Department of Economics

Development Economics Cluster
Labour and Household Economics Cluster

University of Reading

Garbage in, garbage out: the impact of e-waste dumping sites on early child health

by Stefania Lovo and Samantha Rawlings

Discussion Paper No. 2021-07

Department of Economics
University of Reading
Whiteknights
Reading
RG6 6AA
United Kingdom

www.reading.ac.uk

Garbage in, garbage out: the impact of e-waste dumping sites on early child health

Stefania Lovo* Samantha B. Rawlings†

June 24, 2021

Abstract

This paper examines the effect of e-waste dumping sites on early child health. We focus on two major dumping sites in West Africa, in Ghana and Nigeria. We observe children born before and after the creation of these dumps, and estimate a difference-in-difference specification in which we compare outcomes of those born within the vicinity of the dump (within 11km) to those further away, before and after e-waste sites are created. We find that the e-waste sites increase neonatal and infant mortality by 4.5 and 6.5 percentage points, respectively, for children living in the proximity of the site. Event study analysis suggests that the negative effects emerge 2-3 years after the existence of the site, consistent with the gradual and systematic build up on contaminants in the environment. Preliminary analysis considering routes of exposure suggests that water pollution may drive some of the observed effects.

JEL Classification: I10, Q53, Q56, O10
Keywords: E-waste, Health, Infant Mortality, Dumping Sites

*Department of Economics, University of Reading, Whiteknights, Reading RG6 6AA. E-mail: s.lovo@reading.ac.uk

†Department of Economics, University of Reading, Whiteknights, Reading RG6 6AA. E-mail: s.b.rawlings@reading.ac.uk

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 (Lundgren, 2012), with 53 million metric tons (Mt) of e-waste generated globally in 2019; this is estimated to rise to 74 Mt by 2030 (Forti et al., 2020). An important aspect of e-waste is that it is often inappropriately managed, especially in developing countries. Whilst the production of EEE occurs primarily in developed countries, the disposal of waste EEE (WEEE) - and resulting impacts on the environment - occurs predominantly in developing countries (Bimir, 2020).

E-waste in developing countries originates both from domestic and international sources. Internationally, a vast share of e-waste imports is represented by working or repairable electronic equipment that domestic consumers discard (Davis et al., 2019), because used EEE imported into developing countries is often usable but has a short life span (Heacock et al., 2016). A significant share of the international flow is also generated within regions rather than transferred between regions (Lepawsky and McNabb, 2010). Evidence suggests that West Africa is a major trading route of used EEE, with Ghana and Nigeria serving as the main import hubs (Schluep et al., 2011). Indeed, many e-waste dumping sites in the region originated from or in the proximity of second-hand markets (Manhart et al., 2011). Evidence, however, also indicates the existence of a non-negligible international flow of e-waste that enters developing countries illegally (Kellenberg, 2010).

E-waste contains significant amounts of precious metals and other valuable materials, and it is estimated, for example, that 7% of the world's gold is currently contained in e-waste (UNEP et al., 2019). This results in a market for salvage, and e-waste in developing countries is typically transported to dump sites or workshops where it is stripped of valuable materials. In African countries, e-waste management is predominantly performed by those in the informal sector, with manual stripping of components and deposit of unwanted components in open dumpsites.[1] Such informal workers lack protective equipment and frequently this involves illicit labour of pregnant women and minors (Baldé et al., 2017). After salvage, the remainder of the e-waste is burned, or discarded into the environment at the dump site (Kellenberg, 2010). This is of concern because e-waste consists of a number of environmental contaminants. These include organic pollutants such as polychlorinated biphenyls, which are components of e-waste and are known endocrine disruptors (Bergman et al., 2013), potentially hazardous chemical elements in electrical components that are known to have developmental effects on children such as

[1] The size of this informal economy is large, with recent estimates suggesting that 100,000 people work in the informal e-waste sector in Nigeria (ILO, 2019).

lead, cadmium and arsenic (Chen et al., 2010), and carcinogenic polycyclic aromatic hydrocarbons (PAH) formed and released into the environment during burning of e-waste materials (Wang et al., 2012). These contaminants pose a number of risks to health, and potential routes to exposure include ingestion, inhalation and dermal contact, with high levels of environmental contamination meaning residents living near to e-waste areas are at significant risk of environmental exposure (Grant et al., 2013). Children and the young are particularly at risk, due to additional routes of exposure such as breastfeeding and placental exposure and through behaviours such as persistent hand to mouth activities (Grant et al., 2013). Children are also at increased risk 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). Observational studies suggest that exposure to e-waste is significantly associated with a range of health problems amongst children, including adverse neonatal outcomes (Grant et al., 2013).[2]

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). 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 et al., 2012; Luechinger, 2014; Tanaka, 2015; Currie and Neidell, 2005; Currie et al., 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, yet the impact of waste has received little attention. An exception is Currie et al. (2011), who investigate the impact of toxic waste dumps in the US on infant health, exploiting the introduction of the Comprehensive Environmental Response, Compensation, and Liability Act (known as Superfund), which led to cleanups of dangerous hazardous waste sites in the US. They find that cleanups of hazardous waste sites reduce 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. A more recent work by Gennaioli and Narciso (2017) investigates the impact of illegal dumping of (non-specified) hazardous waste in Ethiopia on infant health. However, given the absence of information on locations of illegal waste dumping sites, the study relies on predictions based on road construction. The premise underlying the paper is that road construction facilitates disposal of toxic

[2]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 birthweights, whilst 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).

waste. It finds that an additional road within a 5 kilometer radius is associated with an increase in infant mortality by 3 percentage points.

This paper investigates how exposure to e-waste sites impacts infant and neonatal mortality employing a difference-in-difference approach. We exploit a household's distance to the dumping site to define exposure to pollution from the hazardous waste at birth or in the womb. Our identification strategy relies on the comparison of children born before and after the existence of the dump, in areas within and outside of the vicinity of the dump. We define vicinity of the dump using non-parametric analysis, but later relax assumptions about treatment distance in a further specification in which distance from e-waste sites is used as a measure of treatment intensity.

To our knowledge, this is the first study to investigate the causal impact of e-waste dumping sites on early childhood health. This is particularly important given their extensive presence in developing countries, including a number of African and Central Asian countries and China (Forti et al., 2020). We find large and statistically significant effects of proximity to e-waste sites on neonatal and infant mortality. The creation of an e-waste site increases neonatal and infant mortality by 4.5 and 6.5 percentage points, respectively, for children living in the proximity of the site. Event study analysis is used to understand the dynamics of the relationship and suggests that these effects emerge 2-3 years after the existence of the site, suggesting that effects emerge once contaminants have had time to build up in the environment. When we consider distance as a measure of treatment intensity, we find that dump-induced mortality declines with distance from e-waste sites. Suggestive evidence for Ghana indicates that water pollution partially explain the observed effects.

The rest of the paper proceeds as follows. We give an overview of background and context regarding illegal trade of e-waste and the sites used in the analyis in section 2. Section 3 outlines the data used, section 4 outlines our empirical specifications, whilst section 5 presents our results. We discuss robustness checks in section 6, and potential mechanisms underlying our results in 7. Finally, section 8 concludes.

2 Background and Context

2.1 International Conventions on Exporting Hazardous Waste

In response to increasing exports of hazardous wasted 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 22 March 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 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, 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 2016, an estimated 44.7 Mt of E-waste was generated, approximately 6kg per person on the planet, leading to the UN describing a 'tsunami of waste' (UNEP et al., 2019).[3]

In addition, the export of electronic equipment labelled as 'for re-use' is still permitted (UNEP, 1989).This has led to significant levels of imported used EEE into African countries which ultimately ends up discarded, either because it has a short life-span (Heacock et al., 2016), or because it is illegally labelled as for re-use when it is WEEE (Kellenberg, 2010).[4]

2.2 E-waste sites

We focus on two major e-waste sites in Accra, Ghana and in Lagos, Nigeria. We identify these e-waste sites, their location, and the year in which they were established, using details published in the 2014 Waste Atlas Report on the world's 50 biggest dumpsites (Waste Atlas Partnership, 2014). The site coverage in the report was determined by (physical) size and spread of the site, estimated amount of waste disposed of, number of people potentially influenced by the site, and risks posed by the site to environmental and health. Inclusion in the report is conditional on data on site being available; this include both official data, and so-called 'grey' literature e.g. news/media. The Waste

[3]This estimated figure has subsequently risen to 53 Mt in 2019 (Forti et al., 2020).

[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).

Atlas Report also details of the types of waste handled at sites, including e-waste.[5]

Choice of dumping site in this research was determined by the following criteria: the site was established after e-waste became a significant waste flow in the late 1990s (Grant and Oteng-Ababio, 2012; Forti et al., 2018) and that there is availability of sufficient data on birth outcomes (see section 3 for details on the data used). Further details on each site is given below.

Agbogbloshie site, Accra, Ghana

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 192,000 tonnes of e-waste every year (Waste Atlas Partnership, 2014). 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 10km of the site of 2,350,000 (Waste Atlas Partnership, 2014). It has received intense media reporting regarding the scale of the problem, and is notorious amongst NGOS such as Greenpeace.[6] 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 significant amount of evidence suggests the existence of the site has led to extensive pollution of the surrounding area and increased levels of hazardous chemicals in the water, ground, as well as in human subjects. It has been argued that residents of nearby settlements, as well as those working and residing in the central business district, are at risk of daily exposure to significant levels of environmental toxins through air, dust, water, and food; nursing infants face additional risk through exposure via breast milk (Daum et al., 2017). The Odaw river runs through the middle of the waste site, and the Korle lagoon is adjacent to it; these water bodies form part of the major catchments in the Accra metropolis, and cover an area of $250km^2$ (Huang et al., 2014). The Odaw river frequently floods during rainfall, transferring surface chemical contaminants into adjacent lagoons and the river, as further discussed below (Brigden et al., 2008).

Higher concentrations of copper, cadmium, lead, iron, and chromium have been found in the river (Huang et al., 2014), and significantly higher concentrations of PCBs have been found downstream from the waste site relative to downstream from the central business district (Hosoda et al., 2014). Studies have found elevated levels of heavy metals and organic pollutants in the marine life, including fish, downstream and the city's coast (Bandowe et al., 2014; Hosoda et al., 2014). Numerous hazardous chemicals and toxic

[5] Other categories of waste include municipal waste and hazardous waste.

[6] See for example https://www.theguardian.com/environment/gallery/2014/feb/27/agbogbloshie-worlds-largest-e-waste-dump-in-pictures.

metals, such as lead, have been found in soil samples from the surrounding area (Brigden et al., 2008). Workers at Agbogbloshie have been found to have elevated levels of lead in their urine (Feldt et al., 2014). Breast milk samples from women residing near Agbogbloshie have been found to contain abnormally high concentrations of PBDEs and similar contaminants (Daum et al., 2017). There is some evidence to suggest e-waste poisoning of the food chain, with eggs laid by free-range chickens from Agbogbloshie found to have elevated levels of hazardous chemicals; eggs sampled exceeded EU standards for some toxins by 171-fold (IPEN and BAN, 2019).

Solous site, Lagos, Nigeria

Solous is a dumping site established in 2006 in Lagos, Nigeria, receiving a large amount of waste, both municipal and e-waste. For example, estimates suggest that it received 428,728 metric tonnes of waste in the first two quarters of 2009 (Balogun and Adegun, 2016).[7] An estimated 4 million people live within 10km of the site, and the nearest settlement to the site is 200m away (Waste Atlas Partnership, 2014). In addition, a road runs through the middle of the site, establishing it as a trade route and business centre (Ife-Adediran and Isabota, 2018) and it has been described as "an entire human community on its own, where buying, selling, eating, drinking, playing, visiting and other normal activities take place daily" (p.710 Ife-Adediran and Isabota, 2018). Whilst it has been studied less in the environmental sciences literature than Agbogbloshie, nonetheless evidence suggests that the 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 et al., 2017); this has lead to nearby water that is unfit for human consumption (Adegun, 2013). Since the majority of the population of Lagos rely on boreholes and hand-dug wells for their water supply (Osibanjo et al., 2017), and evidence suggests that residents in the dump vicinity depend on groundwater as their source of domestic water supply (Balogun and Adegun, 2016),[8] such contamination may be a significant mechanism through which the health of individuals may be affected by proximity to the dumpsite.

A complication of the inclusion of this site into the study is the existence of an older,

[7] There are no estimates separately for e-waste vs. municipal waste.

[8] We confirm this using the DHS data; in our sample, 48% of individuals within 20km of the dump use borewater or wells as their source of drinking water, with the remaining either using piped water (22%) or bottled/sachet water (22%). The DHS does not ask about sources of non-drinking water, but we may expect it to be significantly higher because people are unlikely to use bottled water for e.g. for cooking and bathing

large dumpsite 14km away, known as the Olusosun/Olushosun waste site. The Olushosun 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 us from having a clean 'before' and 'after' period for exposure to e-waste, so that we do not include it in our main analysis. In analysing the Solous site we therefore exclude all households living within 'treated' distance of Olushosun (further details are discussed in section 3.). In section 6.5 we do provide some estimates using the Oloshosun site and an approximate time of treatment determined from import data.

3 Data

We use data from the Demographic Health Surveys (DHS) for Ghana (1998, 2003, 2008) and Nigeria (2003, 2008, 2013). These are nationally representative surveys, using standardised questionnaires that are comparable across countries. 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 is documented. 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 a GPS dataset containing the latitude and longitude location of the cluster within which the household is placed.[9]

To increase sample size, we supplement our analysis with data from the Malaria Indicator Surveys for Nigeria (2010, 2015) which are also administered by the DHS programme.[10] 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 our analysis, as well as GPS of cluster location.[11] Figure A.1 of the Appendix show the location of the two dumping sites and the distribution of survey clusters in the surrounding area of the site within the treatment zone (0 - 11km) and the control zone (11 - 20km).[12]

All women interviewed in the DHS are asked for the date of birth of each child and, if the child has died, their age at death.[13] Our measure of newborn and infant health is

[9]Cluster sizes are small, with approximately 25-30 houses per cluster.

[10]See https://dhsprogram.com/What-We-Do/Survey-Types/MIS.cfm for a further discussion of these data

[11]Our results are robust to the exclusion of the MIS surveys.

[12]For Nigeria, we also show the location of the earlier established dumpsite, Olusosun, that is not included in our analysis for reasons discussed above. We also show the 11km radius around Olusosun, to show which clusters are therefore excluded from our analysis of the Solous dumpsite.

[13]This is reported as age in days if less that one month old at death, or age in months if older than one month at time of death.

captured by measures of mortality in the first month (neonatal) and first year (infant) of life.[14] We construct dummy variables for neonatal and infant mortality that are equal to 1 if the child died before 30 days, or before 1 year, respectively.[15] We drop from our estimating sample those children who have not been fully exposed to the measure of mortality under study.[16] Our sample considers children born 20km within the vicinity of the dumps five years before and after it's establishment, leaving us with a sample of 2341 (2151) births in our neonatal (infant) mortality regressions, born to 1302 (1218) mothers.

Table 1 shows summary statistics for the births in our sample, for all households. Average neonatal (infant) mortality is 3.3% (5.0%), and these rates are broadly similar in Ghana (Panel B) and Nigeria (Panel C). The sample is primarily urban, and individuals tend to have either primary or secondary level of education. Country (i.e. dump) specific statistics show broadly similar patterns across the two dumpsites, with the exception of education; whilst the proportions of primary and secondary education are similar, the Nigerian sample has fewer individuals with less than primary education, and more with higher education.

