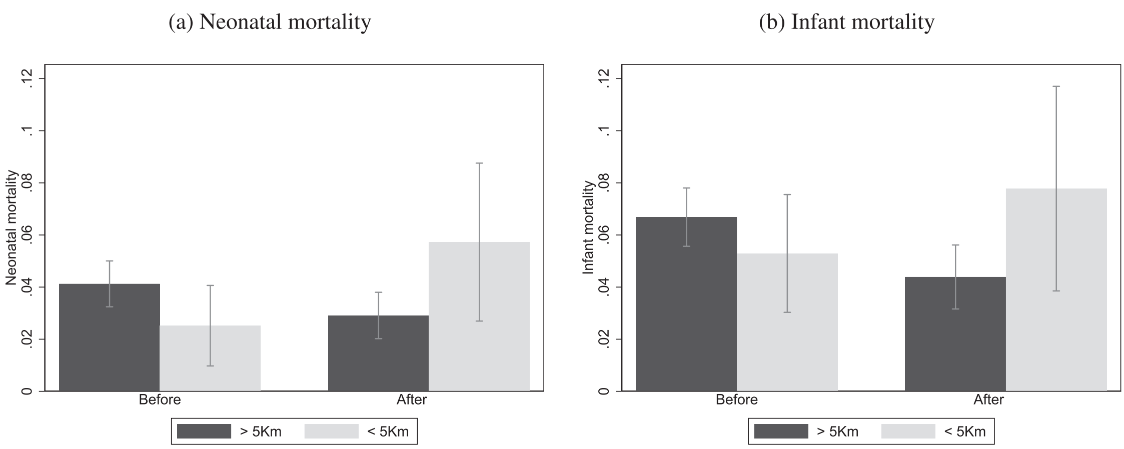
15 Nonetheless, results in supplementary online appendix S2.4 show effects on height and weight using surviving children from the DHS Child Recode survey. These are consistent with the effects observed in the main analysis for mortality, but are imprecisely estimated. The study is not able to investigate the impact of dumping sites on child anaemia—which can reflect heavy metal poisoning—or acute respiratory infection—which may result from air pollution as a result of burning of waste—because there is a lack of information on these outcomes in the data.

Table 1. Summary Statistics

	Pooled sample			Ghana			Nigeria		
	N	Mean	SD	*N*	Mean	SD	*N*	Mean	SD
Neonatal mortality	3,359	0.036	0.187	805	0.030	0.170	2,554	0.038	0.192
Infant mortality	3,085	0.054	0.226	727	0.051	0.220	2,358	0.055	0.227
Mother < primary schooling	3,359	0.069	0.253	805	0.125	0.331	2,554	0.051	0.22
Mother primary schooling	3,359	0.182	0.386	805	0.214	0.410	2,554	0.172	0.378
Mother secondary schooling	3,359	0.594	0.491	805	0.607	0.489	2,554	0.589	0.492
Mother higher education	3,359	0.155	0.362	805	0.053	0.225	2,554	0.188	0.390
Spouse < primary schooling	2,957	0.041	0.197	710	0.097	0.296	2,247	0.023	0.149
Spouse primary schooling	2,957	0.135	0.341	710	0.032	0.177	2,247	0.167	0.373
Spouse secondary schooling	2,957	0.589	0.492	710	0.725	0.447	2,247	0.547	0.498
Spouse higher schooling	2,957	0.235	0.424	710	0.145	0.352	2,247	0.264	0.441
Mother age at birth	3,359	27.985	5.557	805	27.352	6.035	2,554	28.185	5.383
Male birth	3,359	0.509	0.500	805	0.513	0.500	2,554	0.508	0.500
Multiple birth	3,359	0.036	0.186	805	0.037	0.190	2,554	0.036	0.185

Source: Authors' calculations based on DHS data for Ghana and Nigeria.
Note: The table presents the mean and standard deviation of selected child, woman, and spousal variables for all births included in the sample. Inclusion in the sample is determined by the household cluster lying within 20 km of a dumpsite, and includes only children born between 5 years pre- and 5 years post the opening of a dumpsite. The infant mortality indicator is reported for the infant mortality sample, inclusion of which is dependent on child having been fully exposed to infant mortality risk (if still alive, born ≥ 12 months before survey). All other variables are reported for the neonatal mortality sample, which is conditional on the child being fully exposed to neonatal mortality risk (if still alive, born ≥ 1 month before survey).

Figure 2. Average Neonatal (Left) and Infant (Right) Before and After the Creation of the E-Waste Sites



Source: Authors' analysis based on data from the DHS for Ghana and Nigeria.
Note: The plots show average mortality by distance to the dumping sites, before and after their creation, and the corresponding 95 percent confidence interval.

4. Empirical Specification

The main identification strategy is based on a difference-in-differences specification that uses the date of creation of a dumpsite to determine treatment, and compares children located close to the e-waste sites to those farther away, effectively considering the distance from a dumpsite as a measure of treatment intensity of exposure to pollution from the site. The study estimates the following equation:

$$Y_{ijdt} = \alpha + \beta \text{DIST}_{jd} + \gamma \text{Post}_{dt} \times \text{DIST}_{jd} + \nu_t + \nu_s + \theta_d + \epsilon_{ijdt}, \tag{1}$$

where i indicates a child born in year t from mother j in the proximity of dumpsite d, Post_{dt} is an indicator variable that equals 1 if a child was born after the local dumpsite was created, and DIST_{jd} is the continuous distance variable ($0\,\text{km} \leq \text{DIST}_{jd} \leq 20\,\text{km}$). The study drops from the analysis any clusters more than 20 km from the dumpsites. Lastly, ν_t is a vector of child–year-of-birth fixed effects, ν_s are year of interview fixed effects, and θ_d are dump-specific fixed effects. The dependent variable Y_{ijdt} is either neonatal mortality (1 = died before 30 days, 0 otherwise) or infant mortality (1 = died before 13 months, 0 otherwise), so that a worsening of infant health is represented by a positive coefficient for γ. Standard errors are clustered at DHS cluster level; there are 180 clusters in the analysis.[16] In equation (1), distance to the e-waste site is expected to have no effect on health outcomes for children born before the creation of the site ($\beta = 0$), while a negative effect in the post-dump period would imply that the health conditions of children born in the proximity of the site have worsened relative to those farther away.

