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Four phases of the Flint Water Crisis: Evidence from blood lead levels in children

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ABSTRACT

The Flint Water Crisis (FWC) is divisible into four phases of child water-lead exposure risk: Phase A) before the switch in water source to the Flint River (our baseline); Phase B) after the switch in water source, but before boil water advisories; Phase C) after boil water advisories, but before the switch back to the baseline water source of the Detroit Water and Sewerage Department (DWSD); and Phase D) after the switch back to DWSD. The objective of this work is to estimate water-lead attributable movements in child blood lead levels (BLLs) that correspond with the four phases in the FWC. With over 21,000 geo-referenced and time-stamped blood lead samples from children in Genesee County drawn from January 01, 2013 to July 19, 2016, we develop a series of quasi-experimental models to identify the causal effect of water-lead exposure on child BLLs in Flint. We find that the switch in water source (transitioning from phase A to B) caused mean BLLs to increase by about 0.5 μg/dL, and increased the likelihood of a child presenting with a BLL ≥ 5 μg/dL by a factor of 1.91–3.50, implying an additional 561 children exceeding 5 μg/dL. We conservatively estimate cohort social costs (through lost earnings alone) of this increase in water-lead exposed children at $65 million, contrasted with expected annual savings of $2 million from switching water source. On the switch from Phase B to C, we find BLLs decreased about 50% from their initial rise following boil water advisories and subsequent water avoidance behaviors by households. Finally, the return to the baseline source water (Phase D) returned child BLLs to pre-FWC levels further implicating water-lead exposure as a causal source of child BLLs throughout the FWC.

1. Introduction

From 1967 till April 2014, the City of Flint purchased treated water wholesale from the Detroit Water and Sewage Department (DWSD), now the Great Lakes Water Authority (GWLA). Throughout this period the Flint Water Service Center (FWSC) maintained a backup water treatment facility. Facing another expected increase in the price of treated water from the DWSD – prices nearly tripled ($/mcf) from 2002 to 2012 – Flint's Emergency Manager (EM), with the consent of City Council, decided to join the newly constituted Karegnondi Water Authority (KWA) in 2013. By joining the KWA, which was constructing its own pipeline to transmit raw water from the same DWSD source of Lake Huron, Flint officials anticipated savings of $600 million over the next 30 years (Lynch, 2016). In the interim, the City of Flint had the option of continuing to purchase treated water from DWSD or treat Flint River water at its own facility. After failing to come to an agreement on a short-term contract with DWSD, and in an effort to save $2 million annually in the meantime, Flint decided on the Flint River water source treated at their FWSC (Felton, 2014; Fonger, 2014).

Within a few weeks of the switch to Flint River water, residents started complaining about the taste and odor of their drinking water. In mid-May 2014, residents reported issues of skin inflammation in their children (Davis et al., 2016). During this time, water discoloration was observed throughout the distribution system (Felton, 2014; Veolia North America, 2015), and there was an unusually large number of water main breaks (Fonger, 2015). Starting in summer 2014, a number of water quality problems developed, some of which resulted in violations of Safe Water Drinking Act (SWDA) standards. Escherichia coli (E. coli) and total coliform violations resulted in the issuance of a series of boil water alerts (Emery, 2016; Masten et al., 2016). While boil advisories were not meant to address the problem of lead contaminated water – as the lead problem was not fully understood in this episode of the crisis – retrospective analyses of the period (see Christensen et al., 2017) indicate a substantial and sustained increase in the purchase of bottled water among residents in Genesee County following the issuance of boil water alerts, indicating significant water avoidance

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by the local population.

By Aug. 31, 2015, Marc Edwards, a professor at Virginia Polytechnic Institute and State University, had analyzed 252 water samples from homes in Flint. He found that 20% of the samples had lead levels that exceeded the 15 μg/L action level (Edwards, 2015). In September, a team led by a local pediatrician, Mona Hanna-Attisha, published data showing that blood lead levels (BLLs) in children increased significantly after the switch to the Flint River water source (Hanna-Attisha et al., 2016). After much publicity regarding the lead problem, on October 16, 2015, the source water for the City of Flint was switched back to treated Lake Huron water supplied by DWSD.

One can divide this abbreviated description of events into four phases corresponding to meaningful breaks in the risk of child water-lead exposure: A) before switch; B) after switch prior to boil advisories; C) after switch after boil advisories; and D) after switch back. With an extraordinary dataset (secured by confidentiality agreement with the Michigan Department of Community Health, Childhood Lead Poisoning Prevention Project) of over 21,000 geo-referenced and time-stamped blood lead samples from children in Flint (and outside Flint in Genesee County) drawn from January 1st, 2013 to July 19th, 2016, we analytically leverage these four phases to identify the causal effect of water-lead exposure on child BLLs in Flint. We develop a series of difference-in-differences models to estimate water-lead attributable movements in child blood lead levels (BLLs) that correspond with exogenous breaks in the Flint Water Crisis (FWC).

Our work extends the work of Hanna-Attisha et al. (2016) in multiple ways. First, by inclusion of many control groups – variously constituted by children residing at the periphery of Flint proper – we address confounding from other sources of lead exposure that are coincidental with the timing of the switch in water source (see Laidlaw et al. (2016)). Second, by division of the post-switch period into before and after the issuance of official boil water advisories, we capitalize on awareness and subsequent water avoidance behaviors of households as an additional source of variation in water-lead exposure risk. This provides some assessment of public health interventions undertaken during the crisis. Third, we extend the analysis of the FWC to the switch-back period, testing whether the return to Detroit water (and away from the highly corrosive Flint River water source) restored child BLLs to pre-crisis levels.