Appendix Table A.1 considers whether there is evidence that compositions of birth vary between treatment (within 11km) and control (within 11-20 km) areas, and within these areas, before and after e-waste sites were established. The choice of 11km as our measure of treatment is driven by non-parametric analysis of the data as described and shown in section 4. There are some differences in the levels of education, particularly spousal education, between treatment and control areas, but these differences are stable over time (columns (I) and (II)). *Within* treatment and control areas, there also appear to be very little change in the compositions of births before and after the e-waste sites were opened, and any changes tend to be broadly similar across the treatment and control. For example, there is some (weak) evidence that spousal education was higher amongst births occurring after e-waste sites were established, in both control and treatment areas, but these differences are only statistically significant at the 10% level.[17] Thus, table A.1 shows little evidence that compositions of births changed differentially over time for treatment and control areas.

[14]Evidence from developed nations commonly uses birth weight as a measure of newborn/inutero health (e.g. (Currie et al., 2011)); however, birth weight is often poorly recorded in the DHS surveys, and this is particularly the case in these surveys. Between 70-80% 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).

[15]Due to age heaping, we include the 30th day and 13th month in our definitions of neonatal and infant mortality.

[16]For example, if a child were 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.

[17]For control areas, it appears that the proportion ofn births born to fathers with secondary schooling was higher, whereas for treatment areas it is higher for higher education.

Table 1: Summary statistics

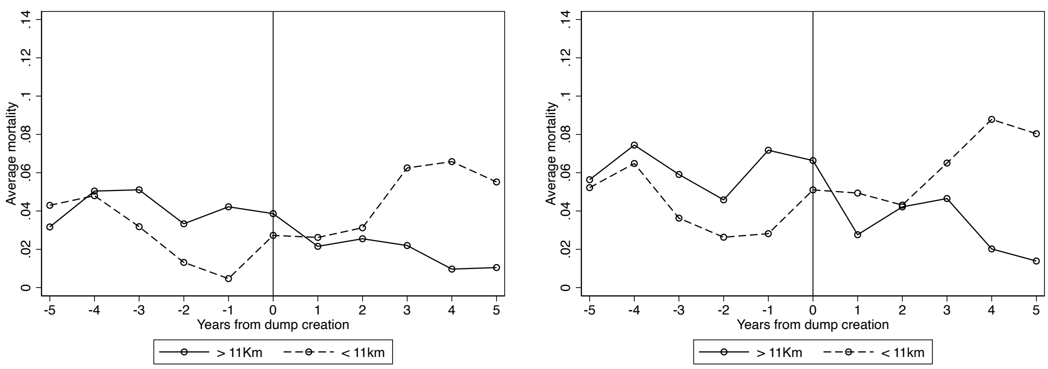
Variable	Mean	Std. Dev.	Min.	Max.	N
All					
Neonatal mortality	0.033	0.18	0	1	2341
Infant mortality	0.050	0.218	0	1	2151
< Primary schooling	0.086	0.28	0	1	2341
Primary schooling	0.194	0.395	0	1	2341
Secondary schooling	0.585	0.493	0	1	2341
Higher education	0.136	0.343	0	1	2341
Spouse < primary schooling	0.048	0.214	0	1	2030
Spouse primary schooling	0.136	0.343	0	1	2030
Spouse secondary schooling	0.607	0.489	0	1	2030
Spouse higher schooling	0.208	0.406	0	1	2030
Urban	0.943	0.232	0	1	2341
Male birth	0.512	0.5	0	1	2341
Multiple birth	0.041	0.199	0	1	2341
Mother age at birth	27.794	5.64	14	47	2341
Ghana					
Neonatal Mortality	0.03	0.17	0	1	805
Infant Mortality	0.051	0.22	0	1	727
< Primary schooling	0.125	0.331	0	1	805
Primary schooling	0.214	0.41	0	1	805
Secondary schooling	0.607	0.489	0	1	805
Higher education	0.053	0.225	0	1	805
Spouse < primary schooling	0.097	0.296	0	1	710
Spouse primary schooling	0.032	0.177	0	1	710
Spouse secondary schooling	0.725	0.447	0	1	710
Spouse higher schooling	0.145	0.352	0	1	710
Urban	0.932	0.252	0	1	805
Male birth	0.513	0.5	0	1	805
Multiple birth	0.037	0.19	0	1	805
Mother age at birth	27.352	6.035	14	45	805
Nigeria					
Neonatal Mortality	0.035	0.184	0	1	1536
Infant Mortality	0.05	0.218	0	1	1424
< Primary schooling	0.065	0.247	0	1	1536
Primary schooling	0.183	0.387	0	1	1536
Secondary schooling	0.573	0.495	0	1	1536
Higher education	0.179	0.384	0	1	1536
Spouse < primary schooling	0.022	0.147	0	1	1320
Spouse primary schooling	0.192	0.394	0	1	1320
Spouse secondary schooling	0.543	0.498	0	1	1320
Spouse Higher schooling schooling	0.242	0.429	0	1	1320
Urban	0.949	0.221	0	1	1536
Male birth	0.512	0.5	0	1	1536
Multiple birth	0.044	0.204	0	1	1536
Mother age at birth	28.026	5.409	14	47	1536

Source: Authors calculations based on DHS data.

Figure 1 plots average mortality rates over time for households in the treated areas (11km) vs. control (11-20km). Though the small sample size in our analysis leads to some noise, we see that, prior to the establishment of the e-waste sites, neonatal and infant mortality rates roughly co-moved for those living within and outside of the vicinity of the e-waste sites. In the post-site period instead, we see a divergence in trends and a sharp increase in mortality rates amongst those living in the vicinity of e-waste sites. This effect persists and strengthens over time; for example, the (2 year) rolling-average of neonatal (infant) mortality within the vicinity of the sites rises from 2.7% (5.1%) in the year of creation to 5.5% (8.1%) 5 years after - an almost twofold increase in mortality in a five year period. The rise is not immediate, and appears 2-3 years after the dump was created, consistent with time to diffusion of pollutants in the environment. It is worth noting, however, that the purpose of these graphs is only descriptive. For example, while we observe some differences in mortality in the pre-dump period, appropriate testing for pre-trends will be provided below.

Figure 1: Average neonatal (left) and infant (right) over time

(a) Neonatal mortality (b) Infant mortality



Authors' calculation based on the DHS data for Ghana and Nigeria. For consistency, we consider a common number of years (5) before and after the dump for both countries. The plots are created by computing rolling 2-year averages of infant and neonatal mortality.

4 Methodology

4.1 Graphical Evidence: non-parametric estimation

Since apriori we have no information on how far a household must be to be classified as in our treatment group, we first consider non-parametric evidence concerning the relationship between distance from the dump and mortality. We combine information on GPS of the cluster with GPS of the dumping sites to calculate household distance from the site. We then plot non-parametric local polynomial smoothed estimations of the relationship between distance from dumping site and mortality, separately before and after creation of the dumps.[18],[19] We expect to see no relationship between distance and mortality prior to the creation of the dumping sites, and an increase in mortality close to the dump after its creation which declines with distance.

4.2 Empirical Specification

Our main identification strategy is based on a difference-in-differences specification that uses the date of creation of a dumping site to determine treatment, and compares children located close to the site (0 - 11km) to those farther away (11-20km). Our choice of treatment distance (11km from the site) is given by the results of the non-parametric analysis shown above, discussed in section 5. Formally, we estimate the following equation:

$$Y_{ijt} = \beta_0 + \beta_1 Post_k + \beta_2 D_{ij} + \beta_3 Post_t \times D_{ij} + \nu_t + \theta_d + \epsilon_{ijt}, \tag{1}$$

where i indicates a child born in year t from mother j. $Post_k$ is an indicator variable which equals 1 if a child was born after the local dump was created. D_{ij} is the treatment dummy indicating proximity to a dump (within 11km). Lastly, ν_t is a vector of child year of birth fixed effects and we include dump-specific fixed effects θ_d.[20] The coefficient of primary interest is that of the interaction term, β_3. Our dependent variable Y_{ijt} 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 β_3. Given the binary nature of these variables, the above equations are estimated using a linear probability model. Standard errors are clustered at the household cluster level; there are 180 clusters in our analysis. In a robustness check, we control for dump-specific time trends ($\theta_d \times T$), mother and child characteristics X_{ijt}, and cohort dummies interacted with pre-dump local characteristics of clusters to account for differential evolution over time in local development associated with mortality (see section 6).

In a second specification we relax our assumption concerning treatment distance, and use the distance from e-waste site as a measure of treatment intensity of exposure to

[18] A similar strategy has been employed by e.g. Currie and Walker (2011) who consider the effect of living in the vicinity of road toll plazas on infant mortality, and Linden and Rockoff (2008) who consider the impact of proximity to a sex offender's house on local housing prices.

[19] Our results are robust to instead using locally weighted smoothing (lowess).

[20] Note that the inclusion of ν_t means that in practice, $Post_k$ drops out of the estimating analysis. The choice of omitted category in our dump-specific fixed effects is arbitrary and in our analysis, it is the Ghanain dump, Agbogbloshie.

pollution from the site. We estimate the following equation:

$$Y_{ijt} = \beta_0 + \beta_1 Post_t + \beta_2 DIST_{ij} + \beta_3 Post_t \times DIST_{ij} + \nu_t + \epsilon_{ijt} \tag{2}$$

Here, $DIST_{ij}$ is the continuous distance variable ($0km \leq DIST_{ij} \leq 20km$). In this specification, we expect distance to the e-waste dumping site to have no effect on health outcomes for children born before the creation of the site ($\beta_2 = 0$), 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 relatively to those further away.

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

$$Y_{ijt} = \beta_0 + \beta_1 D_{ij} + \sum_{k=-4}^{k=5} \gamma_k 1\{K_{it} = k\} + \sum_{k=-4}^{k=5} \gamma_k 1\{K_{it} = k\} \times D_{ij} + \alpha_i + \epsilon_{ijt}, \tag{3}$$

Here, we replace our dummy $Post_k$ from equation 1, with a more flexible specification in which we include dummies for lags and leads relative to the creation of the dump $\sum_{k=-4}^{k=5} \gamma_k 1\{K_{it} = k\}$; the omitted category being 5 years prior to the creation of the dump ($k = -5$). In all other respects equation 3 mirrors that of equation 1. We similarly perform this extended analysis for our measure of treatment intensity (distance in km) as given in equation 2.

The validity of our empirical strategy relies on the assumption that the polluting effects of the dumping site 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 dumping site. While the common trends assumption cannot be tested, the event study analysis above allows us to test for differences in pre-dump trends in health outcomes for children living close and far from the site location.

Yet, other unobserved time-varying factors correlated with the creation of the dump and affecting differently areas closer and farther from the site could challenge the validity of our results. In particular, one concern might be dump-induced migration. Specifically, if families in relatively worse/better health conditions had moved in the proximity of the site this would bias our results. In section 6 we investigate whether this is a concern in two ways; first, by comparing the characteristics of women in our sample interviewed before and after the e-waste sites were established, and second by estimating the relationship for non-migrant households only. A caveat to the second approach is that there is limited information on years of residence in these particular DHS surveys,[21] and we are only able to perform the latter robustness check for Ghana. In addition, since we are able

[21] Although in DHS survey rounds V and VII information on years of residency were collected, in DHS

to observe children born from the same mother before and after the creation of the dump, in a further robustness check we are able to show a specification including mother fixed effects. This allows us to mitigate the concerns about unobserved heterogeneity in residential sorting. On the other hand, however, it does considerably restrict our sample and, therefore, requires further considerations that will be discussed below.

5 Results

5.1 Distance and mortality: a non-parametric approach

Figure 2 shows the local polynomial smooth for the relationship between distance from e-waste dumping site and mortality before and after site creation. The graphs demonstrate that, prior to the existence of the dumps, there was no relationship between distance and mortality, for either neonatal or infant mortality. In the post-dump period, there is a sharp increase in mortality in the immediate vicinity of dumps which persists for around 5km, before declining sharply until approximately 11km (indicated on the graphs), at which point the relationship begins to flatten out. The graph also shows that areas outside of the dump vicinity experienced declining mortality in the post-dump period, consistent with general improvements in health over time. Results for individual dumps are shown in Figure A.2 of the Appendix and show consistent results in both countries.

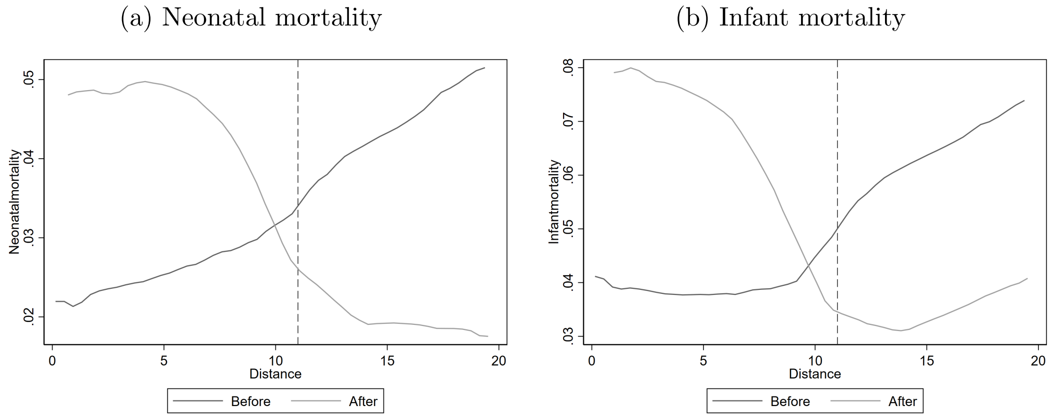
We use the evidence from this graphical exercise to inform our analysis, considering children living within 11km from the dump as being 'treated', i.e. exposed to pollution from the e-waste. This assumption is relaxed when we consider our distance measure which captures intensity of treatment.

5.2 Main results

Regression results from the difference-in-difference specification in equation 1 are reported in table 2. Estimates of our coefficient of interest ($Post_t \times D_{ij}$) indicate a significant increase in mortality in the post-dump period, for children living in the vicinity of the dump, compared to those living outside the treatment area. Children born within the vicinity of an e-waste site are 4.5 (6.5) percentage points more likely to die in the first month (year) of life. These effects are large relative to the mean, which in the whole sample over the whole 10-year pre- and post- period is 3.3 (5.0)% respectively. These large effects are reflective of the very sharp 2-4 fold increase in mortality that occurred

rounds VI, which make up the bulk of our surveys, this information was not collected. We therefore have no information on residency in the surveys for Nigeria conducted in 2010, 2013 and 2015, so that we have very limited information on residency in the post-dump period.

Figure 2: Non-parametric estimation: distance and neonatal (left) and infant (right) mortality



Authors' calculation based on the DHS data. Includes both dumping sites. For consistency between the two countries we consider a common number of years before and after the dump. The plots are created by estimating a kernel-weighted local polynomial regression (bandwidth = 2.5) of distance from dump on mortality.

in the post-dump period in treatment areas in our sample (Figure 1).

