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Determinants of Exposure to Endocrine Disruptors Following Hurricane Harvey

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Abstract

Hurricane Harvey was a category four storm that induced catastrophic flooding in the Houston metropolitan area. Following the hurricane there was increased concern regarding chemical exposures due to damage caused by flood waters and emergency excess emissions from industrial facilities. This study utilized personal passive samplers in the form of silicone wristbands in Houston, TX to both assess chemical exposure to endocrine disrupting chemicals (EDCs) immediately after the hurricane and determine participant characteristics associated with higher

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Declaration of interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Conflict of Interest: Kim A. Anderson and Diana Rohlman, co-authors for this research disclose a financial interest in MyExposome, Inc., which markets products related to the research being reported. The terms of this arrangement have been reviewed and approved by Oregon State University in accordance with its policy on research conflicts of interest. The authors have no other conflict of interest disclosures.

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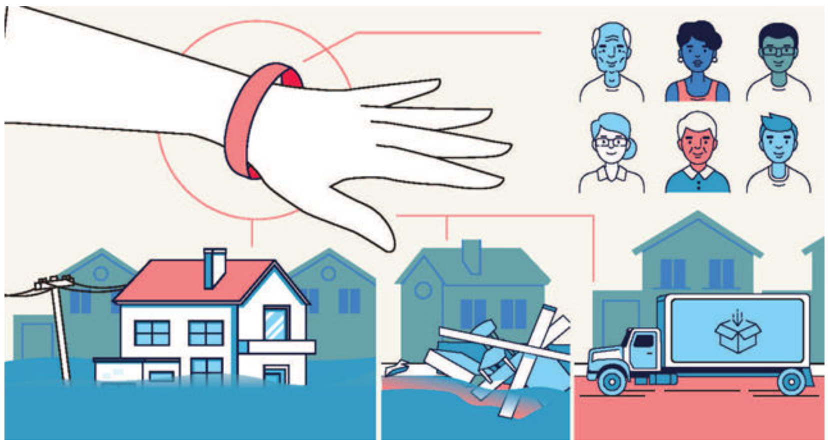
concentrations of exposure. Participants from the Houston-3H cohort (n=172) wore a wristband for seven days and completed a questionnaire to determine various flood-related and demographic variables. Bivariate and multivariate analysis indicated that living in an area with a high Area Deprivation Index (ADI) (indicative of low socioeconomic status), identifying as Black/African American or Latino, and living in the Houston neighborhoods of Baytown and East Houston were associated with increased exposure to EDCs. These results provide evidence of racial/ethnic and socioeconomic injustices in exposure to EDCs in the Houston Metropolitan Area. Since the multiple regression models conducted did not fully explain exposure ($0.047 < R2 < 0.34$), more research is needed on the direct sources of EDCs within this area to create effective exposure mitigation strategies.

Graphical Abstract



Keywords

Hurricane Harvey; environmental justice; passive sampling; endocrine disrupting chemicals; natural disasters; silicone wristbands

1. Introduction

The number of weather and climate-related disaster events and the magnitude of related damages in the US have been increasing in recent decades (NOAA National Centers for Environmental Information (NCEI), 2021). Projections estimate that these events will only become more common in the coming years (Holland and Bruyère, 2014). The increase in extreme weather events will potentially increase the frequency of storm-related pollutant release in heavily industrialized communities, worsening the resident's exposure to industrial emissions. This situation was observed in the Texas Gulf Coast during Hurricane Harvey (Du et al., 2020; Misuri et al., 2019; Qin et al., 2020).

On August 25, 2017, Hurricane Harvey made landfall along the Texas coast approximately 200 miles southeast of Houston, TX, as a Category 4 Hurricane. What made Harvey particularly catastrophic was its slow-motion; the storm stalled over southeastern Texas, inundating the region with as much as 60 inches of rainfall and generating winds speeds

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up to 130 mph (Amadeo, 2018; Misuri et al., 2019; Phillips, 2018; Sebastian et al., 2017). To date, Harvey is the wettest tropical cyclone on record for the US (Phillips, 2018) and is the second costliest natural disaster in US history behind Hurricane Katrina (Amadeo, 2018; NOAA National Centers for Environmental Information (NCEI), 2021).