To gain more insight into the dynamics of the relationship and how it evolves in the post-dump period, the study extends the analysis given in equation (1), and performs an event study analysis, estimating the following specification:

$$Y_{ijdt} = \alpha + \beta_1 \text{DIST}_{jd} + \sum_{k=-5}^{k=5} \gamma_k 1\{K_{it} = k\} \times \text{DIST}_{jd} + \theta_d + \epsilon_{ijdt}, \quad (2)$$

Here, the dummy Post_{dt} from equation (1) is replaced with a more flexible specification that includes indicators for lags and leads relative to the creation of the dump, the omitted category being the year prior to the creation of the dumpsite. As an additional specification, the study also shows event study analysis that uses a dichotomous measure of treatment, identifying treated children as those living within 5 km of the site. For all specifications, results are shown both by pooling data from the two sites and for each dumpsite individually. Because the analysis has only one treatment period, this setting does not suffer issues affecting staggered treatment designs as highlighted in Goodman-Bacon (2021).

The validity of this empirical strategy relies on two assumptions: that the polluting effects of a dumpsite decline with distance, and that the evolution of health outcomes in areas near and far from the site would have been similar in the absence of the dumpsite. While the common trends assumption cannot be tested, the event study analysis allows the study to test for differences in pre-dump trends in health outcomes for children living close and far from the site location. Following the latest developments in the difference-in-differences literature, the study also implements the doubly robust estimator of Callaway and Sant'Anna (2021) to test for pre-trends conditional on covariates.

A potential threat to identification is if the dumpsite induced either in- or out-migration, which could lead to selection bias in the sample under study. For Ghana only, the study is able to investigate the role of in-migration by restricting the sample to non-migrant households. Additionally, since the study observes children born to the same mother before and after the creation of the dumpsite, it includes a further robustness check using a specification with mother fixed effects.[17] This helps mitigate concerns about potential residential sorting, although it significantly reduces the sample size. It is also important to note that this latter specification relies on observing surviving siblings. Since the dumpsite may negatively impact the probability of successful pregnancies, this could lead to an underestimation of the treatment effect.[18]

16 The study also investigated robustness of the results to spatial dependence of standard errors, allowing for spatially clustered standard errors using Conley (1999) spatial HAC standard errors, in which spatial autocorrelation is assumed to linearly decrease in distance (supplementary online appendix S2.5).

17 The study cannot include Nigeria in this analysis because there is no information on residency in the surveys conducted in 2010, 2013, and 2015, so that the study has very limited information on residency in the post-dump period.

18 In supplementary online appendix S2.3 the study shows, however, that there is little evidence of an effect of the dumpsite on fertility or pregnancy loss.

Table 2. The Impact of E-Waste Sites on Newborn and Infant Health

Dependent variable:	(I) Neonatal mortality	(II) Infant mortality
Distance (km)	0.001	0.003**
	(0.001)	(0.001)
Post × distance (km)	−0.004***	−0.005**
	(0.001)	(0.002)
Dump FE	Yes	Yes
Year of birth FE	Yes	Yes
Survey year FE	Yes	Yes
Mean	0.036	0.056
Observations	3,359	3,094

Source: Authors' calculations based on DHS data for Ghana and Nigeria.
Note: The table shows OLS regressions for a sample of births in Ghana and Nigeria. Distance (km) is a variable for the distance of a child's cluster from the dump site. Post is a dummy variable indicating a child was born after the creation of the dump site. Inclusion in the sample is restricted to household clusters lying within 20 km of a dumpsite, and includes only children born between 5 years pre- and 5 years post the opening of a dumpsite. Inclusion in the infant mortality sample is dependent on the child having been fully exposed to infant mortality risk (if still alive, born $\geq$ 12 months before survey). Inclusion in the neonatal mortality sample is dependent on the child being fully exposed to neonatal mortality risk (if still alive, born $\geq$ 1 month before survey). Standard errors (in parenthesis) are clustered at the DHS cluster level. *** *p*-value < 1 percent, ** *p*-value < 5 percent, * *p*-value < 10 percent.

On the other hand, the study is unable to observe outward migration. It is difficult to predict how potential dump-induced outward migration might bias the results, as it is not known a priori whether households in better or worse health conditions are more likely to leave after the creation of the dump. While the study cannot fully rule out this potential source of bias, it investigates this concern by descriptively comparing the characteristics of parents, in both countries, interviewed before and after the establishment of the e-waste sites.

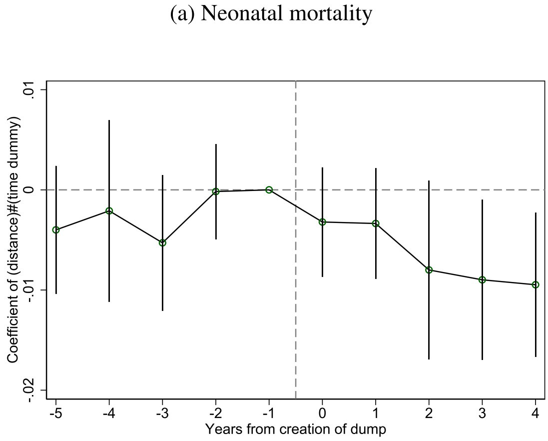
Finally, other unobserved time-varying factors correlated with the creation of the dump and affecting areas differently based on their proximity to the site could challenge the validity of the results. In other words, any effects observed may simply be capturing spurious location trends. To address this concern, in supplementary online analyses, the study investigates whether the results are driven by spurious location trends or general differences between urban slums and peri-urban areas, and also performs a spatial randomization test to provide evidence that the estimated effects do not arise by chance.

5. Empirical Results

Regression results from the difference-in-differences specification in equation (1) are reported in Table 2. Results show that the effect of distance becomes negative and significant only after the e-waste sites were opened. This is consistent with distance capturing exposure to pollution from the site and suggests an increase in mortality for children born in the proximity of the dump relative to those farther away. The estimated effect of distance (which captures the pre-dump effect) indicates that, if anything, mortality prior to the establishment of the waste site was higher in areas away from the sites, though this relationship is weak, and not statistically significant for neonatal mortality. The effects indicate that, after the dump has been opened, moving one additional kilometer away from the dump decreases neonatal and infant mortality by 4 and 5 deaths per 1,000 births, respectively.[19]

19 Estimates for each site in Ghana and Nigeria are similar. The effect sizes on neonatal (infant) mortality for the Ghanaian and Nigerian sites are 4 (7) and 3 (4) deaths per 1,000 births, respectively (Table S1.3).

Figure 3. Event Study for Neonatal (Left) and Infant (Right) Mortality: Distance to Dumpsite



Source: Authors' analysis based on data from the DHS for Ghana and Nigeria.
Note: Includes both e-waste sites. For consistency, the study considers a common number of years (5) before and after the dumpsite for both countries. The plots are created by a linear regression of mortality on a full set of event time indicators (years from dump creation) interacted with distance from the dumpsite (in km) and controlling for country and birth-year fixed effects. The vertical lines indicate 95 percent confidence intervals.