Panel B shows the results of estimating equation 2 where the continuous distance from the e-waste site is used as a measure of treatment intensity. Results show that the effect of distance becomes negative and significant only after the e-waste site was 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 relatively to those further 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 further away, though this relationship is weak (significant only at the 10% level) for neonatal mortality.[22] In appendix table A.2 we show estimates separately for each site in Ghana and Nigeria, and we find similar results, with effect sizes broadly similar, particularly for neonatal mortality.[23]

Results of the event study analysis (equation (3)) are reported in Figure 3 and show that the increase in mortality observed in the post-site period is driven by effects that emerge three years post dump creation, and becomes stronger over time. This is consistent with build up of contaminants in the environment such that the effect of e-waste sites increases with time due to increasing pollution of the surrounding areas. The plot also supports the validity of the empirical design above, showing no evidence of differential

[22]For neonatal mortality then, this implies that distance was not correlated in any direction with health outcomes prior to the creation of the dump

[23]The effect sizes for neonatal (infant) mortality for living within 11 km of the dump in the post period for the Ghananian and Nigerian sites are 4.9 (8.9) and 4.3 (5.4) percentage points, respectively.

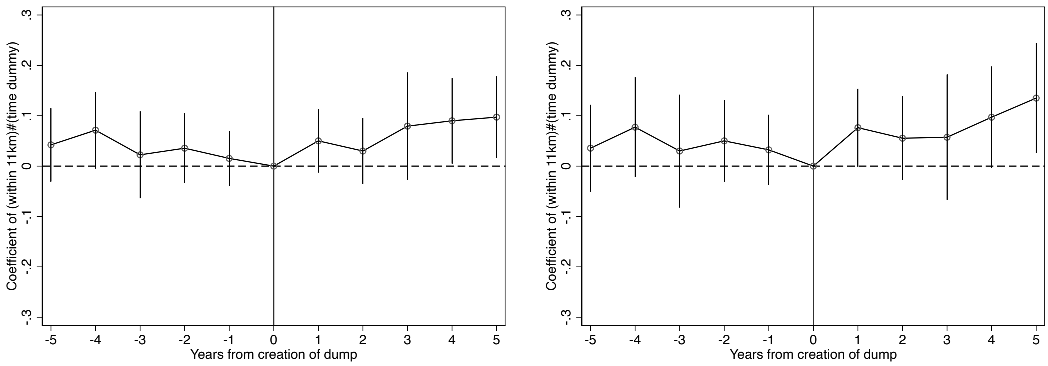
Table 2: The impact of e-waste sites on newborn and infant health

	(I) Neonatal Mortality	(II) Infant Mortality
A: Within 11km of dump		
Within 11km	−0.013	−0.027**
	(0.011)	(0.013)
Post × Within 11km	0.045***	0.066***
	(0.014)	(0.022)
B: Distance in km		
Distance (km)	0.002*	0.003**
	(0.001)	(0.001)
Post × Distance (km)	−0.006***	−0.007***
	(0.002)	(0.002)
Mean mortality	0.033	0.050
Observations	2341	2151
Dump FE	Yes	Yes
Year of Birth FE	Yes	Yes

Standard errors (in parenthesis) are clustered at the DHS cluster level. *** p-value < 1%, ** p-value < 5%, * p-value < 10%. Post is a dummy variable indicating a child was born after the creation of the dump site (For Ghana, t = 2001; for Nigeria, t = 2006). Within 11km is a dummy variable for living within 11km of the dump site. Post × Within 11km is the interaction term indicating the treatment effect. Children born between 5 years pre- and 5 years post are included in the analysis; for Ghana this is 1996-2006 and for Nigeria this is 2001-2011.

effects in health outcomes across groups before the creation of the site. Results for individual dumps are shown in Figure A.3 and Figure A.4 of the Appendix and show consistent results in both countries.

Figure 3: Event study for neonatal (left) and infant (right) mortality: binary treatment



Authors' calculation based on the DHS data. Includes both e-waste sites. For consistency between the two countries we consider a common number of years (5) before and after the dump. The plots are created by a linear regression of mortality on a full set of event time indicators (years from dump) interacted with a dummy indicating whether the household lives within 11Km from the site and controlling for country and year fixed effects. The vertical lines indicate 95% confidence intervals.

We find similar results when considering a continuous treatment measure given by the distance from the dumping site. Event study results are presented in Figure 4 and confirm that the distance to the dumping site did not play any significant role in explaining neonatal and infant mortality of children born before the creation of the dump. The negative effect of distance in the post-dump period confirms that children born in the proximity of the site face greater chance of death than those living further away.

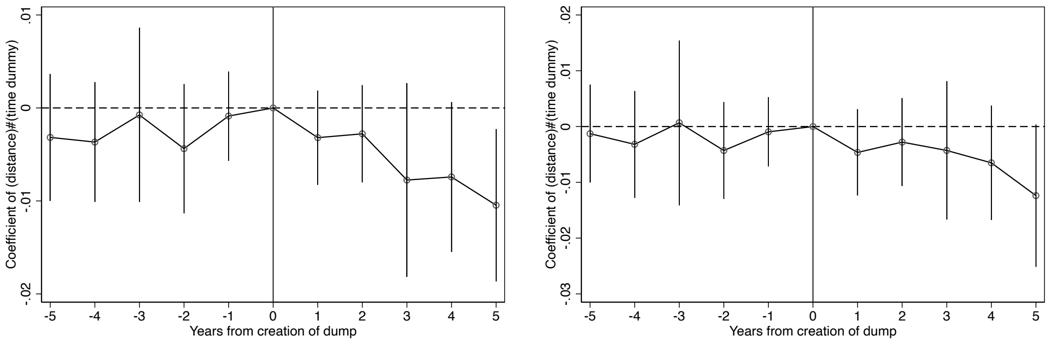
Overall, evidence from estimates of equations (1) - (3) suggest that proximity to e-waste sites has a significantly negative impact on newborn and early life health, increasing the risk of mortality for those exposed to the e-waste sites. This risk decreases with distance, and appears to emerge around 3 years after the creation of the e-waste sites.

6 Robustness checks

The results presented so far suggest that exposure to an e-waste dumping site causes an increase in both neonatal and infant mortality. In this section we provide further support to our results by providing a set of robustness checks with the aim of a) removing potential confounding effects, b) investigating alternative samples and c) considering

Figure 4: Event study for neonatal (left) and infant (right) mortality: intensity of treatment

(a) Neonatal mortality (b) Infant mortality



Authors' calculation based on the DHS data. Includes both e-waste sites. For consistency, we consider a common number of years (5) before and after the dump for both countries. The plots are created by a linear regression of mortality on a full set of event time indicators (years from dump) interacted with distance from the dump (in km) and controlling for country and year fixed effects. The vertical lines indicate 95% confidence intervals.

whether alternative explanations other than the presence of e-waste sites might drive our results.

6.1 Inclusion of additional controls

Though we find limited evidence of differences in compositions of births between areas (see section 3), we investigate robustness of our results to the inclusion of a set of additional control variables. These include a vector of control variables at both child and household level, as well as country (i.e. dump-specific) time trends. We include urban status, mother's age at birth, mother and father's educational level, mother age at birth, and the child's gender and whether the birth was a multiple birth.[24]

A further concern might be that the decision to locate a dumping site in a particular location was determined by characteristics of the surrounding area, where such characteristics of the area also affect mortality. This would violate our identification assumption that there are no time-varying or cluster-specific effects correlated with the dump site location that also determine mortality. Our estimate could then confound the effect of the dump with changes in other characteristics of the area that also affect mortality. We therefore also investigate the inclusion of interactions between cohort dummies and

[24]Father's education level is not available for the Nigeria MIS-DHS surveys, so that these surveys are not included in this analysis. Our results are robust to dropping controls for father's education and including MIS-DHS surveys in the following robustness checks (results available on request).

variables that capture urbanisation extent and local economic activity at the cluster level prior to the existence of the dump sites. To capture urbanisation extent, we use data provided in the DHS spatial co-variates file on the built-up index of a cluster. This is an index ranging from 0 (extremely rural) to 1 (extremely urban) for the area within the 2 km (urban) or 10 km (rural) buffer surrounding the DHS survey cluster location.[25] It is available for either 1990 or 2000, and we use 1990, which is prior to both the Ghanaian and Nigerian sample time frames. For local economic activity, we use nightlight data as a proxy for local economic activity, sourced from the National Oceanic and Atmospheric Administration (NOAA).[26] Figures A.5 and A.6 show variation in nightlight data in 1995, 2000, 2005 and 2010 for Ghana and Nigeria and demonstrate that, over the time period we consider, both areas have become more developed, with increases in nightlight intensity seen. They also show that, in 1995, areas nearer the dump sites were those where more economic activity was observed. We therefore calculate the average 1995 nightlight value for the area within the 2 km buffer of our clusters, and include this in the analysis.[27]

Our results are robust to the inclusion of additional control variables, and to the interaction of cohort dummies with built-up extent in 1990 and local economic activity in 1995 (Table 3, and our coefficients of interest are unchanged by their inclusion.

6.2 Residential sorting

We next focus on the potential residential sorting induced by the creation of the dump, i.e. the possibility that families in relatively worse/better health conditions have been attracted or displaced by the creation of the dump. As described in section 3, our sample of women is drawn from surveys carried out in Ghana in 1998, 2003 and 2008, whilst for Nigeria we have surveys from 2003, 2008, and 2013. Thus, we observe women interviewed before and after the e-waste sites were established.[28] Table 4 therefore considers the composition of the 1302 *women* in our sample, interviewed before and after the e-waste sites were established, as well as separately for treatment and control groups. Note that this differs from Table A.1, which considers compositions of *births*, which are retrospectively reported by women at the time of the survey.

There is very little evidence of changes in the composition of women living within 20km of e-waste sites, with the few observed differences only statistically significant at the

[25]In our sample, just 7 of the 180 clusters are classified as rural by the DHS.

[26]We use the DMSP-OLS Nighttime Lights Time Series which is available from 1992-2013. This has been used by a number of recent studies to consider economic activity at a localised level; see Donaldson and Storeygard (2016) for a discussion of the uses of this data in economics.

[27]Average nightlight values within the 2km buffer were calculated by the Authors in ArcGIS Pro, through overlaying the gridded nightlights data over the cluster locations and computing zonal statistics within 2km buffers of the cluster points.

[28]Recall, the Ghananian e-waste site was opened in 2001 and the Nigerian site in 2006.

Table 3: The impact of dumping sites on newborn and infant health: additional controls

	(I)	(II)	(III)	(IV)	(V)	(VI)	(VII)	(VIII)	(IX)	(X)
			Neonatal Mortality					Infant Mortality		
A: Within 11km of dump										
Within 11km	–0.009	–0.008	–0.009	–0.010	–0.011	–0.022*	–0.018	–0.015	–0.016	–0.015
	(0.010)	(0.011)	(0.013)	(0.012)	(0.013)	(0.012)	(0.013)	(0.015)	(0.014)	(0.014)
Post × Within 11km	0.039***	0.042***	0.037**	0.039**	0.042**	0.055**	0.059**	0.048**	0.053**	0.051**
	(0.014)	(0.016)	(0.017)	(0.015)	(0.017)	(0.022)	(0.024)	(0.022)	(0.022)	(0.021)
Mean	0.033	0.036	0.036	0.036	0.036	0.050	0.055	0.055	0.055	0.055
N	2341	2030	2030	2030	2030	2151	1871	1871	1871	1871
B: Distance in km										
Distance (km)	0.002	0.001	0.002	0.002	0.002*	0.002*	0.002	0.002	0.002	0.002
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Post × Distance (km)	–0.005***	–0.005***	–0.005***	–0.005***	–0.005***	–0.006**	–0.006*	–0.004*	–0.005*	–0.005*
	(0.001)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.003)	(0.002)	(0.003)	(0.002)
Mean	0.033	0.036	0.036	0.036	0.036	0.050	0.055	0.055	0.055	0.055
N	2341	2030	2030	2030	2030	2151	1871	1871	1871	1871
Dump FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
YOB FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Dump-trends	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
X Controls	No	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes
Nightlights	No	No	Yes	No	Yes	No	No	Yes	No	Yes
Built-up Presence	No	No	No	Yes	Yes	No	No	No	Yes	Yes

Standard errors (in parenthesis) are clustered at the DHS cluster level. . *** p-value < 1%, ** p-value < 5%, * p-value < 10%. See notes to table 2. *X* Controls include urban status, mother's age at birth, mother and father's educational level, mother age at birth, and the child's gender and whether the birth was a multiple birth. 'Nightlights' refers to the interaction of cohort dummies with the average nightlight value in a 2km buffer around the cluster in 1995. 'Built-up Presence' refers to the interaction of cohort dummies with the DHS spatial variable indicating degree of urbanisation in a 2 (5) km buffer around urban (rural) clusters in 1990.

10% level, and no differences between treatment and control zones. For example, whilst the population interviewed after the sites are established tend to be younger at time of interview, this does not differ between the treatment and control zones.[29] Similarly, spousal education appears to be lower amongst the interviewed population after the sites are established but this pattern does not differ between treatment and control zones. Women at the time of the survey are marginally (at 10% level) less likely to be employed, although there are no statistically significant differences in employment status over the last 12 months. Overall, table 4 suggests that there are very few differences in composition of households interviewed before and after the e-waste dumping sites were established. Appendix Table A.3 repeats this for the specific e-waste sites and finds similar patterns; again differences are only ever statistically significant at the 10% level, and rarely in the case of Nigeria.

Nonetheless, to further address any concerns regarding residential sorting we re-estimate equations 1 and 2, and restrict the sample to non-migrant households, i.e. households that we know were living in the same location prior to the creation of the dumping site, hence excluding possible inward migrants. We are only able to do this for Ghana since residency information is not collected in the 2010 or 2013 surveys for Nigeria.[30] From our original sample, we lose 1,536 observations due to dropping Nigeria from the analysis, and a further 268 due to omission of inward migrants, who make up 33.3% of our original Ghana sample. That is, 33.3% of our Ghana sample in the earlier analysis is made up of in-ward migrants. As we might expect, the majority (198) of observations that we lose occurs in the 2008 survey, since our restriction here implies that they must have been living in the area since 2000 (8 years).

Regression results are given in Table 5, and the event study analysis is presented in Figure 5. These results confirm our previous findings and indicate a negative effect of the Agbogbloshie dump site on infant mortality for non-migrant households, and finds similar results when considering the full Ghananian sample (columns (I) and (III)), as compared to the non-migrant sample (columns (II) and (IV)). Our point estimate for neonatal mortality is almost identical, whilst for infant mortality it is slightly larger.

Next, we re-estimate equations (1) and (2) for non-migrants, and include mother FE, so as to compare outcomes for siblings born before and after the creation of the Agbogbloshie e-waste site. Compared to results in table 5, the DID coefficients for infant mortality are of a similar magnitude: children born within 11km of the e-waste site after

[29] This could also be due to the restriction on inclusion in the sample, which is that the woman must have given birth between 1996-2006. This means that older women interviewed in 2003 are potentially more likely to be included since we are including older births.

[30] Although residency information is collected in 2008, this only gives us information on deaths in the 1-2 year period post dump.