The Texas Gulf Coast is home to numerous industrial facilities, including the largest petrochemical industrial complex in the US (the ExxonMobil Baytown Complex) (Meyler et al., 2007), and is one of the fastest growing plastic manufacturing centers in the world (Phillips, 2019). Hurricane Harvey was associated with flood-related damage to chemical plants, oil refineries, and flooding of hazardous waste sites, including 13 Superfund sites within the Houston area (Du et al., 2020; Kiaghadi and Rifai, 2019; Misuri et al., 2019). When refineries and other chemical facilities are forced to shut down and restart due to inclement weather, they release unscheduled pollutants. During Hurricane Harvey there was an estimated 8.3 million pounds of reported air pollution, including volatile organic chemicals (Misuri et al., 2019; Phillips, 2018). This is likely an underestimate since a proclamation went into effect three days after Harvey made landfall that waived state pollution reporting rules (Phillips, 2018).

Public health concerns were immediately raised regarding potential exposure to toxic chemicals from the emergency industrial releases (Nicole, 2018). A pilot study was initiated within Houston less than one month after Hurricane Harvey made landfall using silicone wristbands as personal sampling devices (n = 26). Participants wore the wristbands from September 21^{st}-28^{th}, 2017, and wristband extracts were measured for 1,530 target analytes. The results from the pilot study indicated a high prevalence of endocrine disrupting compounds (EDCs) (Dixon et al., 2019). EDCs, otherwise known as endocrine disruptors (EDs) are exogenous chemicals that interfere with hormone action. EDCs may disrupt the normal level of hormones in the body through several mechanism including mimicking hormone action, downregulating or upregulating hormone production, disrupting hormone syntheses or metabolism, altering hormone receptors, or competitively binding with hormone receptors (Diamanti-Kandarakis et al., 2009; Gore et al., 2015a). EDCs represent a broad group of molecules including organochlorinated pesticides, industrial chemicals, plastics and plasticizers, flame retardants and others. Sources of exposure include food production, industrial activity, personal and home care, and medical products and equipment (Darbre, 2015; Diamanti-Kandarakis et al., 2009; Gore et al., 2015a; Sargis and Simmons, 2019). Several Superfund sites in the area are known to contain EDCs (2021), and flooded during Hurricane Harvey (Phillips, 2018). Additionally, several known EDCs are manufactured within the Houston metropolitan area including those used for flame retardants such as organophosphates (Clark et al., 2017) and plastics such as phthalate esters (Phillips, 2019).

EDCs are utilized in a variety of applications (The International Panel on Chemical Pollution (IPCP), 2017; Zoeller et al., 2012) and are often found in the environment at concentrations associated with a wide range of adverse health outcomes (Attina et al., 2016) (e.g. obesity and diabetes, reproduction abnormalities, hormone-sensitive cancers, thyroid abnormalities, neurodevelopmental deficits and neuroendocrine system dysregulation (Diamanti-Kandarakis et al., 2009; Gore et al., 2015a; Gore et al., 2015b;

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Zoeller et al., 2012)). Despite the hazards, there is limited research on determinants of EDC exposure, but demographic variables including race and socioeconomic status have been previously indicated (Attina et al., 2016; Chan et al., 2021; James-Todd et al., 2012). Given the mass amount of unplanned industrial chemical releases due to Hurricane Harvey (Bodenreider, 2019; Du et al., 2020; Phillips, 2018; Qin et al., 2020) and ongoing production in the area (Clark et al., 2017; Phillips, 2019), it was theorized that residents exposure to EDCs may have increased during post-hurricane flooding and flood clean-up.

This study sought to examine personal exposure to EDCs in a flood-impacted area using silicone wristbands after Hurricane Harvey. Additionally, this study aimed to investigate the relationship that flood exposure, and demographic variables such as age, race, and socioeconomic status had on exposure to EDCs.