Results of the event study analysis (equation (2)) are reported in fig. 3 and confirm that the distance to the dumpsite did not play any significant role in explaining neonatal and infant mortality of children born before the creation of the dump. Results for individual countries are shown in fig. S1.1 and show consistent results. The negative effect of distance in the post-dump period confirms that children born in the proximity of the site face greater risk of death than those living farther away. Similar conclusions are reached when testing parallel trends using a dichotomous treatment variable, where the study defines treated as those children living within 5 km of the site, and when the study implements the doubly robust (DR) estimator proposed by Callaway and Sant'Anna (2021) (see fig. S1.2).[20]

Overall, evidence from estimates of equations (1)–(2) suggest that proximity to e-waste sites had a significantly negative impact on newborn and early-life health, increasing the risk of mortality for those exposed to e-waste sites. This risk decreases with distance, and event-study analysis suggests the risk emerges around three years after the creation of the e-waste sites.

The effects are large, at around 10 percent of mean mortality in the sample. This is not unusual when considering evidence from the wider literature on pollution and health. Most of the evidence on the effects of pollution on mortality focuses on intensity of exposure measured as unit reductions/increases in CO (Currie and Neidell 2005), particulate matters (Knittel, Miller, and Sanders 2016), or total suspended particles (Chay and Greenstone 2003). For example, Alexander and Schwandt (2022) find that *just one* additional emissions-cheating diesel car per 1,000 cars increased PM10 by 2.2 percent and led to a 1.7 percent increase in infant mortality in the United States. A recent paper investigating the impact of mining waste on (all-age) mortality in Italy finds that shutting down mining waste facilities decreases decadal mortality in treated municipalities by 126 deaths per 100,000 inhabitants, which is nearly 15 percent (Deiana and Giua 2023). Thus, the effect sizes are broadly in line with the literature, and in this case, the effect the study finds is the result of a large and sustained increase in the concentration of pollutants.

20 The Callaway and Sant'Anna approach combines the outcome regression approach (Heckman et al. 1997) and the propensity score weighting approach (Abadie 2005) to estimate the causal effect of exposure, conditional on pre-treatment covariates. These include urban status, mother's and father's educational level, mother's age at birth, the child's gender, and whether the birth was a multiple birth. The main results in Table 2 are also robust to the inclusion of these controls; see supplementary online appendix S2.6.

Table 3. The Impact of Dumping Sites on Newborn and Infant Health in Ghana: Non-Migrants and Mother Fixed Effects

	(I)	(II) Neonatal mortality	(III)	(IV)	(V) Infant mortality	(VI)
	All	Non-migrants	Non-migrants	All	Non-migrants	Non-migrants
Distance (km)	0.001	−0.001		0.002	0.001	
	(0.002)	(0.002)		(0.003)	(0.003)	
Post × distance (km)	−0.004*	−0.003	−0.002	−0.007*	−0.012**	−0.015**
	(0.002)	(0.003)	(0.004)	(0.004)	(0.006)	(0.007)
Year of birth FE	Yes	Yes	Yes	Yes	Yes	Yes
Survey year FE	Yes	Yes	Yes	Yes	Yes	Yes
Mother FE			Yes			Yes
Mean	0.030	0.027	0.027	0.051	0.046	0.046
Observations	805	521	521	727	455	455

Source: Authors' calculations based on DHS data for Ghana.
Note: The table shows OLS regressions for the sample of births in Ghana. Distance (km) is a variable for the distance of a child's cluster from the dump site. Post is a dummy variable indicating a child was born after the creation of the Agbogbloshie site ($t = 2001$). Inclusion in the sample is restricted to the household clusters lying within 20 km of a dumpsite, and includes only children born between 5 years pre- and 5 years post the opening of a dumpsite. Non-migrants refers to the restricted sample where the mother was resident in the household prior to the creation of the Agbogbloshie dumpsite. Inclusion in the infant mortality sample is dependent on the child having been fully exposed to infant mortality risk (if still alive, born ≥ 12 months before survey). Inclusion in the neonatal mortality sample is dependent on the child being fully exposed to neonatal mortality risk (if still alive, born ≥ 1 month before survey). Standard errors (in parenthesis) are clustered at the DHS cluster level. *** p-value < 1 percent, ** p-value < 5 percent, * p-value < 10 percent.

In addition, the study estimated non-parametric estimations of the relationship between distance from site and mortality, before and after creation of the dumpsites (fig. S1.3).[21] This descriptive analysis suggests that mortality substantially increased in the vicinity of the dumps after their creation, while it declined further away, leading to large net effects.

Robustness Checks

The results presented so far suggest that exposure to an e-waste site causes an increase in both neonatal and infant mortality. In this section, the study provides further support for the main results by discussing a set of robustness checks.

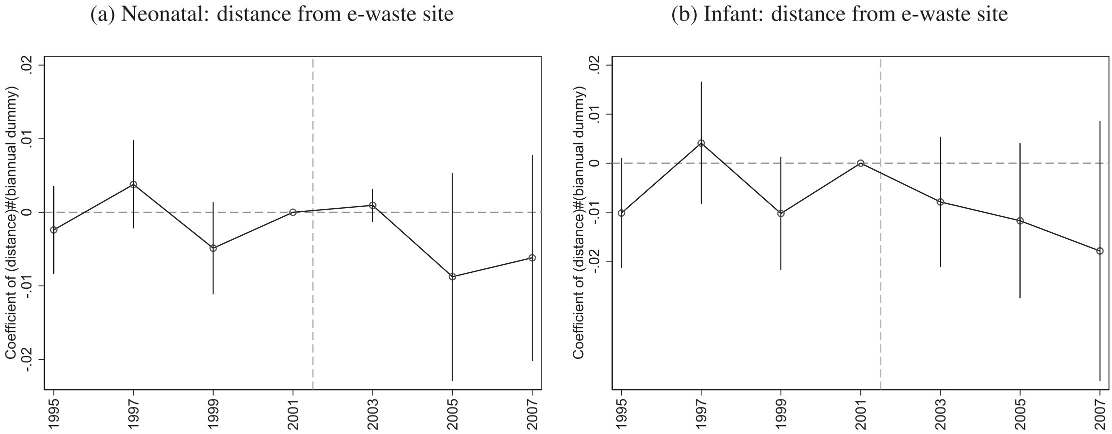
A particular concern for the analysis is that the dumpsites may have induced residential sorting, due to in-migration (for example, due to improved employment prospects) or out-migration (for example, due to possible health effects), leading to selection bias. A priori, it is not clear in which direction such sorting would impact the results. To address this concern, the study uses the Ghana DHS surveys, which collect information on years of residency in current location and allow the study to identify in-migrants. The study therefore re-estimates equations (1) and (2) for non-migrant families only.[22] Regression results are given in Table 3, and the event study analysis is presented in fig. 4. The results reported in columns II and V confirm the previous findings and indicate a negative effect of the dumpsite on infant mortality for non-migrant households.[23] Next, the study also re-estimates equation (1) for non-migrants, and includes mother fixed effects, to compare outcomes between siblings born before and after the creation of the site. Results in columns VI show a coefficient for infant mortality of larger magnitude: one additional kilometer from

21 See e.g. Linden and Rockoff (2008) and Currie and Walker (2011) for similar approaches to modeling the effects of distance.

