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The Impact of Gas Flaring on Child Health in Nigeria

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Abstract

Burning off the gas coming out of oil wells—gas flaring—is a common practice in oil-producing developing countries. This economically wasteful and environmentally damaging process occurs because infrastructure has been built with a focus on oil production rather than gas capture and because weak regulations and limited environmental monitoring make flaring an attractive choice for oil producers. Moreover, gas flaring is harmful to human health, especially because of pollutants. This research focuses on Nigeria, where over 10 percent of all gas produced is flared and about 2 million people in the Niger Delta live within four kilometres of a gas flare. While several studies from developed countries examine relationships between gas flaring and human (especially infant) health, a lack of data limits what research is possible in developing countries. This paper uses infant health data from Demographic Health Surveys, and satellite-detected data on gas flaring to examine the effects of flaring on disease incidence and infant mortality in oil-producing regions of Nigeria. The findings show a strong positive association between gas flaring and the incidence of respiratory diseases and fever among children younger than five years. The study contributes to the literature measuring the wider cost to society of oil and gas production and adds to a growing body of work using satellite data to understand well-being in places where conventional data sources are unavailable or unreliable.

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The impact of gas flaring on child health in Nigeria

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1. Introduction

Routine natural gas flaring – the combustion of the gas associated with crude oil – has been a feature of Nigeria's oil industry ever since production began in the Niger-Delta region in 1956. There are several reasons why a low-income, energy-insecure country like Nigeria routinely burns a valuable source of energy and potential income earner. First, a focus on crude oil and the infrastructure needed to extract and transport oil for refining or for export makes gas an unwanted by-product. This is especially as gas capture and processing requires different infrastructure, with costs often upfront in the life of an oil well, and oil companies are typically unwilling to make these investments. Second, the weak regulatory and policy settings make it easier for companies to flare the gas rather than find alternative uses. For example, it was not until recently that the *2018 Flare Gas (Prevention of Waste and Pollution) Regulations* increased the penalty for flaring from US$0.024 (10 naira) per thousand standard cubic feet (SCF) to US$2 per thousand SCF for companies that produce at least 10,000 barrels of oil per day (Obayomi, 2018).[3]

Nigeria has the largest proven gas reserves in Africa (about 201 trillion cubic feet), or about 2.7 percent of global proven reserves of gas (OPEC, 2018). The latest statistics from the Nigerian Department of Petroleum Resources (DPR) indicated flaring volumes of 321 million SCF for 2018—around 11 percent of total gas produced in the country for that year (DPR, 2020). Prior to the enactment of the 2018 Flare Gas Regulations in July, based on the flaring volume, gas producing companies would only have been liable for a fine of around US$8m (even with 100% compliance with the regulations).[4] Yet PWC (2019) estimate a direct revenue loss of US$761m from flaring in 2018,[5] putting into perspective the wasteful impact of flaring on the Nigerian economy. To give another comparison, the value placed on gas burnt at the well is around 4 percent of annual fiscal revenue and 13 percent of the fiscal deficit in the 2018 national budget. Moreover, the situation was even worse in the past, with about half of all gas produced being flared in 2002. The on-going use of gas flaring reflects limited progress in commercialising the gas (including gas-using industrialisation) and in technological improvements. Overall, gas flaring represents a big revenue loss in a country with a significant income shortfall.

In addition to the economic waste entailed by gas flaring, there are claimed harms to human health due to light, noise, water, and air pollution. In the densely populated Niger-Delta region where oil production takes place, it is estimated that some 2 million people live within 4 kilometres of a gas flare

[3] For companies that produce less than 10,000 barrels, the flare payment penalty is $0.5 per 1000 standard cubic feet of gas flared. Prior to the 2018 change, all companies faced a flare payment of US$0.024 (at October 2021 official naira to dollar exchange rate)

[4] With the enactment of the law, the amount of fine will have been around $642m with 100% compliance based on official 2018 flare volumes.

[5] This excludes lost value from the derivatives that can be produced if the gas was further processed

(Schick, et al., 2018). The combustion process is an important source of noise. Fires generated from the combustion process dot the landscape with people living close to flare sites reported not able to distinguish daytime from night-time (Schick, et al., 2018). With combustion temperatures in excess of 1,000^{0}C, the ambient temperature is raised in areas around the flares, and this negatively impacts local agricultural production (Dung, et al., 2008). It is especially the effect of flaring on air quality that may harm human health. Natural gas contains many different compounds, mainly methane, and a host of hydrocarbon gas liquids (ethane, propane, butane) and nonhydrocarbon gases such as carbon dioxide (U.S. Energy Information Administration, n.d.). Combustion of natural gas is a prominent source of pollutants such as carbon monoxide (CO), carbon dioxide (CO_2), volatile organic compounds (VOCs), sulphur dioxide (SO_2), polycyclic aromatic hydrocarbons (PAH), nitrogen oxides (NOX) and particulate matter (PMx) in the form of soot or black carbon which can travel over long distances due to the height at which flaring takes place (Fawole, et al., 2016, McEwen and Johnson, 2012).

Despite the importance of gas flaring in Nigeria, and the potential health impacts, to date there are only studies that compare health outcomes in a few communities with and without flaring sites (see Gobo et al., 2009 and the review in Ite et al., 2016). Moreover, these studies are not in the economics literature. This paucity of evidence is not surprising because identifying the health impacts of flaring requires detailed data on air quality, flaring volumes, and health records. To bridge this gap, we link geo-referenced child health data from Demographic Health Surveys with satellite-detected gas flaring locations in Nigeria (and estimates of gas flaring volumes). We examine the association between gas flaring and disease incidence, child anthropometric outcomes, and death among children under-5 in the oil producing Niger-Delta region of Nigeria. We find a positive association between gas flaring and the incidence of disease; specifically, cough, respiratory illness, and fever. We also find positive associations between flaring and the probability of a child being either wasted or underweight.