2. Methods

This project is part of the Houston Hurricane Harvey Health (Houston-3H) study, a multicomponent community-engaged research study focused on evaluating Hurricane Harvey flood-related exposures and assessing their impact on short- and long-term health outcomes among Houston-area residents. Full details about the Houston-3H study have been previously published (Oluyomi et al., 2021). Briefly, one month after the Hurricane in 2017 and approximately a year later in 2018, Houston-3H participants completed a health and exposure questionnaire, provided saliva and nasal swab samples for microbiome analysis, and wore a silicone wristband for monitoring exposure to chemicals (Oluyomi et al., 2021). The current analysis utilized chemical exposure data, self-reported questionnaire data, and neighborhood-level socioeconomic data from secondary sources for the 2017 timepoint. The Houston-3H study was approved by the institutional review boards at Oregon State University, Baylor College of Medicine, and the University of Texas Health Science Center.

2.1. Study Population

In 2017, 206 participants enrolled in the chemical exposure component of the Houston-3H study; 172 completed all necessary actions to be included in the following analyses. Detailed explanations of study site selection, neighborhood characteristics, recruitment, and enrollment have been reported (Oluyomi et al., 2021). Of note, flood impacted neighborhoods within Harris County, TX (the county Houston is located within) were systematically selected using preliminary Federal Emergency Management Agency damage assessments. Recruitment centers for the neighborhoods of Addicks, Baytown, and East Houston were located at various community centers and churches. An additional recruitment center at Baylor College of Medicine captured employees whose homes flooded; most of which resided in the Bellaire-Meyerland neighborhood. As previously described: Addicks is an affluent Houston suburb which was primarily affected by reservoir flooding and failed sewage facilities, Baytown contains the nation’s largest refinery and one of the largest chemical manufacturing complexes, East Houston is an older largely lowincome inner-city neighborhood, and Bellaire-Meyerland is largely upper-middle class and is mostly inside the 100-year floodplain (Nicole, 2018; Oluyomi et al., 2021).

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Inclusion criteria for the study included: minimum 5 years of age, English or Spanish language fluency, and residing in flood impacted areas. Multiple individuals from the same household were allowed to participate in the study. Following informed consent, participants completed a questionnaire on floodwater exposures, current exposures to flood waste, and demographics. Participants received a silicone wristband to wear for seven days, and were asked to keep the wristbands on for the duration of the sampling period. Wristbands were returned between September 21, 2017, and October 20, 2017 (within 45 days of the end of Hurricane Harvey).

2.2. Predictor Variables

Questionnaires included information necessary to gauge exposure to flooding, demographic information, and information to calculate an Area Deprivation Index (ADI), which was used to measure a participant's socioeconomic status. Flood-related predictor variables included whether a participant was involved in flood-clean-up, approximate flood amount in home, time spent in a flooded home during sampling, and whether the participant home flooded, and if a participant home flooded whether they were currently living in a flooded home, or had moved to a non-flooded home. Demographic variables evaluated included gender, race/ethnicity (i.e. Asian, non-Latin black/African American, and Latino), ADI, and age (Table 1). Age groups were defined as youth (five-19), adults (20–64), and seniors (>64). The youth group included participants in both middle childhood and adolescence (McKown and Weinstein, 2003; Osterhaus and Koerber, 2021; 2003).

2.2.1. Area Deprivation Index (ADI)—As previously described (Oluyomi et al., 2021), ADI is a composite measure of neighborhood-level socioeconomic disadvantage that is based on 17 US Census measures from the following four categories: poverty, housing, employment, and education (Knighton et al., 2016; Singh, 2003). ADI scores were stratified into quartiles for univariate analysis. Higher ADI scores represent a greater socioeconomic disadvantage.

2.3. Exposure Assessment & Quality Assurance

2.3.1. Silicone Wristband Preparation and Extraction—Conditioning, post-deployment cleaning, and wristband extraction were performed as previously described (Anderson et al., 2017) with limited modifications. Silicone wristbands (size large--width: 1.3 cm; inner diameter: 6.0 cm), were purchased from 24hourwristbands.com (Houston, TX, USA). Upon receipt from the manufacturer, wristbands were rinsed in deionized water to remove particulate matter before being conditioned at 270–300 °C for 180 min under vacuum at 0.1 Torr (Vacuum Oven, Blue-M, model no. POM18VC-2, with Welch Duo-seal pump, model no. 1405). Conditioned wristbands were stored in sealed metal containers at 4 °C. Prior to deployment, the wristbands were transferred to air-tight polytetrafluoroethylene bags for transport.