22 From the original Ghanaian sample (805), the study loses 33.3 percent of children (268). The majority (198) of observations lost occur in the 2008 survey, since inclusion in the sample rests on a household living in the area since 2000 (eight years).

23 The study also finds little differences in women characteristics between migrants and non-migrants households (see Table S1.4).

Figure 4. Event Studies for Neonatal (Left) and Infant (Right) Mortality: Non-Migrant Households (Ghana Only)



Source: Authors' analysis based on data from the DHS for Ghana.
Note: Biannual time indicators are used due to small sample sizes to increase precision, and children born six years after dump creation are included in the analysis. Results are obtained by interacting the biannual time indicator with distance from the dump (in km). The vertical lines indicate 95 percent confidence interval.

the dump decreases infant mortality by 15 deaths per 1,000 births. When the study considers neonatal mortality (column III), however, it does not find evidence of statistically significant differences between children born to the same mothers before and after the e-waste site creation.

A limitation to this analysis is that while it mitigates concerns about *in-migration*, it is silent on the role of *out-migration*, and the study cannot rule out that out-migration may have affected the results, nor lay claim to the direction of any resulting selection bias. Households that migrate out of the area may be those that are more exposed to the dump site (biasing estimates downwards) or may be wealthier and in better health (biasing estimates upwards). Back of the envelope estimates of population changes using DHS surveys before and after the creation of the dump suggest that all communities increased in size, but that growth in population declined with distance from the dumpsite by approximately 1 percent per kilometer for the Ghana site and rose by approximately 0.5 percent per kilometer for the Nigeria site, potentially suggesting some positive population net growth in the Ghanaian context and some limited negative net growth for the Nigerian site relative to places further away.[24] While the study cannot rule out that this migration might cause possible selection bias, it is possible to compare parents interviewed before and after the e-waste sites were established. Hence, the study is able to consider, descriptively, whether there is evidence of differences in observable characteristics of parents living near vs. far from the e-waste sites, before and after the creation of the sites. There is very little evidence of changes in the composition of households (see Table S1.5), but of note is that this evidence is suggestive and limited to observable characteristics only, so that the study cannot rule this out definitively.[25]

In supplementary online appendices S2.7–S2.8, the study provides additional evidence showing that the results are not driven by endogenous site selection or location-specific factors such as local trends or proximity to slum areas, and are further supported by a spatial randomization test that confirms the estimated effects do not arise by chance.

24 The study computed population size at the cluster level using the household (individual) survey weights provided by the DHS surveys. As DHS surveys are designed for representation at the national or regional level, these calculations which refer to smaller areas should be treated with caution.

25 Site-specific analysis of household characteristics is given in Table S1.6 and confirms the findings on the pooled sample.

6. Underlying Mechanisms

Results point towards a substantial increase in mortality for children living in proximity to the two e-waste sites. In this section the study explores two likely channels through which these sites can impact child mortality: contamination of water and of the food chain (Grant et al. 2013).[26]

6.1. Water Contamination: Evidence from the Odaw River in Ghana

To investigate the role of water contamination, the study focuses on the Agbogbloshie site in Ghana, where the Odaw river runs adjacent to the dumpsite and ends in the Korle Lagoon, before entering the Gulf of Guinea. The dumpsite is frequently flooded by heavy rainfall and the river flooding, releasing hazardous chemicals (Brigden et al. 2008). The runoffs from dumpsites (known as lecheate) can reach local waterways and also contaminate groundwater. Higher concentrations of heavy metals (e.g. lead) and other environmental toxins have been found downstream relative to upstream in the river itself and in downstream marine life (e.g. fish) (Bandowe et al. 2014; Hosoda et al. 2014).[27]

The study considers differences in outcomes between children born upstream and downstream of Agbogbloshie, and restricts the analysis to households living within 5 km of the Odaw river, as shown in fig. S1.4.[28] Treatment is defined as living downstream from the dumpsite, compared to living upstream. The study estimates both a difference-in-differences specification and an event study. By comparing pre- and post-dump mortality rates for the two groups, the study aims to provide suggestive evidence that the dumpsite has increased mortality through increased water contamination.

Ideally, the study would consider how the effect varies across household water sources. Unfortunately, the DHS only collect data on source of *drinking* water. This is a problem in this context, because as is common in Accra (Stoler et al. 2012), a significant fraction of the sample rely on bottled/sachet water for their drinking water. One would expect the use of groundwater to be significantly higher than that reported through drinking water because groundwater is frequently used for cooking (Ketadzo, Nkongolo, and Akrofi 2021), and local rivers or other open water sources are frequently used as primary bathing facilities by those who drink sachet water (Stoler et al. 2012). Any effects found by comparing downstream vs. upstream households will, therefore, reflect direct exposure to contaminated water via cooking and bathing, and indirect exposure through contamination of urban crop and animal production.

Results are shown in Table 4, while the event study is shown in fig. S1.5. Results show higher infant and neonatal mortality for children living downstream after the creation of the dumpsite, although the coefficient is only statistically significant for neonatal mortality. The event study supports this analysis, and, although the coefficients are imprecisely estimated, they are suggestive of a greater impact for children living downstream. Overall, these results provide some (suggestive) evidence for Ghana that one route of exposure is through contaminated water.[29]

26 An additional route of exposure is through air (Grant et al. 2013). However, the study is unable to investigate this mechanism given the lack of sufficiently detailed data on air pollution in the region.

27 The study cannot perform a similar analysis of the Nigerian site since there are limited survey clusters located downstream of the nearest (minor) river, which runs 1 km from the site.

28 To avoid the possibility of confounding downstream with distance to the dump, the study excludes from the analysis clusters that are located more than 5 km from the dump.