In a context like Nigeria, our study thus makes three important contributions: First, it provides the first comprehensive examination of gas flaring impacts on child health, for the country that contributes the most (by volume) to gas flaring in Africa and the seventh most globally. Also, most evidence on the health impacts of flaring is for recent unconventional gas production (fracking) whereas gas flaring in Nigeria is associated with conventional oil production. This distinction could be important as the process of fracking has been associated with other forms of air pollutants that may not solely be due to gas flaring. Moreover, most existing evidence is from richer countries, where confounding due to endogenous avoidance behaviour potentially complicates the analyses. In Nigeria there is limited scope for avoidance behaviour, especially due to land market rigidity in the densely populated Niger-Delta area that stems from concerns over the distribution of oil wealth and the huge ethnic divide in this area. The Niger-Delta is home to over 40 different ethnic groups and the location of oil infrastructures determines the benefits enjoyed by the host community including patronage, loyalties, jobs, contracts, scholarships, social facilities, and compensation (Folami, 2017). The rents from oil and gas companies to communities and the ethnic divide promotes a strong attachment to land in this area. A second contribution of our study is to consider offshore gas flaring. Most evidence on health impacts of flaring is from land-based settings, reflecting a preponderance of studies of fracking. While a large literature considers environmental impacts of offshore oil and gas production (see Wiese et al., 2001 for an early study), little is known about impacts of offshore gas flaring on human health. Yet half of all of Nigeria's flaring is offshore, with three-quarters of these flaring locations located within 60 km of areas where people live. Evidence has shown that the type of pollutants generated by flaring can affect air quality up to 108 miles (174km) away (Mauzerall, et al., 2005) so it is likely that that offshore flaring has an impact on coastal communities. The examination of the health impact of offshore flaring also has important policy implications in Nigeria where there is a longstanding debate about the distribution of the gains from offshore oil exploration (Egede, 2005). Finally, our study demonstrates the value that can be added to geo-referenced survey data by linking to satellite observations of environmental phenomena, especially for countries that lack the wherewithal for conventional monitoring (Gibson and McKenzie, 2007; Donaldson and Storeygard, 2016).

The rest of the paper proceeds as follows: Section 2 describes some related literature examining gas flaring and human health, Section 3 describes the data and our method of linking satellite-detected gas flaring locations and estimates of gas flared volumes with human health data from DHS. Section 4 contains our results and Section 5 concludes.

2. Related literature

A large literature relates air pollution to a host of negative health outcomes (see Manisalidis et al., 2020 for a review). However, identifying causal impacts of air pollution is complicated due to the presence of many confounding factors. Air pollution is not randomly assigned, so unobserved factors may be correlated with both air pollution and health outcomes. People may undertake endogenous risk-avoidance behaviours such that richer people or those who place greater weight on health sort into locations with better air quality so observational data may overstate effects of pollution (Neidell, 2009; Moretti & Neidell, 2011; Sun et al., 2017). Conversely, polluting industries, such as oil and gas, may attract younger, healthier in-migrants in search of employment, so observational studies of polluted areas may underestimate the effects of air pollution. It is also difficult to assign pollution exposure to individuals, so measurement errors may bias estimates of the impact of pollution on health. Notwithstanding these identification difficulties, there is causal evidence that air pollution increases child hospitalisations for respiratory problems (Neidell, 2004; Tzivian, 2011), increases infant mortality (Currie and Neidell, 2005; Knittel, et al., 2016), affects birth outcomes (Currie et al, 2009;

Currie and Schmieder, 2009), reduces human capital formation and affects long term human capital outcomes (Bharadwaj et al., 2017; Grineski et al., 2020; Currie et al., 2009). Moreover, these negative effects are typically worse for people in lower socio-economic backgrounds.

A small subset of the literature on negative health impacts of air pollution has focused on flaring, often in the context of unconventional oil and gas production (fracking). Cushing et al. (2020) used satellite observations of flaring from unconventional oil and gas wells in Texas, and link to administrative birth records for pregnant women residing up to 5km from a flaring site. Exposure to frequent nightly flare events was associated with 50% higher odds of preterm birth and shorter gestation compared with no exposure, with effects especially for Hispanic women. Flaring was not associated with reduced birthweight among term infants after controlling for gestational age. Hill (2018) focused more broadly on shale gas development in Pennsylvania and found lower birth weight among infants born to mothers who live close to shale gas wells but an insignificant effect on birth term. Their difference-in-differences model used mothers living within 2.5 km of a shale gas well or permit prior to drilling as a control for treatment of living in the same radius after drilling began (the counterfactual change in infant health is estimated using births prior to drilling at the same distance from the well bore location or permitted location). The risk of low birth weight increased after drilling began. Colborn et al. (2014) focused on air quality around fracking sites in a rural western Colorado area where residences and gas wells co-exist. They found concentrations of pollutants well above critical levels that are associated with lower developmental and IQ scores in prior research in urban areas.

The studies described above are for localised settings in developed countries in the context of fracking but gas flaring in developing countries is mostly in the context of conventional oil and gas production. This distinction may matter as fracking is associated with other pollutants (and other channels of impact on health) that may be less relevant for conventional oil and gas production.[6] Thus, it is unclear how transferrable these findings may be for the health impact of flaring from conventional oil and gas production in developing countries, especially as these countries tend to have weaker environmental regulations and less monitoring than in developed countries.

There are some studies in the Nigerian context, but they are very limited non-econometric studies. A survey of attitudes towards flaring in oil producing communities found that residents perceive gas flaring as hazardous to their health, environment, and general well-being of their community but are resigned to the continued presence of flares (Edino, Nsofor and Bombom, 2009). One case study of 600 households in six Nigerian communities (three with gas-flaring and three without) found that

[6] Fracking involves injection of chemical additives into wells. Exposure to some of these chemicals has been associated with adverse reproductive health and developmental effects in humans [see Webb et al. 2014].

living in a gas-flaring host community is associated with being hypertensive (Maduka and Tobin-West, 2017). Gobo et al. (2009) compared medical records in two communities with a long history of flaring with one with no flaring and found more frequent disease such as asthma, cough, breathing difficulty, eye/skin irritation in flaring communities. Sojinu et al. (2010) study distribution of polycyclic aromatic hydrocarbons (PAHs) in 44 soil sediment samples from rivers and canals adjoining oil and gas producing areas in parts of the Niger-Delta; PAHs from pyrogenic sources were present predominantly in surface soils. Yet while gas flaring associated with oil exploration work in the Delta affects surface soils, Sojinu and colleagues conclude that except for two locations, the observed contamination level from these sites was not a serious threat to the ecosystem.