Before worn wristbands were extracted, they were cleaned to remove particulate matter. For post-deployment cleaning, wristbands were rinsed twice with 18MΩ-cm water and once with isopropanol to remove particulate matter and transferred to amber glass jars and stored at −20C. For extraction, wristband samples were spiked with recovery surrogates and

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extracted with two 100 ml volumes of ethyl acetate at ambient temperature. Sample extracts were combined and reduced to 1 ml under nitrogen (TurboVap LV, Biotage, Charlotte, NC, USA) quantitatively transferred and reduced to 1 ml under nitrogen again (RapidVap, LabConco, Kansas City, MO, USA; N-EVAP 111, Organomation Associates, Berlin, MA, USA). Aliquots of 100 uL underwent solid-phase extraction (SPE) using 3.5 ml acetonitrile loaded onto C18 SPE cartridges (Cleanert S C18, Agela Technologies, Torrance, CA, USA). Aliquots were then solvent exchanged to iso-octane (OA-SYS N-EVAP 111, Organomation Associates, Berlin, MA, USA) and stored at 4 °C before instrument analysis.

2.3.2. Quantitative Analysis—Extracts from silicone wristbands were screened for 1,530 target analytes using a 6890 N gas chromatography with a 5975B Mass Selective Detector in full scan mode in conjunction with a predictive model Automated Mass Spectral Deconvolution and Identification System. This method has been used in several studies involving silicone wristbands as passive samplers (Dixon et al., 2019; Poutasse et al., 2022), and further details regarding the analytical method, including limits of detection (LODs) and limits of quantification (LOQs), have previously been reported (Bergmann et al., 2018).This screening method quantifies target analytes within a factor of 2.5 of the actual value (Bergmann et al., 2018). A complete list of target analytes can be found at http://fses.oregonstate.edu/1530.

The 1,530-screening method has been previously compared to The Endocrine Disruption Exchange list of potential endocrine disrupting chemicals (pEDCs) (Dixon et al., 2019; Poutasse et al., 2022; Poutasse et al., 2020), and has an overlap of 457 pEDCs. In this study, the 1,530-screening method was further compared to the Endocrine Disruptor (ED) List distributed by the European Union (EU) of substances identified as EDs (List 1 or III) or are under evaluation for endocrine disrupting properties (List II)(2021), and a list of EDCs released by the International Panel on Chemical Pollution, commissioned by the United Nations (UN) Environment Program (The International Panel on Chemical Pollution (IPCP), 2017). Twenty-one target analytes overlap with the EU list of EDs, and 17 analytes overlap with the UN commissioned list of EDCs; ten EDs are shared across those two lists. A full list of EDCs screened for and their respective LODs & LOQs can be found in Table SI-1.

2.3.3. Quality Assurance—Quality control samples were taken at each step of the laboratory process. They included: conditioning verifications (n = 2), trip blanks (n = 3), post-deployment cleaning blanks (n = 3), SPE blanks (n = 2), reagent blanks (n = 2), and a laboratory processing blank (n = 1), in addition to instrument solvent blanks, and instrument calibration verifications that were run with each instrument batch. All calibration verifications met data quality objectives of within a factor of 2.5 the true value for 60% of the target analytes. The laboratory processing blank was used to apply a background subtraction to all samples analyzed (Table SI-2) since it represented a summation of possible sample contamination from all laboratory processes.

2.4. Statistical Analysis

Statistical analyses were performed using SAS software version 9.4 (SAS Institute Inc.) and JMP Pro version 15.2.1 (SAS Institute Inc.) utilizing the concentration of analytes flagged

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as EDCs detected in at least 25% of the wristbands as well as sum EDCs (ΣEDCs) as the dependent variables. This study focused on common chemical exposures, therefore analytes detected in less than 25% of the samples were excluded from analysis. ΣEDCs represented the sum of all EDCs detected within this study at least once. Concentrations of EDCs were converted to moles per wristband (mol/ WB). Concentrations below LODs were imputed as LOD/√2.