29 One concern might be that the upstream vs. downstream analysis could be confounding water with air pollution. While the study cannot investigate air pollution directly, it notes that upwind areas do not coincide with downstream areas (Fujimori et al. 2016; Kwarteng et al. 2020).

Table 4. The Impact of E-Waste on Newborn and Infant Health: Downstream vs. Upstream Households (Ghana Only)

	(I) Neonatal mortality	(II) Infant mortality
Downstream	−0.044*	0.002
	(0.022)	(0.033)
Post × Downstream	0.093**	0.074
	(0.040)	(0.068)
Year of birth FE	Yes	Yes
Survey year FE	Yes	Yes
Mean	0.030	0.057
Observations	300	261

Source: Authors' calculations based on DHS data for Ghana.
Note: The table shows OLS regressions for a sample of births in Ghana. Post is a dummy variable indicating a child was born after the creation of the Agbogbloshie site ($t = 2001$). Downstream is a dummy variable for living downstream of the Ogbogbloshie site on the river Odaw. Inclusion in the sample is restricted to only those households lying within 5 km of the Agbogbloshie dumpsite, and includes only children born between 5 years pre- and 5 years post the opening of the dumpsite. Inclusion in the infant mortality sample is dependent on the child having been fully exposed to infant mortality risk (if still alive, born ≥ 12 months before survey). Inclusion in the neonatal mortality sample is dependent on the child being fully exposed to neonatal mortality risk (if still alive, born ≥ 1 month before survey). Standard errors (in parenthesis) are clustered at the DHS cluster level. *** p-value < 1 percent, ** p-value < 5 percent, * p-value < 10 percent.

6.2. Contamination of the Food Chain

One specific mechanism through which individuals may be affected is through contaminated water used in animal production.[30] In both study areas, cattle, goats, and other small animals are raised for meat consumption and are likely to drink contaminated water.[31] Unfortunately, the study cannot directly investigate effects through consumption of food, because the DHS does not collect adequate information on the sources of food consumed by the household.

The study compares mortality outcomes across clusters with different prevalence of urban animal farming. This is determined by using data from the Gridded Livestock of the World database (GLWD) (Robinson et al. 2014) which contains information on livestock density (head of livestock per square kilometer) separately for sheep, goats, pigs, cattle, and chicken at the cluster level. GLWD data have been linked to DHS clusters via the DHS Spatial Covariate data set[32] The study combines these measures of different types of livestock into an indicator variable Livestock, which equals 1 if the cluster livestock density measure is greater than 0 for at least one type of livestock. In the study area, 18.72 percent of clusters are classified as having livestock.[33]

30 Another route of exposure would be urban agriculture, which is present in both areas (see for example Amoah et al. 2007; Oludare et al. 2009). While it would be of interest to investigate the effects of urban crop production, unfortunately data on this in the study sample are not available.

31 This includes contaminated water transported from site to elsewhere but also, in the case of both dumping sites, livestock that graze on the waste itself at the dumping sites (Daum, Stoler, and Grant 2017; Alani et al. 2020).

32 The measure reported in the Spatial Covariate data set is the average livestock density within 2 km of clusters. Livestock density is calculated as within 10 km for rural clusters, but note that 96 percent of the clusters in the sample are classified as urban. See the DHS Program Geospatial Covariate Datasets Manual (Mayala et al. 2018) for more detail and information.

33 While it would be preferable to have a household-level measure of livestock, this information was not collected in the majority of the surveys used in the analysis. However, the study validated the use of the GLWD using the 2008 Ghana DHS survey, confirming that households with livestock are more likely to be based in clusters with higher GLWD livestock density.

Table 5. The Impact of Dumping Sites on Newborn and Infant Health: Urban Livestock Farming

	(I) Neonatal mortality	(II) Infant mortality	(III) Neonatal mortality	(IV) Infant mortality
Post × distance (km)	−0.004***	−0.005**	−0.001	−0.002
	(0.001)	(0.002)	(0.001)	(0.002)
Post × livestock	0.022	0.021	0.140***	0.161***
	(0.015)	(0.021)	(0.029)	(0.056)
Post × livestock × distance			−0.011***	−0.013***
			(0.003)	(0.004)
Livestock	−0.015	−0.012	−0.014	0.030
	(0.010)	(0.012)	(0.018)	(0.032)
Distance (km)	0.002	0.003**	0.002	0.004***
	(0.001)	(0.001)	(0.001)	(0.001)
Distance × livestock			−0.000	−0.004
			(0.002)	(0.003)
Dump FE	Yes	Yes	Yes	Yes
Year of birth FE	Yes	Yes	Yes	Yes
Survey year FE	Yes	Yes	Yes	Yes
Mean	0.036	0.056	0.248	0.250
Observations	3,359	3,094	3,359	3,094

Source: Authors' calculations based on DHS data for Ghana and Nigeria.

Note: The table shows OLS regressions for a sample of births in Ghana and Nigeria. Distance (km) is a variable for the distance of a child's cluster from the dump site. Post is a dummy variable indicating a child was born after the creation of the dump site. Livestock is a dummy variable for being in a cluster with livestock density greater than 0. Inclusion in the sample is restricted to households lying within 5 km of the Agbogbloshie dumpsite, and includes only children born between 5 years pre- and 5 years post the opening of the dumpsite. Inclusion in the infant mortality sample is dependent on the child having been fully exposed to infant mortality risk (if still alive, born ≥ 12 months before survey). Inclusion in the neonatal mortality sample is dependent on the child being fully exposed to neonatal mortality risk (if still alive, born ≥ 1 month before survey). Standard errors (in parenthesis) are clustered at the DHS cluster level. *** p-value < 1 percent, ** p-value < 5 percent, * p-value < 10 percent.

Results are shown in Table 5. Columns (I) and (II) show results when the study simply adds an indicator for livestock and its interaction with Post in the analysis. There is no rise in mortality in areas with livestock within the 20 km zone around the dumpsites in the post dumpsite period. Columns (III) and (IV), however, extend this specification to allow for variation by distance from the dumpsite in a triple difference framework which includes the interaction between an indicator for post-dump, an indicator for livestock, and distance from the dumpsite. The study now finds that households in the proximity of the sites who are in higher-density livestock areas experience higher neonatal (infant) mortality after the creation of the dump, than those in areas without livestock. This effect, however, declines with distance from the site, with a negative and statistically significant effect on the triple interaction term. Thus, the mortality increases that the study observes in the post-dump period in livestock areas appear to be strongest in households near to the dump as opposed to far. The study therefore finds some suggestive evidence that the main effects in both countries may be driven by contamination of the food chain, though the study recognizes that it cannot test directly whether this is due to animal consumption of water, or through other mechanisms.