In summary, there has been no large-scale examination of the impact of gas flaring on human health in Nigeria even with a 60-year history of routine gas flaring. Prior evidence is limited to the type of studies discussed above which focused on a handful of communities. Our study overcomes some of these data limitations by examining the association between flaring and health outcomes using linked georeferenced data on all flaring locations from satellite observations (including offshore flare sites) and pooled cross-sectional child health information from Demographic and Health Surveys (DHS).

3. Data and Methods

Data

We use data from two sources: the first is satellite observation on gas flaring locations and estimates of flare volumes. These come from the Visible Infrared Imaging Radiometer Suite (VIIRS) on-board the *Suomi* satellite. Launched in 2012, the VIIRS sensors can detect heat emitted by gas flares through the collection of shortwave and near-infrared data at night, recording peak radiant emissions from flares. Elvidge, et al. (2016) present a methodology for estimating the volume of gas flared at each site with the accuracy of the flared gas volume estimates rated at ±9.5%. These data and methods have been used to identify global flaring locations and to estimate global gas flaring volumes (World Bank, 2020). A publicly available website: www.gasflaretracker.ng has the geographic coordinates of each flaring point in Nigeria as well as monthly estimates of the flare volume from each location.

Our child health data come from the 2013 and 2018 Nigerian Demographic Health Survey (DHS). These nationally representative cross-sectional surveys have demographic and health details for women aged (15-49) and for children aged (0-5). A stratified, two-stage cluster design is used, with the geo-coordinates of each cluster reported with some displacement for confidentiality reasons.[7] The DHS collects information on women's birth histories and child health characteristics including self-reported

[7] The displacement is up to 2km for urban clusters and 5km for rural clusters, with 1 percent of rural clusters displaced up to 10km.

measures of cough, other respiratory symptoms, and fever. Anthropometric measurements are made for children under 5. We focus on all DHS clusters in the oil producing Niger-Delta region and in Cross-River State. Although Cross-River was delisted as an oil producing state in 2009, it is in close-proximity to current offshore oil and gas wells off the coast of Nigeria.

Method

We use a market potential approach to link gas flaring locations to the risk of exposure to gas flaring for each DHS cluster. Specifically, we calculate the inverse distance weighted average flare volume from each flare site for each DHS cluster:

$$RF_{ct} = \sum_{f=1}^{F} \left(d_f^{-1}\right) * FV_f \qquad (1)$$

Where d_f^{-1} is the inverse of the distance[8] between cluster c and flaring location f; and FV_f is the gas flare volume in flaring site f. This inverse-distance weighted flaring volume for each cluster(RF_{ct}) is our key variable of interest. There are some advantages to taking this market potential approach: first, this approach does not treat each flaring site as equal but takes into account the volume of gas flared in each location as well as the fact that flare sites closer to DHS clusters should have more impact on health outcomes than flare sites farther way. Secondly, this approach allows us to take into account the potential effect of offshore flaring, treating it in an equivalent way to onshore flaring. If instead, we used flaring averages for the local administrative areas where the DHS cluster was located, the offshore sites would be missed. About half of all of Nigeria's flaring happen offshore and three-quarters of these flaring locations are located within 60 km of areas where people live, which is well within the distance that the air pollution from flaring has been shown to travel.

We have three groups of outcome variables. First, the reported incidence of diseases in young children such as fever, cough, diarrhoea, and respiratory issues.[9] Second, anthropometric measurements yield z-scores for height-for-age (HAZ), weight-for-height (WHZ), and weight-for-age (WAZ). A child is considered stunted, wasted or underweight if HAZ, WHZ or WAZ for the child is less than two standard deviations below the median measurement for the reference group (WHO Multicentre Growth Reference Study Group, 2006). Third, measures of mortality at the cluster level: specifically, infant mortality (the proportion of children who died before they are 12months old), child mortality (the proportion of children who died when they were between 12 and 59 months old), and under-5 mortality (the proportion of children under 59months old who died).

[8] We use the Stata routine *geonear* to calculate the Euclidean distance between each DHS cluster and each flaring location.

[9] This is defined as reporting one of the following symptoms: cough, blocked nose, short breath, and blocked chest.

To establish the association between flaring and child health outcomes, we regress the child health outcome variables on risk of exposure to gas flaring controlling for child, parent, and household characteristics. Previous research (e.g., Hill, 2018 and Cushing et al., 2020) and data availability in our context guided the choices of control variables. We run our regressions at two levels. We take both a child-level approach and an aggregated cluster level approach.

Under the cluster level approach, we aggregate the incidence of diseases (disease rate), health outcomes (probability of stunting, wasting, and being underweight) and child level mortality to the cluster level and run a regression of these outcomes on the risk of flaring for each cluster with cluster level controls (averages). The main specification under this approach is:

$$Y_{ct} = \alpha + \beta_1 RF_{ct} + \sum_{d=1}^{D} \theta_d X_{ct}^{d} + \gamma_t + \epsilon_{ct} \qquad (2)$$

Where Y_{ct} are measures of child health i.e. the incidence of cough, respiratory symptoms, fever, diarrhoea, infant, child and under-5 mortality in cluster c in year t. RF_{ct} is the flaring exposure for DHS cluster c in time t . The X_{it} are control variables at the cluster level, γ_t are year effects and ϵ_{ct} are the idiosyncratic errors. The main coefficient of interest, β_1 indicates the association between gas flaring and the rates of child morbidity and mortality at the cluster level.