Associations between questionnaire data and concentrations of EDCs were first examined by performing univariate and bivariate analysis using a non-parametric test (i.e. Wilcoxon rank sum test or Kruskal Wallis test) with multiple comparisons. As an alternative analysis, a modified Kaplan-Meier survivability curve for non-detected values was additionally applied with a Mantel-Cox log-rank chi-square test. Variables showing a p-value < 0.2 in either the non-parametric analysis or the modified survivability analysis were subsequently included in a stepwise multiple linear regression model through a process known as univariate filtering. During the backward step-by-step building of the multiple regression models, the cut-off for the p-value was set at < 0.05, and non-significant variables were consecutively excluded until a set of significant variables was retained. To ensure that multicollinearity among the retained variables was not impacting the results, variables were additionally dropped when the variance inflation factor (VIF) was > 4.0. Reference groups were designated based on either being a null flood exposure group (i.e. no flood clean-up, no home flooding, and zero time in flooded home), or in the case of the demographic variables, reference groups were the groups that had the smallest average concentration of ΣEDCs.

3. Results & Discussion

3.1. Study Population Characteristics—In total 172 participants from 150 households were included in the conducted analysis; 12% of the households were shared with two or more participants. The distribution of participant characteristics, including demographic variables and exposure-related variables is available in Table 1. As discussed, we primarily recruited participants from four Houston metro area neighborhoods. Nonetheless, participants who lived outside those four neighborhoods were retained in this analysis as “Unclassified;” they were 11% of the study sample. The study population was predominantly female (73%) and included individuals from all age groups, including youth (11%), adults (69%), and seniors (20%). The average age of youth, adults, and seniors were 13, 48, and 72 respectively A majority of participants indicated that their homes flooded (83%) and participated in flood clean-up (70%). All other covariates were more evenly distributed Table 1.

VIF was utilized to evaluate the relationships between demographic and flood related variables. Multiple variables were somewhat correlated and had VIFs ranging between two and three. In summary, individuals who had a high ADI were more likely to live in Baytown and East Houston, identify as Black/African American or Latino, and were more likely to continue living in a flooded home without remediation. These relationships were within the acceptable range for intercorrelated variables and unique relationships with the dependent variables were able to be distinguished (Figure 1).

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3.2. Chemical Detections

Detections of EDCs ranged from one to 14 per wristband, with an average of 10 EDCs detected per wristband. Out of the 172 participant wristbands, 16 EDCs were detected at least once, 13 EDCs were detected in over 25% of the samples, and seven EDCs were detected in at least 80% of the samples. Overall, nine out of the top 15 detected chemicals detected using the 1,530-screen are classified as EDCs. A full list of EDCs detected and their associated detection frequencies can be found in Table 2.

3.3. Analysis of Exposure Determinants

This study investigates whether demographic and self-assessed flood-related variables were associated with silicone wristband concentrations of EDCs detected in at least 25% of the study population. Full findings for EDC concentrations and results of the univariate analyses of the potential determinants of exposure are shown in Table SI 4–13 and the bivariate analyses are summarized in Table 3 & Table 4. Results of the multiple regression models for butyl benzyl phthalate (BBP), di-n-butyl phthalate (DBP), diethyl phthalate (DEP), lilial, diisobutyl phthalate (DIBP), triphenyl phosphate (TPP), 2,4-di-tert-butylphenol, butylated hydroxyanisole (BHA), bis(2-ethylhexyl) phthalate (BEHP), and ΣEDCs are summarized in Table 5. No significant multiple regression models could be constructed for benzophenone, butylated hydroxytoluene (BHT), benzyl salicylate, and triclosan.

Similar to the bivariate analysis, significant findings within the regression analysis were dominated by demographic variables with limited exceptions. Overall, the proportion of variance of EDC concentrations explained by the multiple regression models was low to moderate ($0.047 < R2 < 0.34$). These findings suggest that flood-related variables and demographic variables alone do not fully explain personnel chemical exposure to EDCs.

3.3.1. Sum EDC Exposure—ΣEDCs was not associated with any flood related variables (Table 3). Many of the demographic variables studied were associated with ΣEDCs including ADI, race/ethnicity, age group and neighborhood (Table 4). As ADI increased so did ΣEDC. ΣEDC were also high in the lower income communities of Baytown and East Houston, and participants who identified as Latino or Black/African American (Figure SI-1). When adjusted in the multiple regression analysis only identifying as Latino ($p = 0.0092$) or Black/African American ($p = 0.0075$) remained statistically significant (Table 5). As discussed EDCs come from a variety of sources (Attina et al., 2016; The International Panel on Chemical Pollution (IPCP), 2017), and individual EDCs may better explain sources of exposure than the model predicted for the ΣEDCs.