7. Conclusions

This paper estimates the health impacts of e-waste dumping sites on newborn and infant health in Ghana and Nigeria, which are major hubs in terms of trade and disposal of e-waste (Schluep et al. 2011). It finds that proximity to an e-waste site increases neonatal and infant mortality. One additional kilometer from the dumping site decreases neonatal mortality by 4 deaths per 1,000 births and infant mortality by 5 deaths per 1,000 births. These effects are large relative to the mean, and reflect sharp observed increases in mortality in communities near to e-waste sites in the years after a dump site is opened. The study continued to find negative effects on health when the analysis is restricted to non-migrants, and when it considers sibling fixed effects, although data restrictions lead to substantial losses in sample size, which affect the ability to precisely estimate the effects in these specifications. A caveat to the results is that the study cannot exclude the potential influence of out-migration, and the direction of this potential bias remains uncertain. Additional evidence suggests water contamination, with supporting data from Ghana, and locally sourced farm products, with evidence from both Ghana and Nigeria, as possible routes of exposure.

This work has implications for the appropriate management of e-waste dumping sites, in a context in which there is growing concern about both the illegal flow of e-waste and the export of near end-of-life electronics, which end up soon discarded in the destination country. The results reveal the catastrophic impacts that the inappropriate management of e-waste has had on local communities and highlight the importance of growing efforts to revisit and strengthen the rules on the trade and management of e-waste.

Data Availability Statement

The data used in this paper are publicly available for download from the DHS website.

References

Abadie, A. 2005. "Semiparametric Difference-in-Differences Estimators." *Review of Economic Studies* 72(1): 1–19.

Adegun, O. 2013. "Variation of Leachate Characteristics from Selected Dumpsites in Lagos, Nigeria." *Journal of Applied Sciences in Environmental Sanitation* 8(4): 249–256.

Alani, R., A. Ogunbanmwo, D. Nwude, and M Ogbaje. 2020. "Evaluation of the Environmental Impacts of Electronic-Waste Management in Lagos Using Alaba International Market and Ikeja Computer Village as Case Studies." *Evaluation* 4(2): 283–97.

Alexander, D., and H Schwandt. 2022. "The Impact of Car Pollution on Infant and Child Health: Evidence from Emissions Cheating." *Review of Economic Studies* 89(6): 2872–910.

Amoah, P., P. Drechsel, M. Henseler, and R Abaidoo. 2007. "Irrigated Urban Vegetable Production in Ghana: Microbiological Contamination in Farms and Markets and Associated Consumer Risk Groups." *Journal of Water and Health* 5(3): 455–66.

Adedeji, O. H., and I. A Ademiluyi. 2009. "Urban Agriculture and Urban Land Use Planning: Need for a Synthesis in Metropolitan Lagos, Nigeria." *Journal of Geography and Regional Planning* 2(3): 043–050.

Andrews, A. 2009. "Beyond the Ban–Can the Basel Convention Adequately Safeguard the Interests of the World's Poor in the International Trade of Hazardous Waste." *Law Env't & Dev. J.* 5(2): 167.

Arceo, E., R. Hanna, and P Oliva. 2012. "Does the Effect of Pollution on Infant Mortality Differ Between Developing and Developed Countries? Evidence from Mexico City." *Economic Journal* 126(591): 257–80.

Asamoah, A., M. N. Fini, D. K. Essumang, J. Muff, and E. G Søgaard. 2019. "PAHs Contamination Levels in the Breast Milk of Ghanaian Women from an E-Waste Recycling Site and a Residential Area." *Science of the Total Environment* 666: 347–54.

Azerigyik, R. A., O. Amponsah, and S. A Takyi. 2018. "Clarifying the Debate on the Nexus Between Slum Upgrading and the Economic Well-Being of Beneficiaries with Insight from Ashaiman, Ghana." *Journal of Architectural and Planning Research*: 35(3): 194–217.

Badmos, O. S., D. Callo-Concha, B. Agbola, A. Rienow, B. Badmos, K. Greve, and C Juergens. 2020. "Determinants of Residential Location Choices by Slum Dwellers in Lagos Megacity." *Cities* 98: 102589.

Bakhiyi, B., S. Gravel, D. Ceballos, M. A. Flynn, and J Zayed. 2018. "Has the Question of E-Waste Opened a Pandora's Box? An Overview of Unpredictable Issues and Challenges." *Environment international* 110: 173–92.

Baldé, K., E. D'Angelo, V. Luda, O. Deubzer, and R Kühr. 2022. *Global Transboundary E-Waste Flows Monitor 2022*. Bonn, Germany: United Nations Institute for Training and Research (UNITAR).

Baldé, C. P., R. Kuehr, T. Yamamoto, R. McDonald, E. D'Angelo, S. Althaf, G. Bel *et al.* 2024. "The Global E-Waste Monitor." *United Nations University (UNU), International Telecommunication Union (ITU) & International Solid Waste Association (ISWA), Geneva/Bonn*, 1–147.

Balogun, I., and B Adegun. 2016. "Variability of Groundwater Quality Around Selected Dumpsites in the Lagos Metropolis." *Ife Research Publications in Geography* 11(1): 42–51.

Bandowe, B. A. M., M. Bigalke, L. Boamah, E. Nyarko, F. K. Saalia, and W Wilcke. 2014. "Polycyclic Aromatic Compounds (PAHs and Oxygenated PAHs) and Trace Metals in Fish Species from Ghana (West Africa): Bioaccumulation and Health Risk Assessment." *Environment International* 65: 135–46.

Benshaul-Tolonen, A. 2019. "Local Industrial Shocks and Infant Mortality." *Economic Journal* 129(620): 1561–92.

Bernhardt, A., and N Gysi. 2013. "The world's Worst 2013: The Top Ten Toxic Threats." *Blacksmith Institute and Green Cross Switzerland*.

Bobadoye, S. A., and A. A Fakere. 2013. "Slum Prevalence in Nigeria: What Role for Architects." *World Environment* 3(2): 45–51.

Brigden, K., I. Labunska, D. Santillo, and P Johnston. 2008. "Chemical Contamination at E-Waste Recycling and Disposal Sites in Accra and Korforidua, Ghana." Greenpeace Research Laboratories Technical Note 10/2008.

Callaway, B., and P. H Sant'Anna. 2021. "Difference-in-Differences with Multiple Time Periods." *Journal of Econometrics* 225(2): 200–30.