At the individual level, we run regressions of whether each individual child has the particular disease or condition on exposure to flaring for each cluster while controlling for individual, parental and household characteristics with clustered standard errors at the DHS cluster level:

$$Y_{ict} = \alpha + \beta_2 RF_{ct} + \sum_{d=1}^{D} \theta_d X_{ict}^{d} + \gamma_t + \epsilon_{ict} \qquad (3)$$

Where Y_{ict} is the outcome variable measures of each child i in cluster c at time t in year t. RF_{ct} is the exposure to gas flaring for DHS cluster c in time t. X_{it} are the vector of individual, parental and household control variables, γ_t are the year effects for each DHS-year and ϵ_{ict} are the idiosyncratic errors. The main coefficient of interest, β_2 indicates the association between child health outcomes and flaring at the individual level.

4. Results and Discussion

Table 1 has annual estimates of flaring from 2012 to 2018 (covering timing of the DHS), comparing satellite-detected estimates with the official estimates reported by the Department of Petroleum Resources [DPR] (2018). The satellite-detected estimates are broken down by location, while the DPR figures are just totals. We examine both offshore and onshore flaring and aggregate onshore flaring to the state level (the second administrative level). Flaring volumes show that around half of all gas flared happens offshore. About 56% of flaring in 2013 was offshore, reducing to 48% in 2018. With respect to onshore flaring, Delta State has the highest flaring by volume with around a quarter of all gas flared in 2018 in this state. Two states (Ondo and Anambra) had gas flared in 2013 but not at the time of our second DHS in 2018. The gap between satellite estimates and the official data vary by year. In 2013, official estimates are two percent higher than satellite estimates while in 2018 official estimates are around 32 percent less than satellite estimates. The official estimates rely on self-reporting by oil companies, so it is likely that recent gaps between official estimates and satellite estimates is picking up under-reporting by gas companies in anticipation of regulatory changes.[10]

Table 1: Gas volume flared in million standard cubic feet (MMSCF) by location in Nigeria

Flare location by satellite	2012	2013	2014	2015	2016	2017	2018	Share 2013	Share 2018
Abia	1,027	2,255	2,601	1,032	1,096	1,604	1,556	1%	0%
Akwa Ibom	3,715	6,070	4,992	5,206	5,059	5,528	5,350	1%	1%
Anambra	91	610	533	414	-	-	-	0%	0%
Bayelsa	39,400	38,600	45,100	32,500	42,000	42,600	50,000	9%	11%
Delta	46,900	59,000	54,500	59,600	45,500	66,800	107,000	14%	23%
Edo	12,200	18,100	18,200	18,800	7,324	13,800	23,200	4%	5%
Imo	15,100	14,200	8,608	6,901	7,961	6,816	6,053	3%	1%
Ondo	2,434	2,635	2,447	-	-	-	-	1%	0%
Rivers	45,600	42,500	47,900	41,800	53,400	53,300	52,200	10%	11%
Offshore	194,000	236,000	204,000	181,000	181,000	182,000	226,000	56%	48%
Total flaring by satellite estimates	480,623[11]	419,970	388,880	347,254	343,340	372,448	471,359	100%	100%
Official flaring estimates from DPR[12]	465,257	427,971	393,840	330,933	288,917	324,192	321,290		
Gap (as % of satellite total)	3%	2%	1%	-5%	-16%	-13%	-32%		

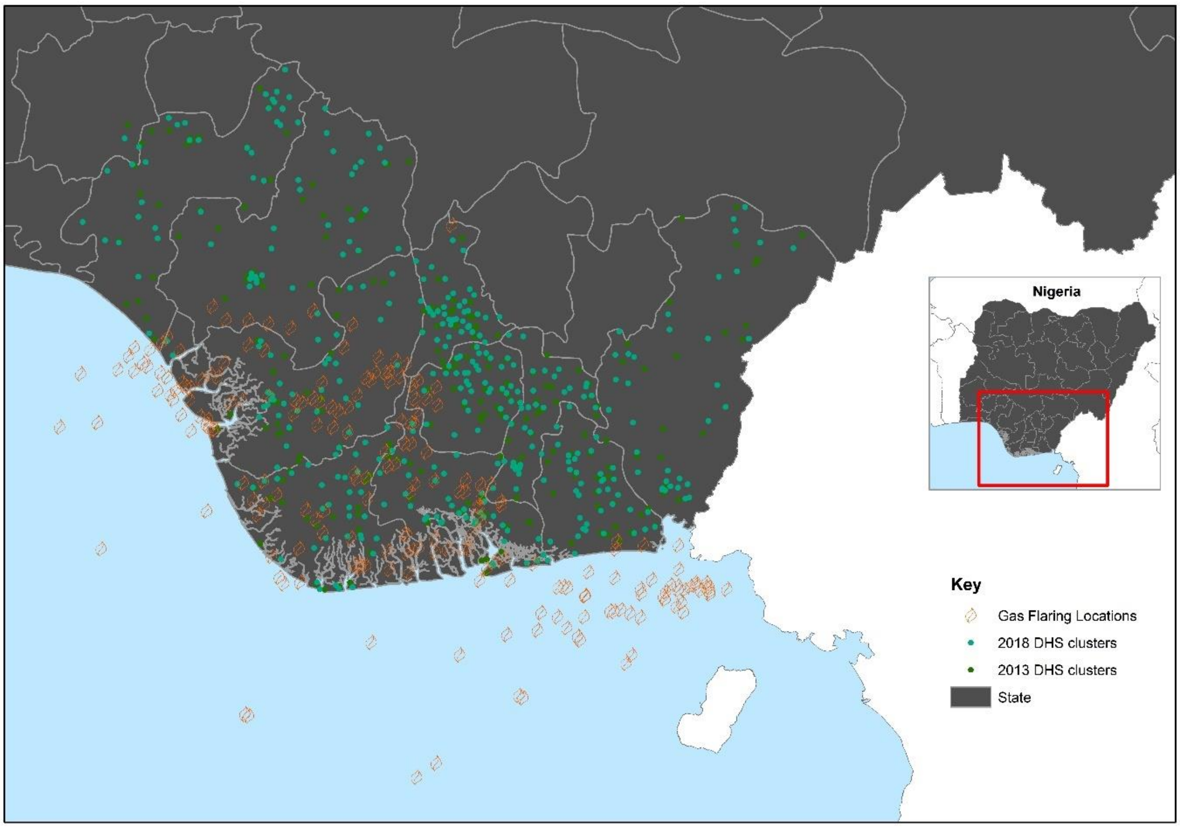
[10] For example, from 2017, the government had approved the National Gas Policy and the Gas flaring prohibition bill was deliberated upon by the Senate in March 2017 with public hearing for stakeholders in the industry and the public in May 2017.