Table 4: Composition of women in sample before and after e-waste sites

	All women interviewed within 20km of dumping site				Women interviewed within treatment zone				Women interviewed within control zone			
	Before	After	Difference	N	Before	After	Difference	N	Before	After	Difference	N
Woman age	32.824	28.761	-4.063*	1302	32.532	28.229	-4.303*	658	33.096	29.976	-3.120*	644
Spouse age	40.104	37.437	-2.667*	850	39.465	35.825	-3.640*	455	40.800	40.500	-0.300	395
Urban	0.944	1.000	0.056*	1302	1.000	1.000	0.000	658	0.892	1.000	0.108*	644
No Schooling	0.082	0.159	0.077*	1302	0.082	0.159	0.077*	1302	0.082	0.159	0.077*	1302
Completed Primary	0.177	0.188	0.011	1302	0.169	0.188	0.018	658	0.184	0.190	0.006	644
Completed Secondary	0.603	0.601	-0.002	1302	0.621	0.583	-0.038	658	0.586	0.643	0.056	644
Completed Higher	0.137	0.051	-0.087*	1302	0.123	0.042	-0.081*	658	0.151	0.071	-0.080	644
Spouse No Schooling	0.044	0.081	0.036*	1094	0.044	0.081	0.036*	1094	0.044	0.081	0.036*	1094
Spouse Completed Primary	0.130	0.121	-0.009	1094	0.096	0.071	-0.024	576	0.165	0.225	0.060	518
Spouse Completed Secondary	0.610	0.637	0.027	1094	0.638	0.690	0.052	576	0.582	0.525	-0.057	518
Spouse Completed Higher	0.215	0.161	-0.054	1094	0.211	0.143	-0.069	576	0.220	0.200	-0.020	518
Employed	0.824	0.754	-0.071*	1175	0.798	0.760	-0.038	631	0.853	0.738	-0.114*	544
Employed (last 12 months)	0.834	0.812	-0.022	1184	0.834	0.812	-0.022	1184	0.834	0.812	-0.022	1184

*** p-value < 1%, ** p-value < 5%, * p-value < 10%.

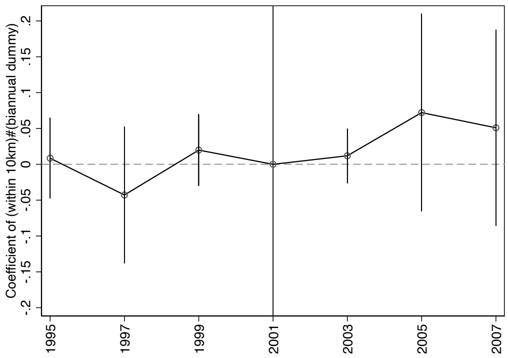
Table 5: The impact of dumping sites on newborn and infant health: non-migrants only, Ghana

	(I)	(II)	(III)	(IV)
	Neonatal Mortality		Infant Mortality	
	All	Non-migrants	All	Non-migrants
A: Within 11km of dump				
Within 11km	–0.012	0.001	–0.043	–0.036
	(0.021)	(0.019)	(0.028)	(0.033)
Post × Within 11km	0.049*	0.053*	0.089**	0.135***
	(0.025)	(0.031)	(0.038)	(0.048)
B: Distance in km				
Distance (km)	0.001	–0.000	0.002	0.002
	(0.002)	(0.002)	(0.003)	(0.003)
Post × Distance (km)	–0.005*	–0.004	–0.008*	–0.012**
	(0.002)	(0.003)	(0.004)	(0.005)
Mean mortality	0.030	0.028	0.051	0.049
N	805	537	727	469
Year of Birth FE	Yes	Yes	Yes	Yes

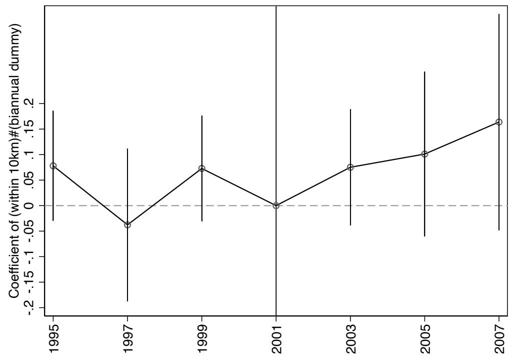
Standard errors (in parenthesis) are clustered at DHS cluster level. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. Post is a dummy variable indicating a child was born after the creation of the Agbogbloshie site (t = 2001). Within 11km is a dummy variable for living within 11km of the Agbogbloshie site. Post × Within 11km is the interaction term indicating the treatment effect. Children born between 1996 (5 years pre) and 2006 (5 years post) are included in the analysis. Non-migrants refers to the restricted sample where the mother has been resident in the household prior to the creation of the Agbogbloshie dump site.

Figure 5: Event study for neonatal (left) and infant (right) mortality: non-migrant households (Ghana only)

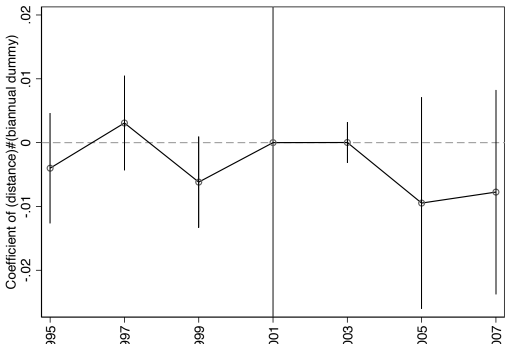
(a) Neonatal: binary treatment



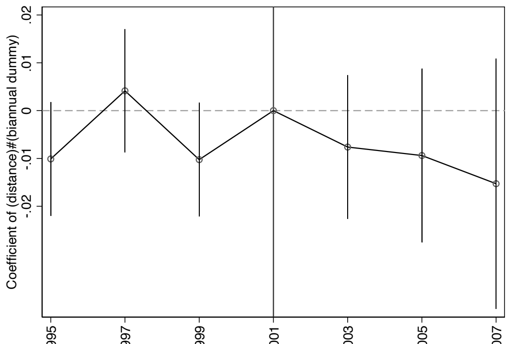
(b) Infant: binary treatment



(c) Neonatal: distance from dump



(d) Infant: distance from dump



Authors' calculation based on the DHS data for Ghana. The plots are created by a linear regression of mortality on a full set of event time indicators (biannual) and year of birth fixed effects. Biannual time indicators are used due to small sample sizes to increase precision, and children born 6 years after dump creation are included in the analysis. Results using distance from the dump are obtained by interacting the biannual time indicator with distance from the dump (in Km). The vertical lines indicate 95% confidence interval.

the dump are 12.1 percentage points more likely to die than their siblings born before the dump was created (Table 6). The effect of distance after the dump is also remarkably similar to the analysis that does not include mother FE. When we consider neonatal mortality however, we do not find evidence of statistically significant differences between children born to the same mothers before and after the e-waste site creation.

Overall, taken together, tables 4, A.3, 5 and 6 suggest that residential sorting arising as a result of the establishment of the dump sites does not drive our main results.

Table 6: The impact of dumping sites on newborn and infant health: mother FE, non-migrants only

	(I)	(II)	(III)	(IV)
	Within 11km		Distance	
	Neonatal Mortality	Infant Mortality	Neonatal Mortality	Infant Mortality
Post × Within 11km	−0.009	0.121*		
	(0.043)	(0.071)		
Post × Distance (km)			−0.002	−0.015**
			(0.004)	(0.007)
N	521	455	521	455
Mother FE	Yes	Yes	Yes	Yes
Year of birth FE	Yes	Yes	Yes	Yes
N	487	422	487	422

Standard errors (in parenthesis) are clustered at mother level. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. Post is a dummy variable indicating a child was born after the creation of the Agbogbloshie site (t = 2001). Within 11km is a dummy variable for living within 11km of the Agbogbloshie site. Post × Within 11km is the interaction term indicating the treatment effect. Children born between 1996 (5 years pre) and 2006 (5 years post) are included in the analysis. Non-migrants refers to the restricted sample where the mother has been resident in the household prior to the creation of the Agbogbloshie dump site.

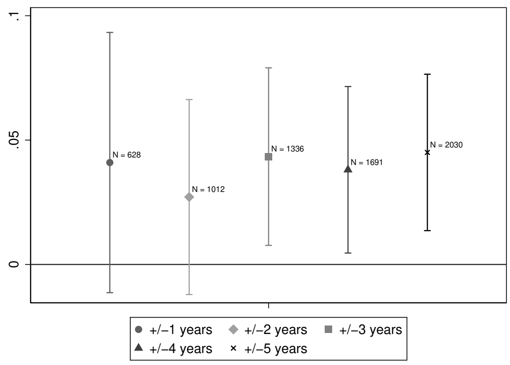
6.3 Varying the time window used in the analysis

Our main analysis focuses on the five year period pre- and post- e-waste dumping site establishment. Here, we investigate how our estimates vary when we investigate different samples - for 1-4 years pre- and post- site opening.

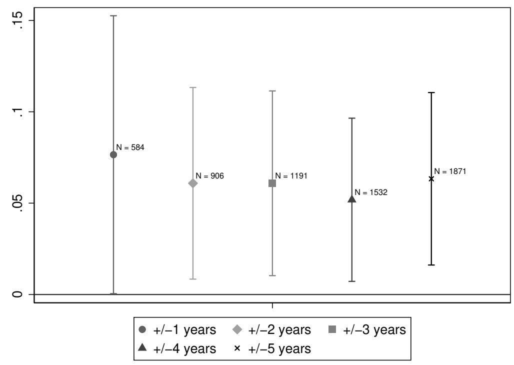
Figure 6 shows estimated coefficients and 95% confidence intervals for different time windows. Overall the coefficients from our main analysis (+/- 5 years) are fairly stable, but in general they become attenuated and insignificant for smaller windows of time, consistent with the smaller sample sizes and a shorter time frame within which contaminants can be built up in the environment (for example, children born in the year after the site was established are exposed to only up to 2 years build up of contaminants in the first year of their life). Overall, however, our results are broadly consistent, particularly when including children from 3 years post site creation.

Figure 6: Investigating sample windows in analysis

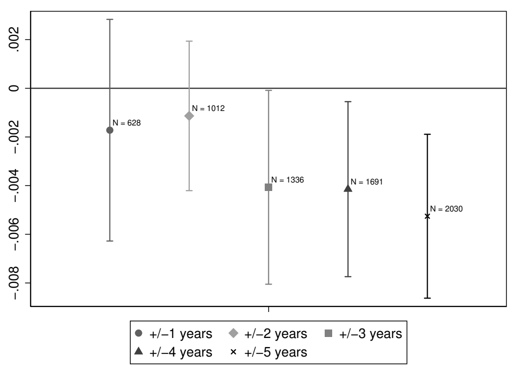
(a) Neonatal: binary treatment



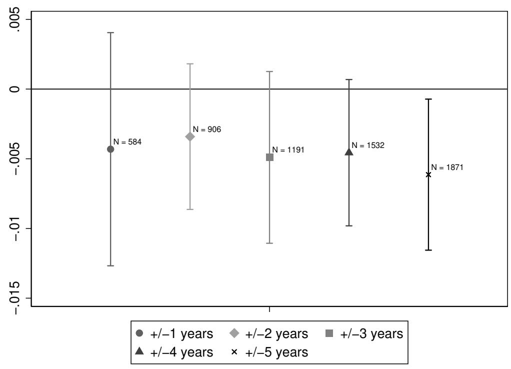
(b) Infant: binary treatment



(c) Neonatal: distance from dump



(d) Infant: distance from dump



Plots show estimated coefficients from estimating equations 1 and 2 for various sample windows from +/- 1 year dump creation to +/- 5 years dump creation. N is sample size of the analysis. The vertical lines indicate 95% confidence interval.

6.4 Slum effects

One concern with our results might be that we are not picking up effects of the dumping site, per se, but other poor environmental conditions for children, such as living in the proximity of slum areas. The Agbogbloshie site in Ghana is located in the proximity of three major slum areas (Figure A.10). In particular, it is contiguous to one of the largest slums in Accra: Old Fadama, also known as Sodom and Gomorrah. This slum area was estimated to host about 30,000 residents in 2004 (Oppong et al., 2020) and is classified as one of the four major extralegal settlements in Ghana (Paller, 2015).[31] While we are not aware of specific policies affecting the livelihood of slum residents during the period of analysis, we are still concerned about the possible confounding effects of deteriorating living conditions in the slum areas surrounding the site. Indeed, evidence suggests that the health of urban children in slums is poorer than urban children in non-slum areas (Fink et al., 2014).

To investigate whether the effects we find for the Agbogbloshie site in Ghana might reflect slum-related effects, we estimate a placebo regression using a similar-size slum area in Kumasi, the second largest city in Ghana. The Aboabo settlement in Kumasi is an extralegal slum that hosted about 34,000 residents in 2000 (Dakpallah, 2011) and is also located within the urban centre. Figure A.11 shows the location of the DHS clusters used in the placebo analysis. We re-estimate equations 1 and 2, using the households within 11 Km from Adoabo slum as a placebo treatment, and maintaining the treatment year as 2011.

Table 7 shows results from this analysis. Whilst mortality is higher within 11km of the slum (and declines with distance from the slum), there is no differential effect of the slum in the post e-waste site period (i.e, $\beta_3 = 0$). Thus, results from the placebo analysis do not suggest that changes occurring in slums in Ghana after the e-waste site was established are driving our results in the main analysis.

6.5 Olushosun waste site, Nigeria

In the analysis above we have not used data on the larger Olushosun dump in Lagos, as this site was established in 1992 as a generic landfill and only later became a dumping site for e-waste. In this section, we argue that the dumping of e-waste at Olushosun is likely to have started around 1998 and, to further corroborate our previous results, we estimate the effect of living in the proximity of the Olushosun site on neonatal and infant mortality.

Nowadays the majority of e-waste processed in West African countries is domestically generated out of the consumption of new or used electronic (Schluep et al., 2011). However, over our period of analysis, a larger share of e-waste is likely to have been generated from the international flow of used and end-of-life EEE from more advanced economies, which were used for a short number of years or immediately discarded. For example, personal computers (PCs) were first introduced in the 70s but became more widely ac-

[31] Settlements in Ghana can be classfied according to three types: indigenous (landlords are indigenous and local customs dominate local politics), purchased (when neighbourhoods formed historically when settlers purchased plots of land from authorities), and extralegal. Only indigenous settlements are recognised by the government, and extralegal settlements in particular are associated with poor quality housing such as shacks and kiosks (Paller, 2015).

Table 7: Placebo analysis: Adoabo slum

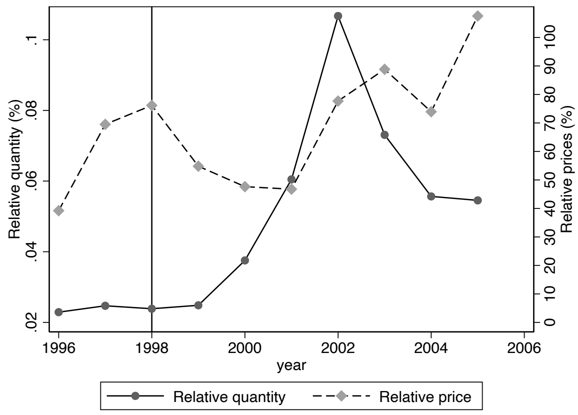
	(I) Neonatal Mortality	(II) Infant Mortality
A: Within 11km of dump		
Within 11km	0.040***	0.023
	(0.014)	(0.029)
Post × Within 11km	0.002	0.043
	(0.020)	(0.036)
B: Distance in km		
Distance (km)	–0.004**	–0.005**
	(0.001)	(0.002)
Post × Distance (km)	0.003	0.002
	(0.002)	(0.004)
Mean mortality	0.042	0.071
N	755	691
Year of birth FE	Yes	Yes

Standard errors (in parenthesis) are clustered at the DHS cluster level. *** p-value $<$ 1%, ** p-value $<$ 5%, * p-value $<$ 10%. Post is a dummy variable indicating a child was born after 2001. Within 11km is a dummy variable for living within 11km of the Adoabo slum. Post × Within 11km is the interaction term indicating the placebo treatment effect. Children born between 1996 (5 years pre) and 2006 (5 years post) are included in the analysis.

cessible only during the early 90s. Hence, given the average life-span of about 5 years for a computer at the time (Ogungbuy et al., 2012), an international market for second-hand laptops and PCs is likely to have emerged during the late 90s. Unfortunately, data on EEE imports does not distinguish between new and used EEE, although evidence suggests that as late as 2009 around 70% of all imported EEE in Ghana was used and 35% in Nigeria in 2011. It has been argued that the lower percentage found in Nigeria is due to government enforcement at that time of laws against importing used EEE and that in earlier time periods - such as the 90s, which we consider here - the percentage of imports that were used EEE are likely to similar to those observed in Ghana (Schluep et al., 2011).