3.3.2. Butyl benzyl phthalate (BBP)—No flood-related demographic variables were associated with BBP (Table 3), but race/ethnicity and gender were both associated to BBP using the nonparametric analysis (Table 4). Without adjusting for covariates, females had greater chemical exposure to BBP than males (Table SI-12). There were no statistical significances using multiple comparisons between the different races/ethnicities. However, participants identified as Black/African American and Latino trended higher concentrations of BBP than those who identifying as White or Asian (Figure SI-1). This trend held true in the multiple regression analysis; individuals who identified as Black/African American (p

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= 0.0339) or Latino (p = 0.0329) had higher concentrations of BBP in wristband extracts than individuals who identified as Asian (Table 5). BBP is plasticizer used in a variety of industrial applications including adhesives and sealants, floor coverings, paint and coatings, and other commercial and consumer products including food packaging (EFSA Panel on Food Contact Materials et al., 2019; Tue Nguyen et al., 2018). Due to its industrial use and Houston's prowess as a plastics industrial center (Phillips, 2019) it's plausible that exposure stems from industrial sources. However, consumer preferences and housing characteristics may also contribute to exposure.

3.3.3. Di-n-butyl phthalate (DBP)—DBP had no statistically significant findings in any univariate analysis (Table 3, Table 4). When it was adjusted for covariates in the multiple regression model Black/African Americans had less exposure than their reference group (Asians) (p = 0.0176), and the neighborhood of Bellaire-Meyerland had less exposure than the neighborhood reference group of Addicks (p = 0.0289) (Table 5). This suggests that participants who identified as Asian and lived in the Addicks neighborhood had higher levels of exposure to DBP. DBP does have industrial uses as a plasticizer, but it is also used as a solvent for perfumes (EFSA Panel on Food Contact Materials et al., 2019; Wallace, 2005). DBP can also have natural sources such as microbial biosynthesis (Tian et al., 2016).

3.3.4. Diethyl phthalate (DEP)—DEP had no statistically significant findings in any univariate analysis (Table 3, Table 4). When adjusted for covariates in the multiple regression model, Black/African Americans had higher concentrations of DEP in their wristbands than the reference group (p = 0.0418) (Table 5). DEP has a wide range of uses that extend from a plasticizer of hard molded plastics (e.g. automobile parts, toys, toothbrushes), to use in food packing, and as an ingredient in personal care products (e.g. perfumes, cosmetics, soaps, mosquito repellent) (Weaver et al., 2020).

3.3.5. Lilial—Lilial had statistically significant findings for two flood related variables: time in flooded home and living situation (Table 3). With the exception for those who spent zero time in a flooded home, there was a trend of increasing concentration with increasing time in home. Those who lived in flooded homes had higher concentration of lilial than those who moved after flooding (Figure SI-5). Lilial was also found to have statistically significant relationships with ADI, race/ethnicity, age group, and neighborhood using both the nonparametric and survival analysis (Table 4). As ADI increased so did the concentration of lilial. Concentrations of lilial were also high in the lower income communities of Baytown and East Houston, participants who identified as Latino or Black/African American, and adults (Figure SI-5). When adjusted in the multiple regression model, the neighborhoods of Baytown (p = 0.0309) and East Houston (p= 0.0037) still had higher concentrations compared to the reference neighborhood (Table 5). Lilial is a fragrance chemical frequently used in cosmetic products and household cleaners where it is labelled as Butylphenyl methylpropional (Darbre, 2015).

3.3.6. Benzophenone—Benzophenone had no statistically significant findings in any univariate analysis (Table 3, Table 4) and no significant regression model could be generated.