[11] Satellite estimates for 2012 are from the month of March. Annualising the estimates from March leads to a full-year estimate of 480,623MMSCF

[12] Official estimates are from the Department of Petroleum Resources 2018 Annual report. The report comes with a disclaimer which states that figures presented are subject to ongoing review based on continuous reconciliation with various stakeholders

Figure 1 identifies all flaring spots as well as the location of all DHS clusters in the Niger-Delta region.

Figure 1: Gas flaring locations (onshore and offshore) and DHS clusters (2013 and 2018) in the Niger-Delta region of Nigeria



The median distance between DHS clusters and each flaring sites is 181km (in both 2013 and 2018), including onshore and offshore flaring sites. For onshore sites the median distance is 153km. The closest DHS cluster to a flare site in 2018 (2013) is 0.87km (0.69km).

Table 2 presents summary statistics from the pooled 2013 and 2018 Demographic Health Surveys for our child health outcomes, parental and household characteristics in the oil producing states (including Cross-River State).

Table 2: Summary statistics of child health outcome and parental and household control variables from pooled 2018 and 2013 DHS

Variable	Weighted Obs.	Mean	Std. Dev.	Min	Max
Child Incidence of Disease					
Cough	9,722	0.17	0.38	0	1
Respiratory Issues	9,789	0.18	0.38	0	1
Fever	9,720	0.19	0.39	0	1
Diarrhoea	9,714	0.06	0.23	0	1
Child Anthropometric Characteristics					
Stunted	6,317	0.18	0.39	0	1
Wasted	6,316	0.09	0.29	0	1
Underweight	6,323	0.11	0.32	0	1
Child Mortality					
Infant mortality (under 12months) rate	10,555	0.05	0.22	0	1
Child Mortality (12-59months) rate	10,555	0.01	0.12	0	1
Under 5 Mortality (0-59months) rate	10,555	0.07	0.25	0	1
Child Characteristics					
Gender (Boy Child Dummy)	9,789	0.51	0.50	0	1
Age Of Child (Years)	9,789	2.37	1.49	0	5
Parental Characteristics					
Mother Education (Years)	9,788	9.97	3.94	0	20
Age mother's first child	9,789	21.85	4.79	12	48
Mother's Current Partner Education (Years)	9,006	10.61	3.83	0	20
Mother Reads Newspaper	9,771	0.27	0.44	0	1
Household Characteristics					
Has TV Dummy	9,562	0.73	0.44	0	1
Poorest Wealth Quintile	9,789	0.02	0.13	0	1
Poorer Wealth Quintile	9,789	0.09	0.29	0	1
Middle Wealth Quintile	9,789	0.23	0.42	0	1
Richer Wealth Quintile	9,789	0.32	0.47	0	1
Richest Wealth Quintile	9,789	0.34	0.47	0	1
Fuel Type: Electricity/LPG/Natural Gas/Biogas)	9,565	0.09	0.29	0	1
Fuel Type: Kerosene	9,565	0.33	0.47	0	1
Fuel Type: (Coal/Charcoal/Wood/Straw/Shrubs)	9,565	0.58	0.49	0	1
Poor Roof Dummy	9,561	0.06	0.23	0	1
Poor Wall Dummy	9,562	0.18	0.38	0	1
Person Per Room	9,779	3.34	1.66	0.02	12
Urban or Rural	9,789	1.52	0.50	1	2

Note: The wealth quintiles are based on the national wealth distribution

Table 3: Relationships between gas flaring and cluster-level incidence of disease, under-nutrition and mortality: No control variables

VARIABLES	(1) Cough rate	(2) Respiratory Issues rate	(3) Fever rate	(4) Diarrhoea rate	(5) Stunting rate	(6) Wasting rate	(7) Underweight rate	(8) Infant Mortality rate	(9) Child Mortality rate	(10) Under-5 Mortality rate
Flaring exposure	0.0966**	0.0848**	0.0678*	-0.0496	0.0332	0.0618	0.0602	-0.0100	-0.0322	-0.0229
	[0.0406]	[0.0407]	[0.0407]	[0.0408]	[0.0410]	[0.0409]	[0.0409]	[0.0408]	[0.0408]	[0.0408]
Year=2018	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	-0.0000	-0.0000	0.0000
	[0.0833]	[0.0834]	[0.0835]	[0.0836]	[0.0840]	[0.0839]	[0.0839]	[0.0837]	[0.0837]	[0.0837]
Constant	0.0000	-0.0000	-0.0000	0.0000	-0.0000	-0.0000	-0.0000	0.0000	-0.0000	-0.0000
	[0.0653]	[0.0653]	[0.0654]	[0.0655]	[0.0655]	[0.0654]	[0.0654]	[0.0656]	[0.0655]	[0.0655]
Observations	603	603	603	603	595	595	595	603	603	603
R-squared	0.0093	0.0072	0.0046	0.0025	0.0011	0.0038	0.0036	0.0001	0.0010	0.0005