Absent information on the condition of imported EEE we infer volumes of imported used EEE by considering EU15 exports of automatic data-processing machines (mostly laptops and personal computers) towards Nigeria in the 1990s. Figure 7 plots the evolution of relative prices and quantities exported to Nigeria from the EU in this time period. Over the period of analysis, we observe a generalised decline in computing equipment prices, and we therefore use relative prices to capture relative differences in quality of items exported to Nigeria. The graph shows a sharp decline in relative prices and a sharp increase in the percent of exports of computing equipment towards Nigeria starting from 1998. For example, items exported to Nigeria in 1999 cost half the average price of products exported by EU15 countries. This pattern is indicative of an increase in the export of lower-price computing equipment, which we assume most likely to include second-hand items. A similar pattern is observed for Ghana (Figure A.7, left panel) since 1999. The decline in the average import price is, however, less sharp, with relative prices already low. Yet, the remarkable increase in the import of computing equipment that is 80% cheaper than the average exported products, is still indicative of a substantially lower-quality, and is more likely to include second-hand products. Instead, this is not the case for more advanced economies, as for example in the case of Poland shown in Figure A.7, right panel. This suggestive evidence points toward 1998 being a key year for the international flow of second-hand and end-of-life computing products to Nigeria. It is also consistent with the creation of Ghana's Agbogbloshie site a few years later in 2001.

Figure 7: EU (15) exports of computing equipment to Nigeria



Authors' calculation based on Comext data. Data refers to the product category 8471: Automatic data-processing machines. Quantity indicates net mass (weight of goods in kg without packaging). Relative prices are computed as the unit value of goods exported to Nigeria over the overall average export price in percentage terms. Relative quantity is given by the percentage of total EU export to Nigeria.

We show the effect of living in the proximity of the Olushosun dump site on infant and neonatal mortality, estimating equations 1 and 3 and specifying treatment as the year 1998. Table 8 shows the DID results and A.8 the resulting event study. We consider the period up to 2005 which precedes the creation of the nearby Soluos dumpsite in 2006, investigated above. Note that our 'treatment' here is an estimated date from which e-waste became a significant waste stream at the dump, but that 1992 was the year in which the dump was created. Therefore all children in our analysis were exposed to the existence of the dump site, but what differs is the extent to which the children were exposed to e-waste.

While individual effects are estimated with low precision, the overall effect from the difference-in-differences estimates in Table 8 indicates a negative effect on child health. This is larger and more precisely estimated in the case of infant mortality, indicating that proximity to the dump after e-waste was likely to be a significant waste stream increased infant mortality substantially, by almost 15 percentage points; average mortality over the period was at 7.5%. When we consider non-migrants only i.e. those who were already living in the dump prior to it's creation, the effects are larger, and more precisely estimated, though sample sizes are small due to this restriction.[32] The event study analysis, shown in figures A.8 and A.9, whilst imprecise, support these results, and further show that effect sizes rise over time, in line with our main analysis and consistent with the build up of contaminants in the environment.

Table 8: Olushosun waste site, Nigeria

	(I)	(II)	(III)	(IV)
	Neonatal Mortality		Infant Mortality	
	All	Non-migrants	All	Non-migrants
A: Within 11km of dump				
Within 11km	0.000	0.004	–0.007	–0.065
	(0.020)	(0.024)	(0.023)	(0.050)
Post × Within 11km	0.016	0.050	0.048	0.150**
	(0.024)	(0.037)	(0.030)	(0.060)
Mean	0.045	0.037	0.077	0.065
N	1552	218	1510	214
B: Distance in km				
Distance (km)	0.000	–0.001	0.001	0.012*
	(0.003)	(0.003)	(0.003)	(0.007)
Post × Distance (km)	–0.002	–0.003	–0.005	–0.018**
	(0.003)	(0.004)	(0.004)	(0.008)
Mean	0.045	0.037	0.077	0.065
N	1552	218	1510	214
Year of Birth FE	Yes	Yes	Yes	Yes

Standard errors (in parenthesis) are clustered at the DHS cluster level. *** p-value $< 1\%$, ** p-value $< 5\%$, * p-value $< 10\%$. Post is a dummy variable indicating a child was born after e-waste flows increased to Nigeria (t = 1998). Within 11km is a dummy variable for living within 11km of the Olushoshan site. Post × Within 11km is the interaction term indicating the treatment effect. Children born between 1992 (6 years pre) and 2004 (6 years post) are included in the analysis. Migrants are the restricted sample where the mother has been resident in the household prior to the creation of the Olushoshan dump site (t = 1992).

[32] Since we only have information on migrant status in the 2003 and 2008 surveys, we only use these surveys in the Olushosun analysis. The migrant restriction means that we only include individuals resident since 1992 (the year the dump was created). This means that those interviewed in 2008 would have to have lived in the area for 16 years in order to be included in the analysis, which leads to a substantial drop in the sample size.

7 Potential mechanisms: water contamination

As discussed in sections 1 and 2, likely channels through which such e-waste dumpsites can impact on child mortality include pollution through air, water and food. In this section, we investigate one potential channel through which our estimated effect may operate - water contamination - and provide some suggestive evidence regarding routes of exposure.

Often e-waste components stored outside are flooded by heavy rainfall or by the nearby river flooding, as in the case of Agbogbloshie. The run-offs from dumping sites can reach local waterways and possibly also contaminate ground water. Therefore, one possible channel through which water contamination can affect child and maternal health is through the consumption of locally produced contaminated crops and animal products, as discussed in section 2.

To test this hypothesis we focus on Ghana where we can distinguish between children living upstream and downstream the Odaw river, which runs adjacent to the Agbogbloshie dumpsite and ends into the Korle Lagoon before entering the Gulf of Guinea. Urban crop production in Ghana takes two main forms: backyard farming mostly for personal consumption and market-oriented open-space farming on larger plots (Lydecker and Drechsel, 2010). A study by Amoah et al. (2007), for example, finds contaminants in the lettuce produced at two urban cites in Ghana, one of which is located in our treatment area, downstream of the river Odaw. Cattle, goats, and other livestock are also raised for meat consumption and are likely to drink contaminated water. This hypothesis cannot be tested in the case of the Solous site as there are no survey clusters located downstream of the nearest river, which runs at 1 kilometer from the site. Yet, the contamination of groundwater by leachate from the Solous site has been recorded in the literature (Aderemi et al., 2011).

In the analysis that follows, we restrict the treatment group to households living within 5km of the Odaw river. We then consider those living upstream and downstream as shown in Figure A.12 of the Appendix.[33] We re-estimate equations 1 and 2, and our event study analysis, where the treatment group now refers to downstream clusters which are compared to upstream clusters. By comparing pre- and post-dump mortality rates for the two groups, we aim to provided suggestive evidence that the dumping site has increased mortality though increased water contamination. Note that both groups are affected by the Agbogbloshie site but we expect those living downstream to experience greater negative effects due to increased water contamination.

Results are shown in Table 9 and the event study in Figure 8. For neonatal mortality,

[33] To avoid the possibility of confounding downstream with distance to the dump, we exclude from the analysis clusters that are located more than 5 Km from the dump.

we can see that mortality was *lower* prior to the existence of the e-waste site, but that in the post period this was entirely reversed, so that mortality was higher, by 6.5 percentage points ($\beta_1 + \beta_3$). Coefficients for infant mortality follow the same pattern but results are weaker, with less evidence of a differential effect.[34] The event study supports this analysis, and, although the coefficients are imprecisely estimated, they are suggestive of a greater impact for children living downstream, in particular for neonatal mortality. Overall, these results provide some (suggestive) evidence that one route of exposure is through contaminated water.

Table 9: The impact of dumping sites on newborn and infant health: downstream vs. upstream households

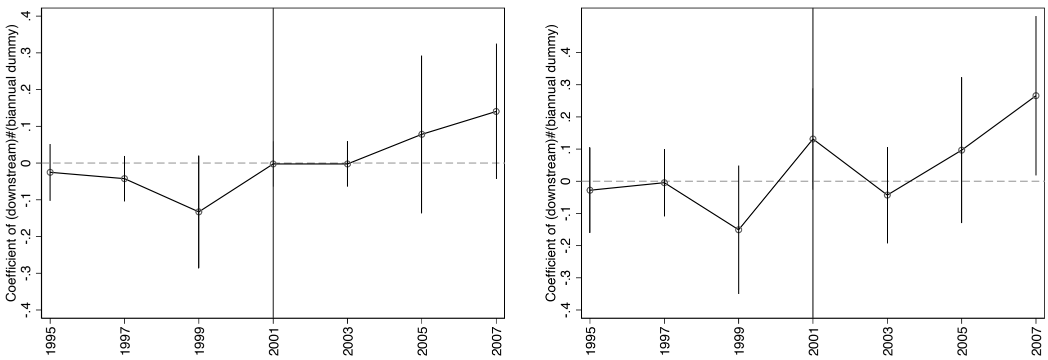
	(I) Neonatal Mortality	(II) Infant Mortality
Downstream	–0.053**	–0.016
	(0.024)	(0.034)
Post × Downstream	0.118***	0.108*
	(0.040)	(0.062)
Mean mortality	0.032	0.059
N	309	270
Year of birth FE	Yes	Yes

Standard errors (in parenthesis) are clustered at mother level. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Figure 8: Event study for neonatal (left) and infant (right) mortality: downstream versus upstream households

(a) Neonatal mortality

(b) Infant mortality



Authors' calculation based on the DHS data for Ghana. The plots are created by a linear regression of mortality on a full set of event biannual time indicators interactd with a dummy variable taking value one for downstream households and controlling for time fixed effects. We consider biannual time indicators rather than annual indicators due to the small sample sizes in this analysis. The vertical lines indicate 95% confidence interval.

[34]Specifically, the effect of β_1 is insignificant and β_3 only significant at the 10% level.

8 Conclusions

This paper estimates the health impacts of e-waste dumping sites on newborn and infant health in Ghana and Nigeria, which are key import routes through which e-waste is shipped to Africa (Schluep et al., 2011). We find that proximity (within 11km) to an e-waste site increases neonatal and infant mortality by 4.5 and 6.5 percentage points, respectively. These effects are large relative to the mean, and reflect sharp observed increases in mortality in communities near to e-waste sites in the post-site period. An alternative specification in which we make no assumptions about treatment distance and consider distance from the e-waste site as intensity of treatment confirms that mortality declines with distance from e-waste sites after their establishment, but not before. We continue to find negative effects on health when we restrict the analysis to non-migrants, and when we consider sibling fixed effects, but data restrictions lead to substantial losses in sample size which affect our ability to precisely estimate effects in these specifications. Preliminary evidence is suggestive of contamination of water sources, and future work intends to investigate this further.

Our work has implications for the regulation of e-waste, in a context in which there is growing concern about both the illegal dumping of e-waste from developed nations to Africa, and the export of near end of life electronics which end up being discarded in the destination country. Our results highlight the importance of growing efforts to re-visit and strengthen the rules on the export of e-waste, and suggest that the practice of e-waste dumping has catastrophic impacts on local communities.

References

Adegun, O. (2013), 'Variation of leachate characteristics from selected dumpsites in lagos, nigeria', *Journal of Applied Sciences in Environmental Sanitation* **8**(4).

Aderemi, A. O., Oriaku, A. V., Adewumi, G. A. and Otitoloju, A. A. (2011), 'Assessment of groundwater contamination by leachate near a municipal solid waste landfill', *African Journal of Environmental Science and Technology* **5**(11), 933–940.

Amoah, P., Drechsel, P., Henseler, M. and Abaidoo, R. (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), 455–466.

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**, 167.

Arceo, E., Hanna, R. and Oliva, P. (2012), 'Does the effect of pollution on infant mortality differ between developing and developed countries? evidence from mexico city', *The Economic Journal* **126**(591), 257–280.

Bakhiyi, B., Gravel, S., Ceballos, D., Flynn, M. A. and Zayed, J. (2018), 'Has the question of e-waste opened a pandora's box? an overview of unpredictable issues and challenges', *Environment international* **110**, 173–192.

Baldé, C. P., Forti, V., Gray, V., Kuehr, R. and Stegmann, P. (2017), *The global e-waste monitor 2017: Quantities, flows and resources*, United Nations University, International Telecommunication Union, and ....

Balogun, I. and Adegun, B. (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., Bigalke, M., Boamah, L., Nyarko, E., Saalia, F. K. and Wilcke, W. (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**, 135–146.

Bergman, Å., Heindel, J. J., Jobling, S., Kidd, K., Zoeller, T. R., Organization, W. H. et al. (2013), *State of the science of endocrine disrupting chemicals 2012*, World Health Organization.

Bernhardt, A. and Gysi, N. (2013), 'The world's worst 2013: The top ten toxic threats', *Blacksmith Institute and Green Cross Switzerland* .

Bimir, M. N. (2020), 'Revisiting e-waste management practices in selected african countries', *Journal of the Air & Waste Management Association* **70**(7), 659–669.

Brigden, K., Labunska, I., Santillo, D. and Johnston, P. (2008), 'Chemical contamination at e-waste recycling and disposal sites in accra and korforidua, ghana'.

Chen, A., Dietrich, K. N., Huo, X. and Ho, S.-m. (2010), 'Developmental neurotoxicants in e-waste: an emerging health concern', *Environmental health perspectives* **119**(4), 431–438.

Currie, J., Greenstone, M. and Moretti, E. (2011), 'Superfund cleanups and infant health', *American Economic Review* **101**(3), 435–41.

Currie, J. and Neidell, M. (2005), 'Air pollution and infant health: what can we learn from california's recent experience?', *The Quarterly Journal of Economics* **120**(3), 1003–1030.

Currie, J., Neidell, M. and Schmieder, J. F. (2009), 'Air pollution and infant health: Lessons from new jersey', *Journal of Health Economics* **28**(3), 688 – 703.

Currie, J. and Walker, R. (2011), 'Traffic congestion and infant health: Evidence from e-zpass', *American Economic Journal: Applied Economics* **3**(1), 65–90.

Currie, J., Zivin, J. G., Mullins, J. and Neidell, M. (2014), 'What do we know about short- and long-term effects of early-life exposure to pollution?', *Annual Review of Resource Economics* **6**(1), 217–247.

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., Stoler, J. and Grant, R. J. (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., Akese, G. and Garb, Y. (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.

Donaldson, D. and Storeygard, A. (2016), 'The view from above: Applications of satellite data in economics', *Journal of Economic Perspectives* **30**(4), 171–98.

Feldt, T., Fobil, J. N., Wittsiepe, J., Wilhelm, M., Till, H., Zoufaly, A., Burchard, G. and Göen, T. (2014), 'High levels of pah-metabolites in urine of e-waste recycling workers from agbogbloshie, ghana', *Science of the Total Environment* **466**, 369–376.