In analyses ahead, we evaluate how the switch to Flint River water influenced child mean BLLs in Flint. We determine the number of children that exceeded the CDCs guidance level of ≥ 5 μg/dL associated with the lead-contaminated drinking water and then calculate a conservative estimate of the cohort-specific damages through expected reductions in lifetime earnings. Consistent with the water-lead exposure source proposition, we evaluate how BLLs in Flint change following the issuance of advisories and subsequent water avoidance behaviors of affected households. Finally, we evaluate if BLLs in Flint returned to pre-FWC levels following the switch back to Detroit water. In the next section, we detail measurement and statistical decisions made to identify the water-lead exposure pathway.

2. Methods

2.1. Data

Blood lead data were obtained from the Michigan Department of Community Health (MDCH) by confidentiality agreement. The dataset contains blood samples on 21,403 children collected from January 1st, 2013 through July 19th, 2016, under the Healthy Homes and Lead Poisoning Prevention (HHLPP) program. The HHLPP is funded by the CDC and designed to support "lead poisoning prevention and surveillance services for children in Michigan." Blood lead data are reported in micrograms per deciliter of blood (μg/dL). The MDCH data also contain information on the census block group residential location of each child, the precise date of blood sample collection, child date of birth (allowing one to derive child age at the moment of sample), child sex (male = 1, female = 0), and the method of blood draw (1 = cutaneous; 0 = venous). As with previous research (Zahran et al., 2011, 2017), we analyze child BLL as a continuous variable (in μg/dL) and then as a binary variable of ≥ 5 μg/dL = 1, < 5 μg/dL = 0, corresponding to the CDCs present reference level of elevated blood lead.

2.2. Four phases of the Flint Water Crisis

We divide the Flint Water Crisis (FWC) into four phases corresponding to exogenous breaks in child risk of water-lead exposure: A) before the switch in water source; B) after the switch in water source but before boil water advisories prompted by the identification of E. coli in the distribution system; C) after boil water advisories while still utilizing the Flint River as the source of drinking water; and D) after the return to DWSD water (now the GLWA). Phase A, the before switch period, is from January 1st, 2013 to April 25th, 2014. Phase B, the after switch/before boil advisory period, is from April 26th, 2014 to September 14th, 2014. Phase C, the after switch/after boil advisory period, is from September 15th, 2014 to September 25th, 2015. Phase D, the after switch back period, is from September 25th, 2015 to July 19th, 2016. The switch points from Phase A to B and from Phase C to D correspond to the dates when the source of water delivered to Flint residents were switched, going from Detroit (DWSD) to Flint River water, and then from Flint River back to Detroit water (GLWA). The switch point from Phase B to C is more ambiguous. From the 16th of August until the 14th of September 2014, City of Flint officials issued a series of targeted boil water advisories. While the motivation was not meant to account for water lead exposure risk – which remained unknown to relevant managerial and technical personnel at the time – the boil advisories induced water avoidance behaviors in the local population that substantially minimized the risk of water lead exposure.

In analyses that follow, the dates of phase transition (detailed above) are forwarded 30 days to variously account for the physical chemistry and physiology involved in the switch from one exposure phase to the next. In the switch from Detroit (Phase A) to Flint River water (Phase B), which occurred on April 25th, 2014, we forward 30 days to account for the chemistry involved in the dissolve of passivation layers inside lead-based pipes in the Flint water system.[1] This passivation lag of 30 days in the switch from Phase A to B is also consistent with the timing of complaints by residents with respect to the color, taste, and odor of drinking water (see Masten et al. (2016)). A 30 day lag in going from Phase B to C is also scientifically warranted to account for the known residence time of lead in child bloodstreams (Hu et al., 1998; Lidsky and Schneider, 2003; Rabinowitz, 1991). A physiological lag of 30 days guards against a potential period classification error where a child sampled in early Phase C might register an elevated blood lead level because of water lead exposures in Phase B. Finally, for both reasons of the time required for the restoration of a passivation layer and the residence time of lead in the bloodstream, a forward lag of 30 days is required in the movement from Phase C to D. Fig. 1 summarizes the four phases of the FWC with lag adjustments.

[1] Flint received water from DWSD since 1967. Over the nearly 50 years of service, water entering the distribution system was managed appropriately resulting a layer coating the inside of pipes (i.e. passivation layer), creating a barrier between lead bearing metals and drinking water. When the City of Flint switched its water supply, the new corrosive water rapidly dissolved this layer allowing lead present in pipes to dissolve into drinking water. Because some of these reactions are kinetically limited and time-dependent changes in water chemistry, the extent of time water was in contact with lead bearing metals created variations in exposure. It can be assumed that the greater the amount of time water spent in the distribution system (i.e. water age), the greater the dissolution of the passivation layer. These conditions responsible for the dissolution of the passivation layer are described by Masten et al. (2016). Following the switch back to Detroit water, now supplied by the GLWA, chemical conditions of the new water supply, mainly the presence of orthophosphate, resulted in precipitation and the rebuilding of the passivation layer.