Standard errors in brackets *** p<0.01, ** p<0.05, * p<0.1

Table 4: Relationships between gas flaring and individual-level incidence of disease and under-nutrition: No control variables

VARIABLES	(1) Child has cough	(2) Child has respiratory issues symptoms	(3) Child has fever	(4) Child has diarrhoea	(5) Child is stunted	(6) Child is wasted	(7) Child is underweight
Flaring exposure	0.0294***	0.0278***	0.0260***	0.0000	0.0001	0.0093**	0.0038
	[0.0074]	[0.0074]	[0.0084]	[0.0038]	[0.0057]	[0.0044]	[0.0046]
Year=2018	0.0567***	0.0666***	0.0545***	0.0018	0.0027	-0.0713***	-0.0240**
	[0.0151]	[0.0153]	[0.0159]	[0.0071]	[0.0137]	[0.0082]	[0.0102]
Constant	0.1431***	0.1415***	0.1557***	0.0556***	0.1820***	0.1156***	0.1236***
	[0.0109]	[0.0108]	[0.0106]	[0.0055]	[0.0090]	[0.0067]	[0.0066]
Observations	10,972	11,040	10,969	10,971	7,222	7,223	7,229
R-squared	0.0124	0.0136	0.0100	0.0000	0.0000	0.0152	0.0014

Standard errors in brackets *** p<0.01, ** p<0.05, * p<0.1

Table 3 shows associations between flaring exposure and incidence of disease, nutritional outcomes, and mortality rates at the cluster level without control variables. Specifically, this table presents results of Equation 2 without control variables ($\sum_{d=1}^{D} \theta_d X_{ct}^{d}$). In this table, flaring and child health outcome measures are standardized, so regression coefficients can be interpreted as effects of a one standard deviation (SD) change in flaring exposure. Except for diarrhoea, the results show positive association at conventional significant levels between flaring and incidence of diseases: Cough (95% sig), respiratory issues (95% sig) and fever (90% sig). In these results without control variables there are no significant associations between flaring and child anthropometrics or child mortality rates.

The results for respiratory health imply that a one SD increase in the volume of gas flared raises the cluster-level cough rates by 0.097 SD. The standard deviation of cough across all clusters is 38% and the mean incidence of cough is 17%. Thus, the results suggest that a SD increase in flaring is associated with an increase in the reported cough rate that is equivalent to 22% of the mean cough incidence across all clusters in both periods.

Table 4 takes an individual level focus to relationship between flaring and child health outcomes (that is, using Equation 3). Consistent with the cluster level results, we find a statistically significant positive association between flaring and incidences of cough, respiratory issues, and fever. A 1-SD increase in flaring volume is associated with around a 3% increase in the probability that a child has cough, reports a respiratory issue, or has fever. Like the cluster level results, we do not find a significant result for diarrhoea. For our anthropometric characteristics, unlike the cluster level regressions, at the individual level, we find a positive association between flaring and the probability that a child is wasted. Given the possibility of omitted variable bias in the relationship between flaring and child health outcomes, for the children who are still alive, we next consider the association between child outcomes and flaring after controlling for parental and household characteristics at the individual and cluster level.

Table 5: Regression of incidence of disease and mortality on gas flaring controlling for cluster characteristics: cluster level

VARIABLES	(1) Cough rate	(2) Respiratory Issues rate	(3) Fever rate	(4) Diarrhoea rate	(5) Stunting rate	(6) Wasting rate	(7) Underweight rate	(8) Infant Mortality rate	(9) Child Mortality rate	(10) Under-5 Mortality rate
Flaring exposure	0.0930**	0.0840**	0.0940**	-0.0198	0.0798**	0.0806*	0.1021**	0.0102	-0.0091	0.0044
	[0.0424]	[0.0425]	[0.0423]	[0.0424]	[0.0404]	[0.0430]	[0.0415]	[0.0423]	[0.0426]	[0.0422]
Wealth quintile	-0.0650	-0.0741	-0.2181***	-0.1710**	-0.2816***	-0.1103	-0.2702***	-0.1371**	-0.1447**	-0.1810***
	[0.0698]	[0.0699]	[0.0696]	[0.0698]	[0.0671]	[0.0714]	[0.0690]	[0.0697]	[0.0702]	[0.0695]
Poor roof rate	-0.0186	-0.0218	0.0073	0.0208	-0.0189	-0.0058	0.0464	-0.0645	0.0190	-0.0506
	[0.0518]	[0.0519]	[0.0517]	[0.0518]	[0.0494]	[0.0525]	[0.0508]	[0.0517]	[0.0521]	[0.0516]
Poor wall rate	-0.0438	-0.0550	-0.1358**	-0.1430**	0.0083	-0.0873	-0.0894	-0.0324	-0.0570	-0.0514
	[0.0609]	[0.0610]	[0.0607]	[0.0609]	[0.0580]	[0.0617]	[0.0596]	[0.0608]	[0.0612]	[0.0606]
Persons per room	0.1034**	0.1022**	0.0418	0.0107	0.0549	0.0075	0.0382	-0.0035	-0.0055	-0.0050
	[0.0414]	[0.0415]	[0.0413]	[0.0414]	[0.0398]	[0.0423]	[0.0409]	[0.0413]	[0.0416]	[0.0412]
Reads newspaper rate	0.0616	0.0514	0.0681	-0.0355	-0.1137**	-0.0060	-0.0655	0.0584	-0.0018	0.0511
	[0.0477]	[0.0477]	[0.0475]	[0.0477]	[0.0459]	[0.0488]	[0.0471]	[0.0476]	[0.0479]	[0.0474]
Rural	0.0235	-0.0111	0.0385	0.0074	-0.0342	0.0046	-0.0689	0.2275**	-0.0217	0.1959**
	[0.0953]	[0.0955]	[0.0950]	[0.0953]	[0.0909]	[0.0966]	[0.0933]	[0.0951]	[0.0958]	[0.0949]
Year=2018	0.0003	-0.0001	0.0005	0.0001	-0.0003	-0.0005	-0.0015	0.0028	-0.0003	0.0024
	[0.0832]	[0.0833]	[0.0829]	[0.0832]	[0.0791]	[0.0841]	[0.0812]	[0.0830]	[0.0835]	[0.0827]
Constant	-0.0143	0.0068	-0.0235	-0.0045	0.0208	-0.0028	0.0420	-0.1386	0.0132	-0.1194
	[0.0873]	[0.0874]	[0.0870]	[0.0873]	[0.0829]	[0.0881]	[0.0851]	[0.0871]	[0.0877]	[0.0868]
Observations	603	603	603	603	595	595	595	603	603	603
R-squared	0.0229	0.0205	0.0293	0.0230	0.1248	0.0104	0.0764	0.0278	0.0143	0.0327