Fink, G., Günther, I. and Hill, K. (2014), 'Slum residence and child health in developing countries', *Demography* **51**(4), 1175–1197.

Forti, V., Balde, C. P., Kuehr, R. and Bel, G. (2020), 'The global e-waste monitor 2020: Quantities, flows and the circular economy potential'.

Forti, V., Baldé, K. and Kuehr, R. (2018), 'E-waste statistics: Guidelines on classifications, reporting and indicators'.

Gennaioli, C. and Narciso, G. (2017), Toxic roads: Unearthing hazardous waste dumping, CGR Working Papers 82, Queen Mary, University of London, School of Business and Management, Centre for Globatlisation Research.

Grant, K., Goldizen, F. C., Sly, P. D., Brune, M.-N., Neira, M., van den Berg, M. and Norman, R. E. (2013), 'Health consequences of exposure to e-waste: a systematic review', *The lancet global health* **1**(6), e350–e361.

Grant, R. and Oteng-Ababio, M. (2012), 'Mapping the invisible and real african economy: urban e-waste circuitry', *Urban Geography* **33**(1), 1–21.

Greenstone, M. and Hanna, R. (2014), 'Environmental regulations, air and water pollution, and infant mortality in india', *American Economic Review* **104**(10), 3038–72.

He, G. and Perloff, J. M. (2016), 'Surface water quality and infant mortality in china', *Economic Development and Cultural Change* **65**(1), 119–139.

Heacock, M., Kelly, C. B., Asante, K. A., Birnbaum, L. S., Bergman, Å. L., Bruné, M.-N., Buka, I., Carpenter, D. O., Chen, A., Huo, X. et al. (2016), 'E-waste and harm to vulnerable populations: a growing global problem', *Environmental health perspectives* **124**(5), 550–555.

Hosoda, J., Ofosu-Anim, J., Sabi, E. B., Akita, L. G., Onwona-Agyeman, S., Yamashita, R. and Takada, H. (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), 575–581.

Huang, J., Nkrumah, P. N., Anim, D. O. and Mensah, E. (2014), E-waste disposal effects on the aquatic environment: Accra, ghana, *in* 'Reviews of environmental contamination and toxicology', Springer, pp. 19–34.

Ife-Adediran, O. and Isabota, O. (2018), 'Gamma dose profile and risk to scavengers and occupants near waste dumpsites in coastal nigeria', *International Journal of Environmental Studies* **75**(5), 708–718.

ILO (2019), Decent work in the management of electrical and electronic waste (e-waste), Issues paper for the global dialogue forum on decent work in the management of electrical and electronic waste (e-waste) (geneva, 9-11 april 2019), International Labour Office, Sectoral Policies Department, Geneva, ILO, 2019.

IPEN and BAN (2019), 'Weak controls: European e-waste poisons africa's food chain'.

Jayachandran, S. (2009), 'Air quality and early-life mortality: Evidence from indonesia's wildfires', *The Journal of Human Resources* **44**(4), 916–954.

Kellenberg, D. (2010), 'Consumer waste, backhauling, and pollution havens', *Journal of Applied Economics* **13**(2), 283–304.

Kitt, J. R. (1994), 'Waste exports to the developing world: A global response', *Geo. Int'l Envtl. L. Rev.* **7**, 485.

Krueger, J. (1998), 'Prior informed consent and the basel convention: the hazards of what isn't known', *The Journal of Environment & Development* **7**(2), 115–137.

Lepawsky, J. and McNabb, C. (2010), 'Mapping international flows of electronic waste', *The Canadian Geographer/Le Géographe canadien* **54**(2), 177–195.

Linden, L. and Rockoff, J. E. (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 Gareau, B. J. (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**, 219–231.

Lundgren, K. (2012), *The global impact of e-waste: addressing the challenge*, International Labour Organization.

Lydecker, M. and Drechsel, P. (2010), 'Urban agriculture and sanitation services in accra, ghana: the overlooked contribution', *International Journal of Agricultural Sustainability* **8**(1-2), 94–103.

Manhart, A., Osibanjo, O., Aderinto, A. and Prakash, S. (2011), 'Informal e-waste management in Lagos, Nigeria. Socio-economic impacts and feasibility of international recycling co-operations', *Final report of component* **3**, 1–129.

Ofudje, E., Alayande, S., Oladipo, G., Williams, O. and Akiode, O. (2014), 'Heavy metals concentration at electronic-waste dismantling sites and dumpsites in lagos, nigeria', *International Research Journal of Pure and Applied Chemistry* pp. 678–690.

Ogungbuy, O., Chidi Nnorom, I., Osibanjo, O. and Schluep, M. (2012), e-waste country assessment nigeria, Report, e 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', *The Lancet Global Health* **1**(6), e313–e314.

Oppong, B. E., Asomani-Boateng, R. and Fricano, R. J. (2020), 'Accra's old fadama/agbogbloshie settlement. to what extent is this slum sustainable?', *African Geographical Review* pp. 1–19.

Osibanjo, O., Adeyi, A. A. and Majolagbe, A. O. (2017), 'Characterisation of groundwater quality around soluos dumpsite in lagos, nigeria', *International Journal of Water* **11**(1), 44–58.

Paller, J. W. (2015), 'Informal networks and access to power to obtain housing in urban slums in ghana', *Africa Today* **62**(1), 31–55.

Pronczuk-Garbino, J. et al. (2007), 'Children's health and the environment. a global perspective', *Int J Public Health* **52**, 67–68.

Schluep, M., Manhart, A., Osibanjo, O., Rochat, D., Isarin, N. and Mueller, E. (2011), Where are weee in africa? findings from the basel convention e-waste africa programme, *in* 'Published by the Secretariat of the Basel Convention'.

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., ITU, I. and UNIDO, U. (2019), 'A new circular vision for electronics time for a global reboot'.

von der Goltz, J. and Barnwal, P. (2019), 'Mines: The local wealth and health effects of mineral mining in developing countries', *Journal of Development Economics* **139**, 1–16.

Wang, Y., Tian, Z., Zhu, H., Cheng, Z., Kang, M., Luo, C., Li, J. and Zhang, G. (2012), 'Polycyclic aromatic hydrocarbons (pahs) in soils and vegetation near an e-waste recycling site in south china: concentration, distribution, source, and risk assessment', *Science of the Total Environment* **439**, 187–193.

Waste Atlas Partnership (2014), 'The world's 50 biggest dumpsites'.

Appendix

Table A.1: Differences in means

	Treatment vs.Control		Control			Treatment		
	Before	After	Before	After	Difference	Before	After	Difference
A: All births								
< primary schooling	-0.005	0.000	0.069	0.095	0.026	0.069	0.100	0.031
Primary schooling	0.000	0.014	0.188	0.202	0.014	0.174	0.202	0.028
Secondary schooling	-0.018	-0.008	0.594	0.567	-0.027	0.602	0.585	-0.017
Higher education	0.022	-0.006	0.149	0.136	-0.014	0.156	0.113	-0.042
Spouse < primary schooling	-0.037*	-0.009	0.030	0.038	0.008	0.039	0.075	0.036
Spouse primary schooling	0.077*	0.016	0.139	0.178	0.039	0.124	0.101	-0.023
Spouse secondary schooling	-0.060*	0.049	0.635	0.574	-0.062*	0.587	0.634	0.047
Spouse higher education	0.020	-0.055*	0.195	0.210	0.015	0.250	0.190	-0.060
Urban	-0.124*	-0.092*	0.908	0.876	-0.032*	1.000	1.000	0.000
Male	0.010	0.024	0.513	0.524	0.010	0.490	0.514	0.024
Multiple birth	0.019*	-0.008	0.042	0.048	0.005	0.050	0.029	-0.021
Mother age at birth	0.115	0.260	28.511	27.436	-1.076*	28.252	27.321	-0.931
B: Ghana								
< primary schooling	-0.032	-0.034	0.071	0.115	0.044	0.106	0.148	0.042
Primary schooling	0.034	-0.021	0.200	0.238	0.038	0.221	0.204	-0.017
Secondary schooling	-0.065	-0.082	0.571	0.546	-0.025	0.653	0.611	-0.042
Higher education	0.063*	0.137*	0.157	0.100	-0.057	0.020	0.037	0.017
Spouse < primary schooling	-0.047	-0.011	0.069	0.071	0.002	0.080	0.118	0.037
Spouse primary schooling	-0.041*	-0.023	0.017	0.000	-0.017	0.040	0.041	0.001
Spouse secondary schooling	0.014	-0.075	0.672	0.735	0.062	0.747	0.721	-0.027
Spouse higher education	0.074*	0.109*	0.241	0.195	-0.047	0.132	0.121	-0.012
Urban	-0.300*	-0.229*	0.771	0.700	-0.071	1.000	1.000	0.000
Male	0.057	0.076	0.543	0.569	0.026	0.467	0.512	0.045
Multiple birth	0.022	-0.032	0.029	0.046	0.018	0.060	0.025	-0.036
Mother age at birth	0.179	-0.991	27.114	27.238	0.124	28.106	27.059	-1.046
C: Nigeria								
< primary schooling	0.059*	0.031	0.069	0.091	0.022	0.038	0.032	-0.006
Primary schooling	-0.004	0.051*	0.186	0.194	0.008	0.134	0.198	0.063
Secondary schooling	0.024	0.039	0.597	0.572	-0.025	0.559	0.548	-0.011
Higher education	-0.079*	-0.121*	0.148	0.144	-0.004	0.269	0.223	-0.046
Spouse < primary schooling	0.016	0.019*	0.024	0.031	0.007	0.005	0.015	0.010
Spouse primary schooling	0.033	-0.034	0.160	0.217	0.057*	0.194	0.184	-0.010
Spouse secondary schooling	0.025	0.178*	0.629	0.539	-0.090*	0.451	0.513	0.062
Spouse higher education	-0.074*	-0.163*	0.187	0.213	0.026	0.350	0.287	-0.062
Urban	-0.083*	-0.071*	0.929	0.917	-0.013	1.000	1.000	0.000
Male	-0.003	0.000	0.509	0.513	0.004	0.508	0.516	0.007
Multiple birth	0.013	0.002	0.044	0.048	0.004	0.042	0.035	-0.007
Mother age at birth	-0.215	0.354	28.728	27.481	-1.247*	28.374	27.696	-0.678

*** p-value < 1%, ** p-value < 5%, * p-value < 10%.

Table A.2: The impact of e-waste sites on newborn and infant health: site specific analysis

	(I)	(II)	(III)	(IV)
	Ghana		Nigeria	
	Neonatal Mortality	Infant Mortality	Neonatal Mortality	Infant Mortality
A: Within 11km of dump				
Within 11km	–0.012	–0.043	–0.014	–0.018
	(0.021)	(0.028)	(0.012)	(0.013)
Post × Within 11km	0.049*	0.089**	0.043**	0.054**
	(0.025)	(0.038)	(0.017)	(0.026)
B: Distance in km				
Distance (km)	0.001	0.002	0.003*	0.003**
	(0.002)	(0.003)	(0.001)	(0.001)
Post × Distance (km)	–0.005*	–0.008*	–0.006***	–0.007**
	(0.002)	(0.004)	(0.002)	(0.003)
Mean mortality	0.030	0.051	0.035	0.050
N	805	727	1536	1424
Dump FE	Yes	Yes	Yes	Yes
Year of Birth FE	Yes	Yes	Yes	Yes

Standard errors (in parenthesis) are clustered at the DHS cluster level.
*** p-value < 1%, ** p-value < 5%, * p-value < 10%.

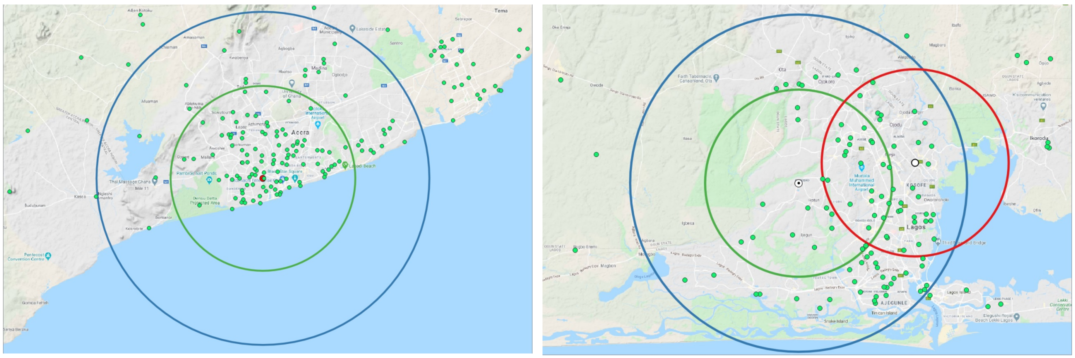
Table A.3: Composition of women in sample before and after e-waste sites: Ghana

	All women interviewed within 20km of dumping site				Women interviewed within treatment zone				Women interviewed within control zone			
	Before	After	Difference	N	Before	After	Difference	N	Before	After	Difference	N
A: Ghana												
Woman age	32.428	28.462	-3.966*	518	32.519	28.065	-4.454*	402	32.154	31.500	-0.654	116
Spouse age	39.384	36.967	-2.417*	316	39.390	35.434	-3.956*	248	39.367	47.125	7.758*	68
Urban	0.940	1.000	0.060*	518	1.000	1.000	0.000	402	0.760	1.000	0.240*	116
No Schooling	0.114	0.202	0.088*	518	0.129	0.196	0.067	402	0.067	0.250	0.183*	116
Completed Primary	0.193	0.173	-0.020	518	0.184	0.185	0.001	402	0.221	0.083	-0.138	116
Completed Secondary	0.640	0.587	-0.054	518	0.655	0.576	-0.079	402	0.596	0.667	0.071	116
Completed Higher	0.053	0.038	-0.015	518	0.032	0.043	0.011	402	0.115	0.000	-0.115	116
Spouse No Schooling	0.081	0.111	0.030	449	0.089	0.100	0.011	350	0.056	0.200	0.144*	99
Spouse Completed Primary	0.028	0.056	0.028	449	0.033	0.063	0.029	350	0.011	0.000	-0.011	99
Spouse Completed Secondary	0.735	0.711	-0.024	449	0.741	0.713	-0.028	350	0.719	0.700	-0.019	99
Spouse Completed Higher	0.156	0.122	-0.034	449	0.137	0.125	-0.012	350	0.213	0.100	-0.113	99
Employed	0.832	0.740	-0.092*	515	0.805	0.750	-0.055	400	0.913	0.667	-0.246*	115
Employed (last 12 months)	0.857	0.817	-0.040	518	0.835	0.815	-0.020	402	0.923	0.833	-0.090	116
B: Nigeria												
Woman age	33.043	29.676	-3.366*	784	32.548	32.000	-0.548	256	33.293	29.367	-3.927*	528
Spouse age	40.465	38.538	-1.926	534	39.537	41.000	1.463	207	41.082	38.091	-2.991*	327
Urban	0.947	1.000	0.053	784	1.000	1.000	0.000	256	0.920	1.000	0.080	528
No Schooling	0.065	0.029	-0.036	784	0.036	0.000	-0.036	256	0.080	0.033	-0.047	528
Completed Primary	0.168	0.235	0.067	784	0.151	0.250	0.099	256	0.177	0.233	0.057	528
Completed Secondary	0.583	0.647	0.064	784	0.579	0.750	0.171	256	0.584	0.633	0.049	528
Completed Higher	0.184	0.088	-0.096	784	0.234	0.000	-0.234	256	0.159	0.100	-0.059	528
Spouse No Schooling	0.023	0.000	-0.023	645	0.014	0.000	-0.014	226	0.028	0.000	-0.028	419
Spouse Completed Primary	0.190	0.294	0.104	645	0.171	0.250	0.079	226	0.201	0.300	0.099	419
Spouse Completed Secondary	0.537	0.441	-0.096	645	0.514	0.250	-0.264	226	0.550	0.467	-0.083	419
Spouse Completed Higher	0.250	0.265	0.014	645	0.302	0.500	0.198	226	0.221	0.233	0.012	419
Employed	0.819	0.794	-0.025	660	0.789	1.000	0.211	231	0.837	0.767	-0.070	429
Employed (last 12 months)	0.818	0.794	-0.024	666	0.783	1.000	0.217	234	0.838	0.767	-0.072	432

Standard errors (in parenthesis) are clustered at the DHS cluster level. *** p-value < 1%, ** p-value < 5%, * p-value < 10%.