Chay, K. Y., and M Greenstone. 2003. "The Impact of Air Pollution on Infant Mortality: Evidence from Geographic Variation in Pollution Shocks Induced by a Recession." *Quarterly Journal of Economics* 118(3): 1121–67.

Chen, A., K. N. Dietrich, X. Huo, and S.-M Ho. 2010. "Developmental Neurotoxicants in E-Waste: An Emerging Health Concern." *Environmental Health Perspectives* 119(4): 431–38.

Conley, T. G. 1999. "GMM Estimation with Cross Sectional Dependence." *Journal of Econometrics* 92(1): 1–45.

Currie, J., M. Greenstone, and E Moretti. 2011. "Superfund Cleanups and Infant Health." *American Economic Review* 101(3): 435–41.

Currie, J., and M Neidell. 2005. "Air Pollution and Infant Health: What Can We Learn from California's Recent Experience?" *Quarterly Journal of Economics* 120(3): 1003–30.

Currie, J., M. Neidell, and J. F Schmieder. 2009. "Air Pollution and Infant Health: Lessons from New Jersey." *Journal of Health Economics* 28(3): 688–703.

Currie, J., and R Walker. 2011. "Traffic Congestion and Infant Health: Evidence from E-ZPass." *American Economic Journal: Applied Economics* 3(1): 65–90.

Currie, J., J. G. Zivin, J. Mullins, and M Neidell. 2014. "What Do We Know About Short-and Long-Term Effects of Early-Life Exposure to Pollution?" *Annual Review of Resource Economics* 6(1): 217–47.

Dakpallah, T. A. G. 2011. *Slum Improvement in Ghana: The Study of Aboabo and Asawase in Kumasi*. PhD thesis, Kwame Nkrumah University of Science and Technology, Kumasi.

Daum, K., J. Stoler, and R. J Grant. 2017. "Toward a More Sustainable Trajectory for E-Waste Policy: A Review of a Decade of E-Waste Research in Accra, Ghana." *International Journal of Environmental Research and Public Health* 14(2): 135.

Davis, J.-M., G. Akese, and Y Garb. 2019. "Beyond the Pollution Haven Hypothesis: Where and Why Do E-Waste Hubs Emerge and What Does This Mean for Policies and Interventions?" *Geoforum* 98: 36–45.

Deiana, C., and L Giua. 2023. "This Site Is Closed! The Effect of Decommissioning Mining Waste Facilities on Mortality in the Long Run." *Journal of Environmental Economics and Management* 119: 102797.

Donaldson, D., and A Storeygard. 2016. "The View from Above: Applications of Satellite Data in Economics." *Journal of Economic Perspectives* 30(4): 171–98.

Duflo, E. 2001. "Schooling and Labor Market Consequences of School Construction in Indonesia: Evidence from an Unusual Policy Experiment." *American Economic Review* 91(4): 795–813.

Fink, G., I. Günther, and K Hill. 2014. "Slum Residence and Child Health in Developing Countries." *Demography* 51(4): 1175–97.

Forti, V., K. Baldé, and R Kuehr. 2018. "E-Waste Statistics: Guidelines on Classifications, Reporting and Indicators."Bonn: United Nations University.

Forti, V., C. P. Balde, R. Kuehr, and G Bel. 2020. "The Global E-Waste Monitor 2020: Quantities, Flows and the Circular Economy Potential." Bonn/Geneva/Rotterdam: United Nations University (UNU)/United Nations Institute for Training and Research (UNITAR) – co-hosted SCYCLE Programme, International Telecommunication Union (ITU) & International Solid Waste Association (ISWA).

Fujimori, T., T. Itai, A. Goto, K. A. Asante, M. Otsuka, S. Takahashi, and S Tanabe. 2016. "Interplay of Metals and Bromine with Dioxin-Related Compounds Concentrated in E-Waste Open Burning Soil from Agbogbloshie in Accra, Ghana." *Environmental Pollution* 209: 155–63.

Gennaioli, C., and G Narciso. 2017. "Toxic Roads: Unearthing Hazardous Waste Dumping." CGR Working Papers 82, Queen Mary, University of London, School of Business and Management, Centre for Globalisation Research.

Goodman-Bacon, A. 2021. "Difference-in-Differences with Variation in Treatment Timing." *Journal of Econometrics*.225(2): 254–77

Grant, K., F. C. Goldizen, P. D. Sly, M.-N. Brune, M. Neira, M. van den Berg, and R. E Norman. 2013. "Health Consequences of Exposure to E-Waste: A Systematic Review." *Lancet Global Health* 1(6): e350–e361.

Grant, R., and M Oteng-Ababio. 2012. "Mapping the Invisible and Real African Economy: Urban E-Waste Circuitry." *Urban Geography* 33(1): 1–21.

Greenstone, M., and R Hanna. 2014. "Environmental Regulations, Air and Water Pollution, and Infant Mortality in India." *American Economic Review* 104(10): 3038–72.

He, G., and J. M Perloff. 2016. "Surface Water Quality and Infant Mortality in China." *Economic Development and Cultural Change* 65(1): 119–39.

Heacock, M., C. B. Kelly, K. A. Asante, L. S. Birnbaum, Å. L. Bergman, M.-N. Bruné, I. Buka, and et al. 2016. "E-Waste and Harm to Vulnerable Populations: A Growing Global Problem." *Environmental Health Perspectives* 124(5): 550–55.

Heckman, J. J., H. Ichimura, and P. E Todd. 1997. "Matching as an Econometric Evaluation Estimator: Evidence from Evaluating a Job Training Programme." *Review of Economic Studies* 64(4): 605–654.

Hosoda, J., J. Ofosu-Anim, E. B. Sabi, L. G. Akita, S. Onwona-Agyeman, R. Yamashita, and H Takada. 2014. "Monitoring of Organic Micropollutants in Ghana by Combination of Pellet Watch with Sediment Analysis: E-Waste as a Source of PCBs." *Marine Pollution Bulletin* 86(1–2): 575–81.

Ife-Adediran, O., and O Isabota. 2018. "Gamma Dose Profile and Risk to Scavengers and Occupants near Waste Dumpsites in Coastal Nigeria." *International Journal of Environmental Studies* 75(5): 708–18.

IPEN,BAN. 2019. "Weak Controls: European E-Waste Poisons Africa's Food Chain." International Pollutants Elimination Network (IPEN).

Jayachandran, S. 2009. "Air Quality and Early-Life Mortality: Evidence from Indonesia's Wildfires." *Journal of Human Resources* 44(4): 916–54.

Kellenberg, D. 2010. "Consumer Waste, Backhauling, and Pollution Havens." *Journal of Applied Economics* 13(2): 283–304.