Standard errors in brackets*** p<0.01, ** p<0.05, * p<0.1

Table 6: Regression of incidence of disease and mortality on gas flaring controlling for individual and household characteristics: individual level

VARIABLES	(1) Child has cough	(2) Child has respiratory issues symptoms	(3) Child has fever	(4) Child has diarrhoea	(5) Child is stunted	(6) Child is wasted	(7) Child is underweight
Flaring exposure	0.0316***	0.0300***	0.0299***	0.0012	0.0063	0.0111**	0.0093*
	[0.0077]	[0.0077]	[0.0086]	[0.0038]	[0.0067]	[0.0044]	[0.0048]
Boy Child	0.0101	0.0102	-0.0041	0.0009	0.0214*	0.0117	0.0185**
	[0.0094]	[0.0093]	[0.0093]	[0.0055]	[0.0113]	[0.0081]	[0.0084]
Mother Education (years)	0.0021	0.0018	0.0041**	0.0018	-0.0031	-0.0019	-0.0033*
	[0.0019]	[0.0019]	[0.0018]	[0.0013]	[0.0025]	[0.0015]	[0.0018]
1.age (years)	0.1050***	0.1059***	0.1070***	0.0409***	0.0045	0.0344*	0.0052
	[0.0162]	[0.0165]	[0.0157]	[0.0108]	[0.0204]	[0.0208]	[0.0190]
2.age (years)	0.0685***	0.0615***	0.1049***	0.0061	0.0954***	-0.0378*	0.0080
	[0.0169]	[0.0164]	[0.0155]	[0.0096]	[0.0217]	[0.0215]	[0.0185]
3.age (years)	0.0589***	0.0547***	0.0642***	-0.0063	0.0817***	-0.0870***	-0.0163
	[0.0155]	[0.0157]	[0.0156]	[0.0105]	[0.0233]	[0.0196]	[0.0190]
4.age (years)	0.0073	0.0009	0.0446***	-0.0268***	0.0384*	-0.0789***	-0.0138
	[0.0165]	[0.0171]	[0.0140]	[0.0088]	[0.0228]	[0.0195]	[0.0205]
5.age (years)	-0.0115	-0.0147	0.0410**	-0.0181	0.0438*	-0.0821***	0.0013
	[0.0189]	[0.0189]	[0.0187]	[0.0115]	[0.0263]	[0.0220]	[0.0236]
Age mother first child	-0.0005	-0.0004	-0.0009	-0.0005	-0.0009	0.0003	0.0012
	[0.0013]	[0.0013]	[0.0013]	[0.0007]	[0.0013]	[0.0009]	[0.0010]
Mother’s partner education (years)	0.0042**	0.0046***	0.0003	-0.0008	-0.0042**	-0.0013	-0.0024*
	[0.0017]	[0.0017]	[0.0019]	[0.0013]	[0.0019]	[0.0014]	[0.0014]
Has TV	-0.0199	-0.0151	0.0007	-0.0087	0.0252	-0.0057	0.0147
	[0.0168]	[0.0163]	[0.0151]	[0.0085]	[0.0188]	[0.0125]	[0.0149]
Poorer Wealth quintile	-0.0135	-0.0212	-0.0020	-0.0731**	-0.0365	0.0033	0.0251
	[0.0385]	[0.0355]	[0.0549]	[0.0367]	[0.0623]	[0.0288]	[0.0367]
Middle Wealth quintile	-0.0203	-0.0251	-0.0335	-0.0790**	-0.0229	0.0048	-0.0024
	[0.0388]	[0.0373]	[0.0565]	[0.0386]	[0.0598]	[0.0283]	[0.0363]
Richer Wealth quintile	-0.0214	-0.0307	-0.0446	-0.0648	-0.0957	-0.0167	-0.0604
	[0.0437]	[0.0423]	[0.0601]	[0.0416]	[0.0616]	[0.0314]	[0.0386]
Richest Wealth quintile	-0.0510	-0.0595	-0.0760	-0.0901**	-0.0999	-0.0268	-0.0626
	[0.0499]	[0.0488]	[0.0623]	[0.0427]	[0.0635]	[0.0347]	[0.0411]
Kerosene cooking fuel type	-0.0474	-0.0454	-0.0014	-0.0056	0.0110	0.0119	0.0166