Figure A.1: Dumping sites and households location

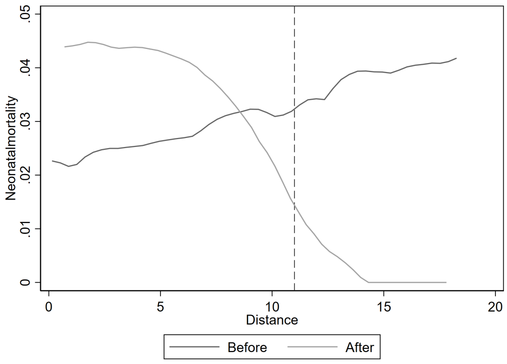
(a) Ghana (b) Nigeria



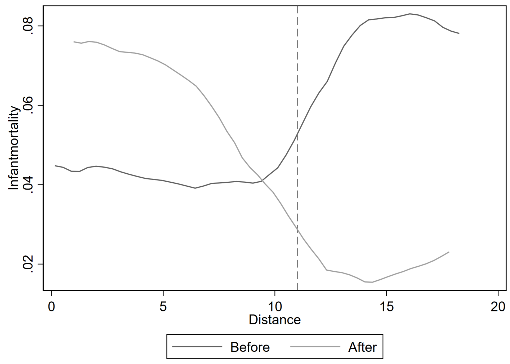
Maps plotting DHS data for Ghana and Nigeria. Dots represent DHS clusters. The green buffer is drawn at 11km from each dumping site, and the blue buffer represents 20km from the site. The red buffer in Nigeria shows the existence of the older dump, not included in the analysis, and all clusters within this buffer are excluded from our analysis.

Figure A.2: Non-parametric relationship between distance and neonatal (left) and infant (right) mortality: by country

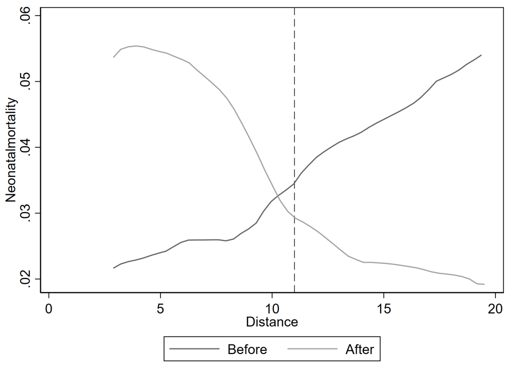
(a) Neonatal: Ghana



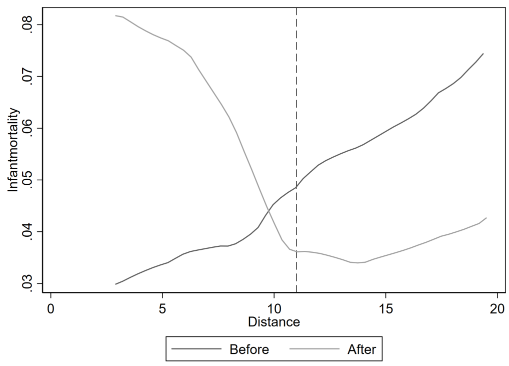
(b) Infant: Ghana



(c) Neonatal: Nigeria



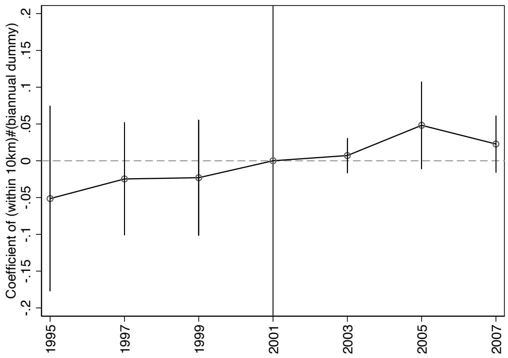
(d) Infant: Nigeria



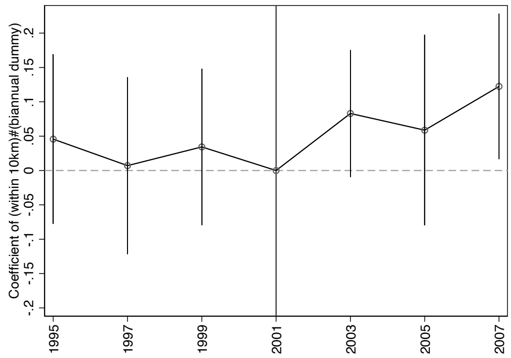
Authors' calculation based on the DHS data for Ghana and Nigeria. For consistency between the two countries we consider a common number of years (5) before and after the dump. The plots are created by estimating a kernel-weighted local polynomial regression (bandwidth = 2.5) of distance from e-waste site on mortality.

Figure A.3: Event study for neonatal (left) and infant (right) mortality: Ghana

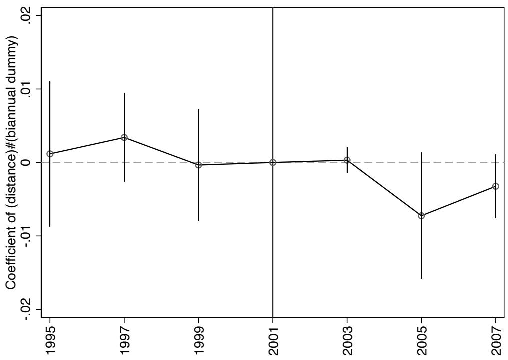
(a) Neonatal: binary treatment



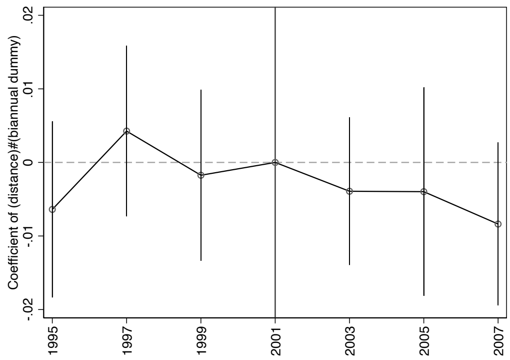
(b) Infant: binary treatment



(c) Neonatal: distance from dump

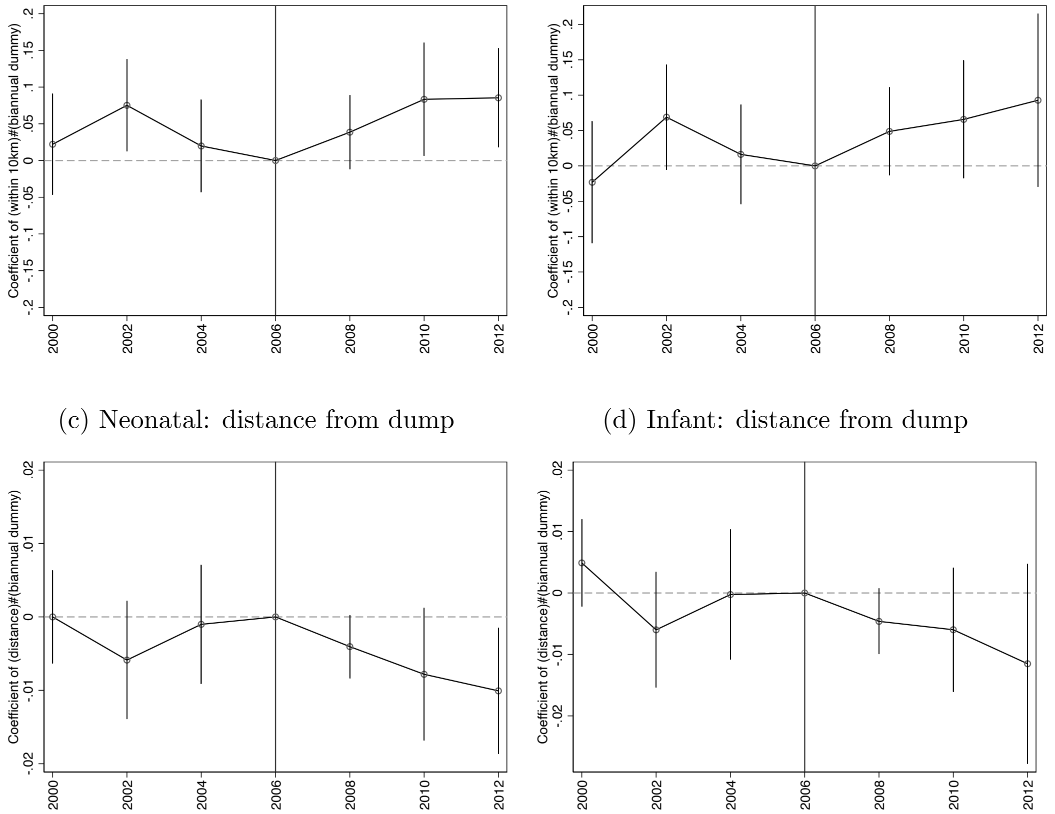


(d) Infant: distance from dump



Authors' calculation based on the DHS data for Ghana. The plots are created by a linear regression of mortality on a full set of event time indicators (biannual) for country and year fixed effects. Results using distance from the dump are obtained by interacting the biannual time indicator with distance from the dump (in Km). The lines indicate 95% confidence interval.

Figure A.4: Event study for neonatal (left) and infant (right) mortality: Nigeria



(a) Neonatal: binary treatment

(b) Infant: binary treatment

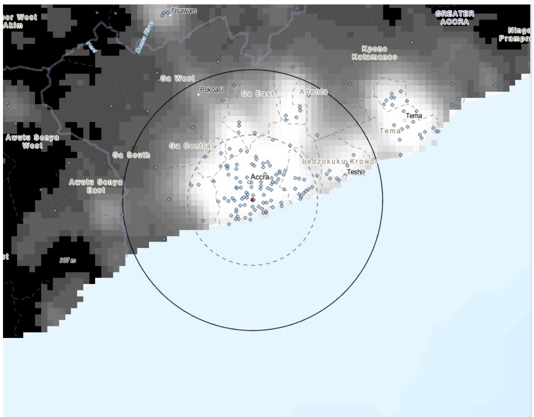
(c) Neonatal: distance from dump

(d) Infant: distance from dump

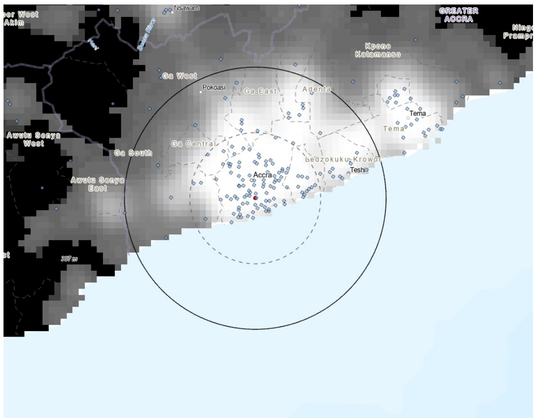
Authors' calculation based on the DHS data for Ghana. The plots are created by a linear regression of mortality on a full set of event time indicators (biannual) for country and year fixed effects. Results using distance from the dump are obtained by interacting the biannual time indicator with distance from the dump (in Km). The lines indicate 95% confidence interval.

Figure A.5: Nightlights over time: Ghana

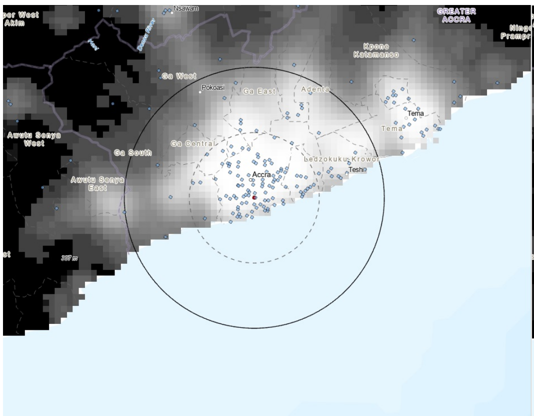
(a) 1995



(b) 2000



(c) 2005



(d) 2010

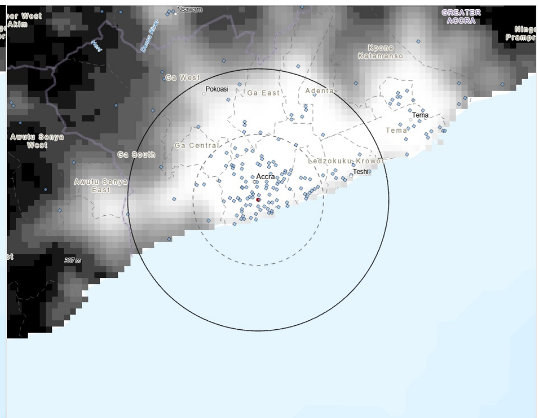
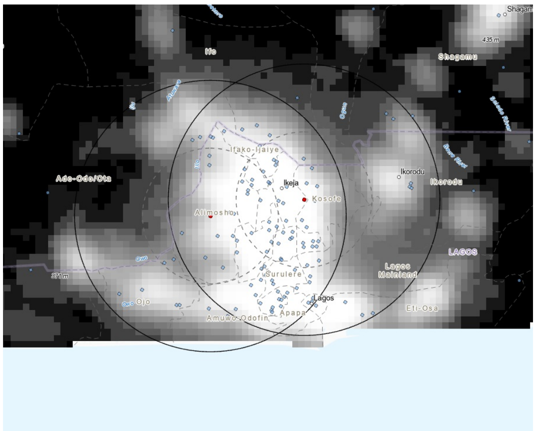


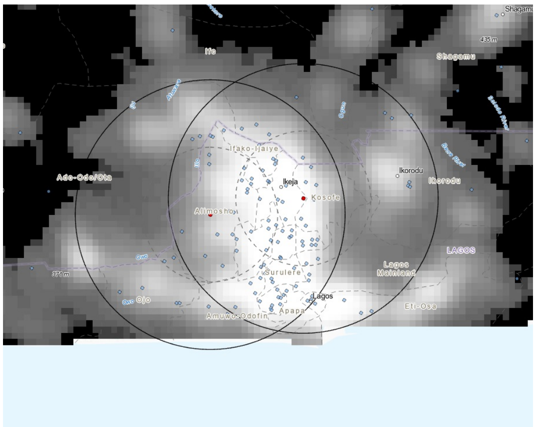
Image and data processing by NOAA's National Geophysical Data Center. DMSP data collected by US Air Force Weather Agency. Red dot indicates the Agbogbloshie Dump; the black circle indicates the 20km buffer zone; the dashed circle indicates the 10km buffer zone; blue dots indicate DHS clusters