Ketadzo, J. A., N. V. Nkongolo, and M. M Akrofi. 2021. "Empirical Analysis of the Impact of Urbanization on Groundwater Quality Within the Slums of Accra, Ghana." *World Water Policy* 7(1): 112–31.

Kitt, J. R. 1994. "Waste Exports to the Developing World: A Global Response." *Geo. Int'l Envtl. L. Rev.* 7(2): 485.

Knittel, C. R., D. L. Miller, and N. J Sanders. 2016. "Caution, Drivers! Children Present: Traffic, Pollution, and Infant Health." *Review of Economics and Statistics* 98(2): 350–66.

Krueger, J. 1998. "Prior Informed Consent and the Basel Convention: The Hazards of What Isn't Known." *Journal of Environment & Development* 7(2): 115–37.

Kwarteng, L., E. A. Baiden, J. Fobil, J. Arko-Mensah, T. Robins, and S Batterman. 2020. "Air Quality Impacts at an E-Waste Site in Ghana Using Flexible, Moderate-Cost and Quality-Assured Measurements." *GeoHealth* 4(8): e2020GH000247.

Landrigan, P. J., and A Garg. 2004. "Children are not little adults" In *Children's Health and the Environment. A Global Perspective*, edited byJ. , 3–17.

Lepawsky, J., and C McNabb. 2010. "Mapping International Flows of Electronic Waste." *Canadian Geographer/Le Géographe canadien* 54(2): 177–95.

Linden, L., and J. E Rockoff. 2008. "Estimates of the Impact of Crime Risk on Property Values from Megan's Laws." *American Economic Review* 98(3): 1103–27.

Lucier, C. A., and B. J Gareau. 2016. "Obstacles to Preserving Precaution and Equity in Global Hazardous Waste Regulation: An Analysis of Contested Knowledge in the Basel Convention." *International Environmental Agreements: Politics, Law and Economics* 16(4): 493–508.

Luechinger, S. 2014. "Air Pollution and Infant Mortality: A Natural Experiment from Power Plant Desulfurization." *Journal of Health Economics* 37: 219–31.

Manhart, A., O. Osibanjo, A. Aderinto, and S Prakash. 2011. "Informal E-Waste Management in Lagos, Nigeria. Socio-Economic Impacts and Feasibility of International Recycling Co-Operations." *Final report of component 3 of the UNEP SBC E-waste Africa Project*, 1–129.

Maphosa, V., and M Maphosa. 2020. "E-Waste Management in Sub-Saharan Africa: A Systematic Literature Review." *Cogent Business & Management* 7(1): 1814503.

Mayala, B., T. D. Fish, D. Eitelberg, and T Dontamsetti. 2018. *The DHS Program Geospatial Covariate Datasets Manual*. Rockville, Maryland, USA: ICF.

NPC. 2011. "Nigeria's Over 167 Million Population: Implications and Challenges." Technical report, National Population Commission NPC.

Ofudje, E., S. Alayande, G. Oladipo, O. Williams, and O Akiode. 2014. "Heavy Metals Concentration at Electronic-Waste Dismantling Sites and Dumpsites in Lagos, Nigeria." *International Research Journal of Pure and Applied Chemistry*: 4(6):678–90.

Ogungbuy, O., I. Chidi Nnorom, O. Osibanjo, and M Schluep. 2012. "E-Waste Country Assessment Nigeria." Report, Secretariat of the Basel Convention, UNEP, or the United Nations.

Ogunseitan, O. A. 2013. "The Basel Convention and E-Waste: Translation of Scientific Uncertainty to Protective Policy." *Lancet Global Health* 1(6): e313–14.

Oppong, B. E., R. Asomani-Boateng, and R. J Fricano. 2020. "Accra's Old Fadama/Agbogbloshie Settlement. To What Extent Is This Slum Sustainable?" *African Geographical Review* 39(4):1–19.

Osibanjo, O., A. A. Adeyi, and A. O Majolagbe. 2017. "Characterisation of Groundwater Quality Around Soluos Dumpsite in Lagos, Nigeria." *International Journal of Water* 11(1): 44–58.

Owusu-Sekyere, K., A. Batteiger, R. Afoblikame, G. Hafner, and M Kranert. 2022. "Assessing Data in the Informal E-Waste Sector: The Agbogbloshie Scrapyard." *Waste Management* 139: 158–67.

Paller, J. W. 2015. "Informal Networks and Access to Power to Obtain Housing in Urban Slums in Ghana." *Africa Today* 62(1): 31–55.

Robinson, T. P., G. W. Wint, G. Conchedda, T. P. Van Boeckel, V. Ercoli, E. Palamara, G. Cinardi, and et al. 2014. "Mapping the Global Distribution of Livestock." *PloS one* 9(5): e96084.

Schluep, M., A. Manhart, O. Osibanjo, D. Rochat, N. Isarin, and E Mueller. 2011. "Where Are WEEE in Africa? Findings from the Basel Convention E-Waste Africa Programme." *Published by the Secretariat of the Basel Convention*.

Stoler, J., G. Fink, J. R. Weeks, R. A. Otoo, J. A. Ampofo, and A. G Hill. 2012. "When Urban Taps Run Dry: Sachet Water Consumption and Health Effects in Low Income Neighborhoods of Accra, Ghana." *Health & Place* 18(2): 250–62.

Stoler, J., R. A. Tutu, and K Winslow. 2015. "Piped Water Flows but Sachet Consumption Grows: The Paradoxical Drinking Water Landscape of an Urban Slum in Ashaiman, Ghana." *Habitat International* 47: 52–60.

Tanaka, S. 2015. "Environmental Regulations on Air Pollution in China and Their Impact on Infant Mortality." *Journal of Health Economics* 42: 90–103.

UNEP. 1989. "Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and Their Disposal." Technical report, UNEP.

UNEP, P., I. ITU, and U UNIDO. 2019. "A New Circular Vision for Electronics Time for a Global Reboot."Cologny/Geneva Switzerland: World Economic Forum (WEF).

von der Goltz, J., and P Barnwal. 2019. "Mines: The Local Wealth and Health Effects of Mineral Mining in Developing Countries." *Journal of Development Economics* 139: 1–16.

Waste Atlas Partnership. 2014. "The World's 50 Biggest Dumpsites." Technical report, D-Waste.

Widmer, R., H. Oswald-Krapf, D. Sinha-Khetriwal, M. Schnellmann, and H Böni. 2005. "Global Perspectives on E-Waste." *Environmental Impact Assessment Review* 25(5): 436–58.