	[0.0294]	[0.0293]	[0.0263]	[0.0100]	[0.0253]	[0.0174]	[0.0176]
Coal/Charcoal/Wood/Straw Shrubs cooking fuel type	-0.0469	-0.0434	0.0123	0.0066	0.0362	-0.0015	0.0259
	[0.0306]	[0.0305]	[0.0272]	[0.0125]	[0.0266]	[0.0184]	[0.0205]
Poor roof	0.0018	0.0007	-0.0037	0.0124	0.0244	-0.0085	0.0055
	[0.0306]	[0.0303]	[0.0369]	[0.0174]	[0.0424]	[0.0205]	[0.0279]
Poor wall	-0.0038	-0.0035	0.0103	0.0031	0.0395*	-0.0166	0.0032
	[0.0206]	[0.0206]	[0.0231]	[0.0129]	[0.0222]	[0.0180]	[0.0174]
Person per room	0.0081**	0.0088**	0.0029	0.0009	0.0032	0.0010	0.0015
	[0.0039]	[0.0039]	[0.0036]	[0.0016]	[0.0040]	[0.0026]	[0.0031]
Mother Reads newspaper	0.0059	0.0053	0.0056	-0.0065	-0.0155	0.0078	-0.0104
	[0.0146]	[0.0145]	[0.0141]	[0.0070]	[0.0155]	[0.0122]	[0.0118]
Rural	-0.0115	-0.0170	-0.0012	-0.0003	-0.0079	-0.0028	-0.0159
	[0.0154]	[0.0160]	[0.0157]	[0.0085]	[0.0150]	[0.0106]	[0.0107]
2018.year	0.0508***	0.0605***	0.0616***	0.0007	0.0265*	-0.0725***	-0.0100
	[0.0165]	[0.0166]	[0.0161]	[0.0070]	[0.0139]	[0.0095]	[0.0106]
Constant	0.1022	0.1054*	0.0880	0.1315***	0.2276***	0.1889***	0.1574***
	[0.0622]	[0.0615]	[0.0789]	[0.0467]	[0.0764]	[0.0519]	[0.0569]
Observations	9,754	9,803	9,750	9,754	6,521	6,523	6,528
R-squared	0.0336	0.0354	0.0252	0.0183	0.0412	0.0446	0.0223

Standard errors in brackets *** p<0.01, ** p<0.05, * p<0.1

Tables 5 and 6 present results of regressions between child health outcomes and flaring, after various characteristics of the parents and household (and also of the child, in Table 6) are controlled for. The cluster-level results in Table 5 use as control variables: the cluster averages for wealth quintile and the average person per room, proportion of households in the cluster with poor wall and poor roof, and the proportion of mothers who read a newspaper (as a proxy for access to information). [13]

After controlling for the cluster level characteristics, we find a positive association between flaring exposure and incidence rates of all diseases considered except diarrhoea. Our results are in line with evidence from Gobo et al. (2009) where analysis of medical records showed a greater frequency of disease types such as asthma, cough, breathing difficulty, eye/skin irritation in areas with a long history of gas flaring compared to areas with no flaring. Our results also imply a varying relationship between wealth and incidence of diseases. Richer clusters on average have significant less fever and diarrhoea, while cough and respiratory symptom incidence show no similar association, suggesting a lesser role for income/wealth as a mitigating factor for respiratory diseases in this context. Aside from flaring exposure, we find overcrowding significantly associated with cough and respiratory symptoms but not with fever and diarrhoea.

For child anthropometrics, we find significant positive associations between gas flaring and rates of stunting, wasting, and under-weight. These effects are larger than what is reported in Table 3, with no control variables included. Across these three anthropometric indicators, a standard deviation higher volume of gas flaring is associated with up to a 0.1 standard deviation higher rate of stunting, wasting or under-weight. However, the data reveal no significant association between flaring exposure and child mortality outcomes.

Our results at the individual level (in Table 6) are consistent with the cluster level findings. We find a positive association between flaring exposure and incidence of all the diseases considered except diarrhoea. A standard deviation higher flare volume is associated with a three-percentage point higher probability that a child has cough, a respiratory symptom, or fever. Among our control variables, only child age, the education of the mother’s partner, and persons per room (an indicator of crowding) had a significant association with flaring.

For child anthropometric characteristics, we find significant positive associations between flaring and the probability that a child is under-weight or wasted but no association with stunting. Weight-based

[13] Poor wall is defined as households where the main wall materials are cane/palm/trunk, dirt, bamboo, stone, plywood, cardboard, reused wood, and metal zinc. Poor roof is defined as households where main roof materials made of thatch/palm leaf, rustic mat, wood planks, palm/bamboo main materials.

child anthropometric indicators are typically considered to reflect shorter-term nutritional deprivation and morbidity, while stunting reflects longer-term conditions. It would therefore be useful for future research to examine lagged effects of gas flaring in prior years. It is important to note that our results may also be picking up other channels of pollution such as oil spillage which are rampant in this region, and which could adversely affect child growth through deleterious effects of on agricultural output.

Relatedly, an important caveat to associations between flaring and child health is that omitted variable bias may still be a problem. In future work, we will investigate the possibility of identifying a causal impact of pollution on health outcomes by comparing the health outcomes of siblings born to the same mother before and after flaring. Sometimes technical factors cause wells to stop flaring for a long period of time before resuming, and this gives an opportunity to compare outcomes of siblings born to the same mother before and after flaring for locations with long stoppages in flaring. By comparing siblings born to the same mother, we can control for a host of other unobservable characteristics that may confound the identification of the causal relationship between gas flaring and child health.

5. Conclusion

We use a newly available dataset on satellite detected gas flaring to examine the relationship between flaring and various child-health outcomes. Our results show a positive association between flaring and incidence of diseases (particularly cough, respiratory symptoms, and fever) and short-term nutritional outcomes (wasting and underweight). Our results are in line with earlier evidence from a smaller subset of flaring communities where flaring has been found to be associated with a host of diseases and poor agricultural production. Our analysis provides the first comprehensive overview of flaring and child health outcomes in the Niger-Delta region, one of the regions with the highest flare activity in the world and where earlier efforts to examine the impact of flaring activity were limited due to the lack of data. While the methods described above can be used to show an association between flaring and human health, omitted variable bias may still be a problem and the association presented by these methods does not necessarily imply causation. In future work, we will investigate the possibility of identifying a causal impact of pollution on health outcomes by comparing the health outcomes of siblings born to the same mother before and after flaring. The method and design described for this project can be extended to other countries in Sub-Saharan Africa such as the Republic of Congo and Gabon that are like Nigeria in their practice of routine gas flaring but where unavailability of data has limited the examination of the health impacts of this practice. The extension of the approach described here provides an opportunity to build an evidence base on the impact of gas flaring on human health in Sub-Saharan Africa.

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