Figure A.6: Nightlights over time: Nigeria

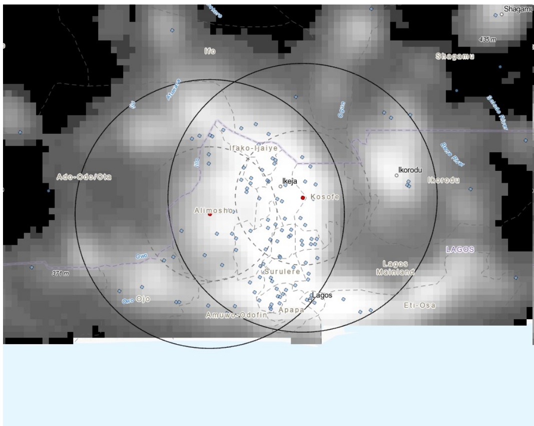
(a) 1995



(b) 2000



(c) 2005



(d) 2010

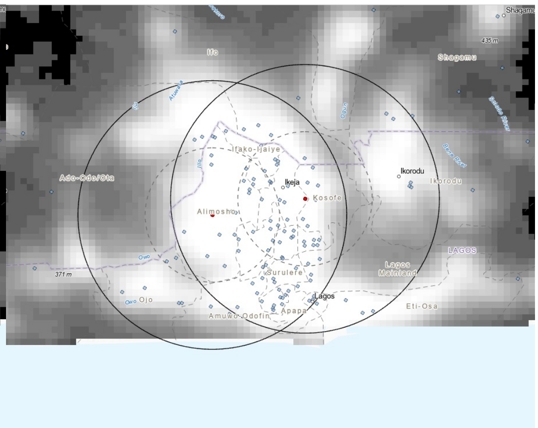
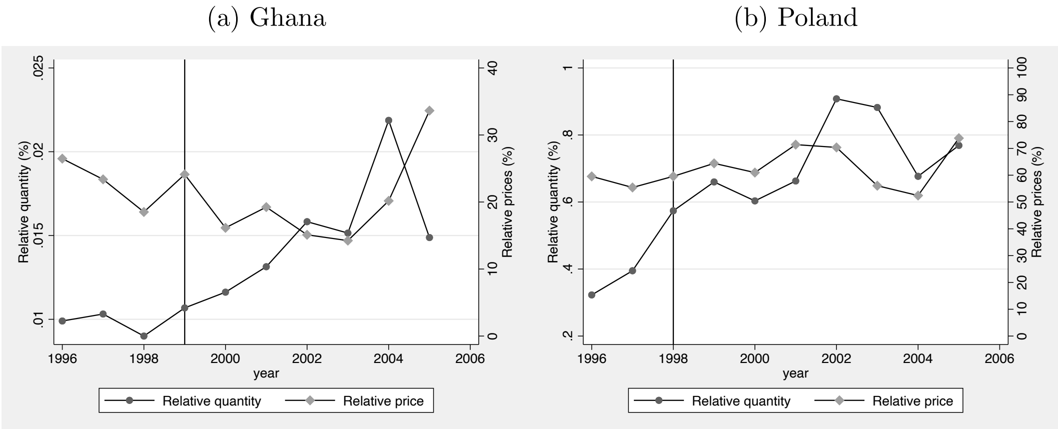


Image and data processing by NOAA's National Geophysical Data Center. DMSP data collected by US Air Force Weather Agency. Red dot indicates the Solous and Olusoshun dump sites; the black circle indicates the 20km buffer zone; the dashed circle indicates the 10km buffer zone; blue dots indicate DHS clusters

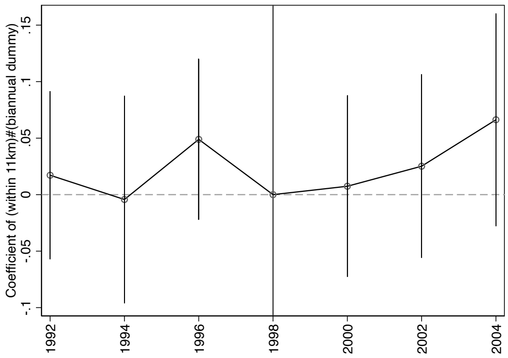
Figure A.7: EU (15) exports of computing equipment to Ghana and Poland



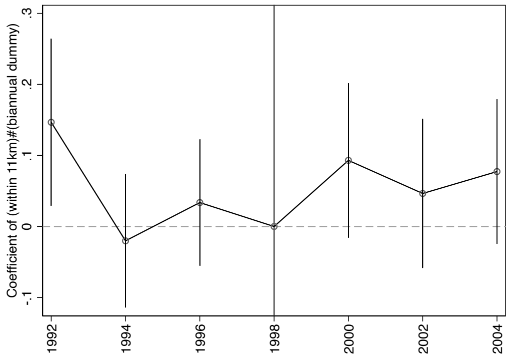
Authors' calculation based on Comext data. Data refers to the product category 8471: Automatic data-processing machines. Quantity indicates net mass (weight of goods in kg without packaging). Relative prices are computed as the unit value of goods exported to Ghana or Poland over the overall average export price in percentage terms. Relative quantity is given by the percentage of total EU 15 export to Ghana or Poland.

Figure A.8: Event study for neonatal (left) and infant (right) mortality: Olushosun dump

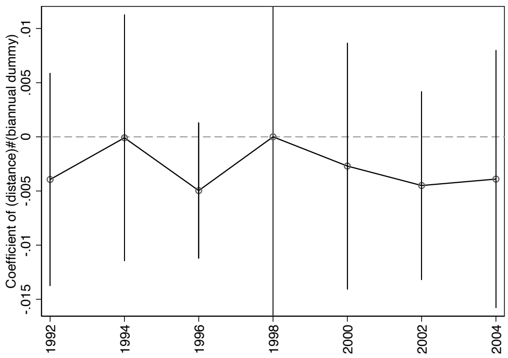
(a) Neonatal: binary treatment



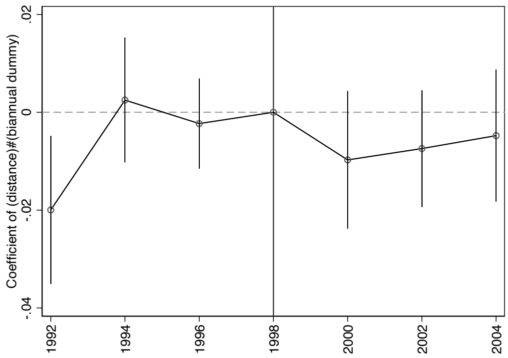
(b) Infant: binary treatment



(c) Neonatal: distance from dump



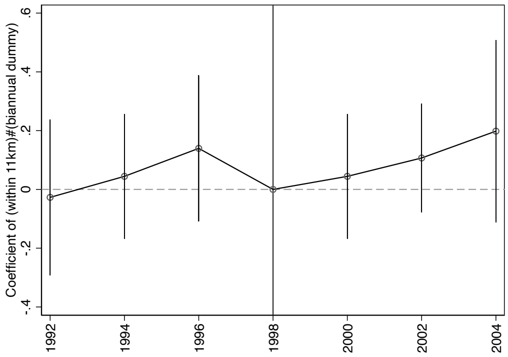
(d) Infant: distance from dump



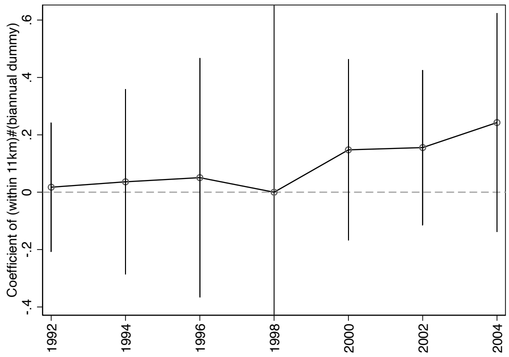
Plots show estimated coefficients from estimating equations 1 and 2. The vertical lines indicate 95% confidence interval.

Figure A.9: Event study for neonatal (left) and infant (right) mortality: Olushosun dump, non-migrants

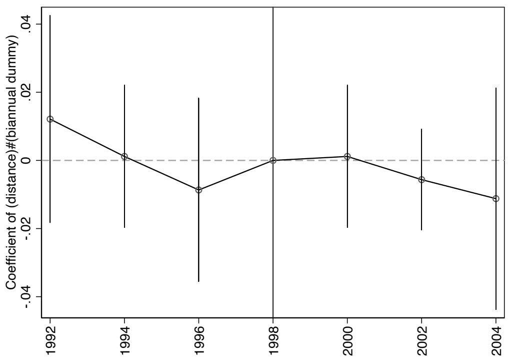
(a) Neonatal: binary treatment



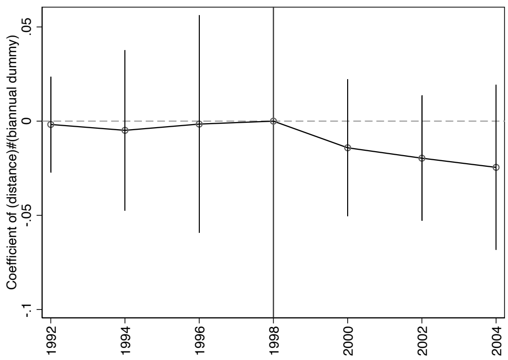
(b) Infant: binary treatment



(c) Neonatal: distance from dump

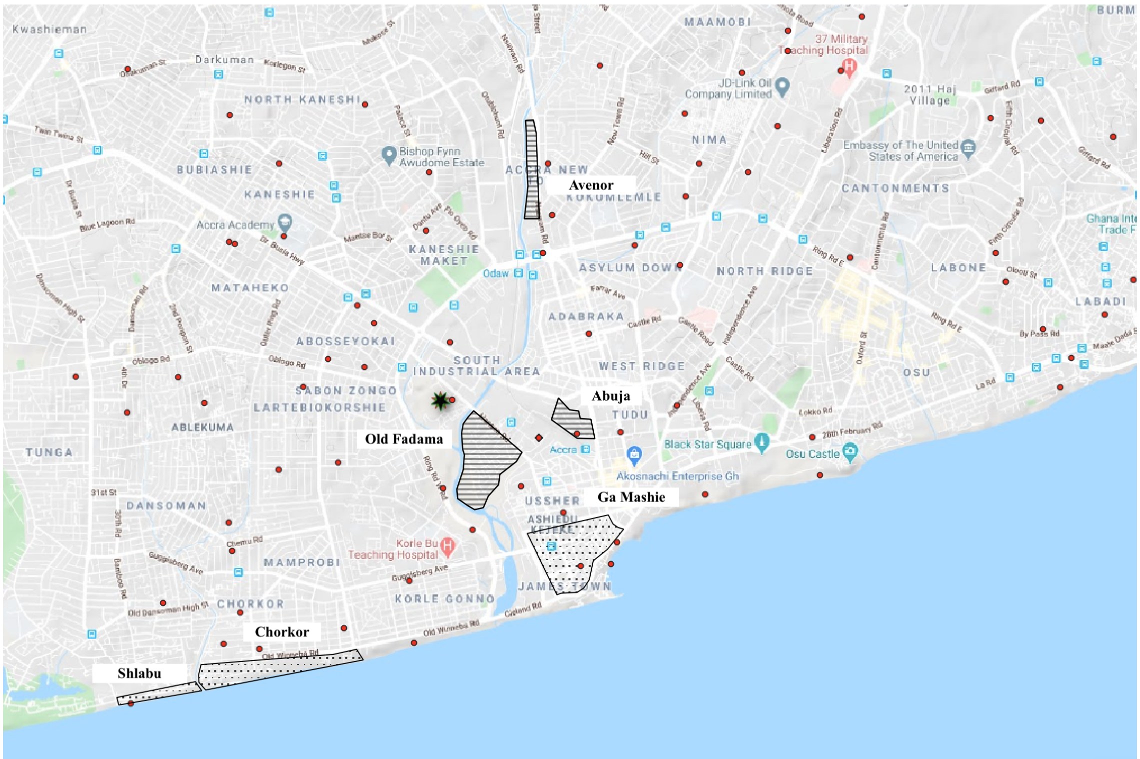


(d) Infant: distance from dump



Plots show estimated coefficients from estimating equations 1 and 2 for resident children only. The vertical lines indicate 95% confidence interval. Non-migrant households only.

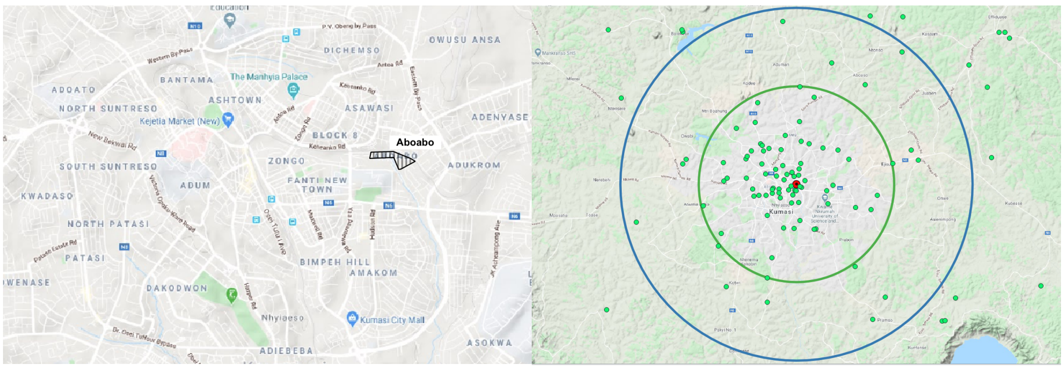
Figure A.10: Slum area in Accra - Ghana



Map plotting DHS data for Ghana. Dots represent DHS clusters within 11km from the e-waste site. The shaded areas represent slums locations. Striped areas are extralegal settlements, which in the postcolonial context, gathered previously marginalized communities to establish territorial authority (Paller, 2015).

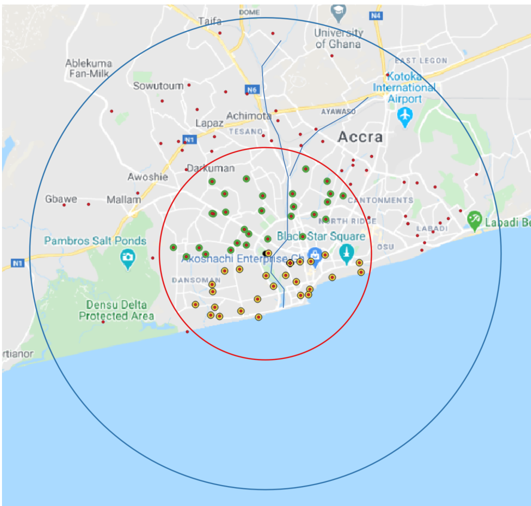
Figure A.11: Aboabo slum in Kumasi - Ghana

(a) Location of Aboabo slum (b) DHS clusters in the proximity of Aboabo



Map plotting location of Aboabo slum in Kumasi, Ghana. Dots represent DHS clusters. The green buffer is drawn at 11km from the slum centre, and the blue buffer represents 20km from the centre.

Figure A.12: Upstream and Downstream clusters in Ghana



Maps plotting DHS data for Ghana. Dots represent DHS clusters. The blue buffer indicates 11km from the e-waste site, hence the red dots are the cluster in the treated group. Dots highlighted in green are categorised as upstream, while those in yellow are categorised as downstream, both are within $5km$ from the river and the dump as shown by the red buffer.