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3.3.7. Diisobutyl phthalate (DIBP)—No flood related demographic variables were associated with DIBP (Table 3), but age group and neighborhood were both associated to BBP using both the nonparametric and survivability analysis (Table 4). In the nonparametric multiple comparison analysis, it was found the unclassified neighborhood had statistically higher concentration than Addicks, and youth had higher levels of exposure than adults (Figure SI-7). Both age and neighborhood were included in the multiple regression model for DIBP and same trends held. When adjusted, the unclassified neighborhood still had a statistically higher concentrations than the reference group ($p = 0.0014$), and youth had higher concentrations of exposure to DIBP than adults ($p = 0.0088$) (Table 5). DIBP is used as a plasticizer in polyvinyl chloride, car interiors, vinyl fabrics, and other industrial and consumer products (Yost et al., 2019). DIBP was also among a group of phthalates that were recently banned in children's toys and child care articles (2017) (Lioy et al., 2015; Meeker, 2012).

3.3.8. Triphenyl phosphate (TPP)—Both flood amount in home and living situation post-flood were associated with TPP (Table 1), as were age group and neighborhood (Table 2). Participants who lived in a flooded home had higher concentrations than those who moved from flooded homes, and youth had higher concentrations than adults and seniors. Lastly, participants living in East Houston had higher concentrations of exposure than those living in Addicks (Figure SI-8). In the multiple regression analysis both youth ($p = <0.0001$) and seniors ($p = 0.0329$) had higher concentrations of exposure compared to adults (Table 5). Previous studies have reported high levels of organophosphate flame-retardant exposure such as TTP in children (Gibson et al., 2019; Kile et al., 2016; Phillips et al., 2018), and have studied the association between TPP and neurodevelopment (DiVall, 2013; Lipscomb et al., 2017; Miodovnik et al., 2011). Flame Retardants are commonly found indoors near textile surfaces, electronics, or house dust where flame retardants are commonly found (Phillips et al., 2018).

3.3.9. Butylated Hydroxytoluene (BHT)—No flood related variables were associated with BHT (Table 3). However, BHT was associated with several demographic variables including ADI, race/ethnicity, and neighborhood (Table 4). Concentrations of BHT generally increased with ADI score. Black/African American participants had higher exposure levels than participants who identified as white. Both participants from the East Houston and Baytown neighborhoods had higher exposure levels than participants from the Bellaire-Meyerland neighborhood (Figure SI-9). No significant regression model could be created for BHT. BHT is an antioxidant utilized as a preservative in a variety of products including personal care products and food products and packaging (2016; García-García and Searle, 2016). Low income households tend to eat more processed food that are likely to contain preservatives (Carney, 2012; Wolfson et al., 2019) such as BHT.

3.3.10. 2,4-di-tert-butylphenol—Variables associated with 2,4-di-tertbutylphenol included the flood related exposure variable, living situation post flood (Table 3), and the demographic variables ADI and neighborhood (Table 4). In this instance individuals who moved away from a flooded home had higher concentrations of exposure than those who stayed living in a flooded home (Table SI-7). Both the third and first ADI quartiles

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had statistically higher concentrations than that of the fourth ADI quartile. Additionally, participants living in Baytown and Bellaire-Meyerland had higher concentrations of exposure than participants living in East Houston (Figure SI-11). In the multiple regression model female participants had greater concentrations levels than males ($p = 0.0257$) (Table 5). 2, 4-di-tert-butylphenol is an intermediate used in the preparation of antioxidants and is additionally used in the manufacture of pharmaceuticals and fragrances (Varsha et al., 2015).

3.3.11. Benzyl salicylate—The only variable associated with benzyl salicylate in the univariate analysis was living situation post flood (Table 3, Table 4). Differences between participants who moved post flood and who stayed living in a flooded home were only seen in the survival analysis (Table SI-9). No significant regression model could be created for benzyl salicylate. Benzyl salicylate is a fragrance and is frequently used in cosmetics (Lapczynski et al., 2007).

3.3.12. Butylated hydroxyanisole (BHA)—BHA was associated with the flood related variables home flooding and flood amount in home (Table 3), and the demographic variables ADI, race/ethnicity, and neighborhood in the univariate analysis (Table 4). Higher concentrations were found in participants whose homes did not flood, specifically, participants whose homes did not flood had higher concentrations of exposure compared to participants with greater than two feet of flooding (Figure SI-12). The concentrations of BHA increased with ADI through the first three quartiles, but dropped substantially in the fourth quartile. Concentrations were highest in Baytown participants and Black/African American participants (Figure SI-12). In the multiple regression model both participants who lived in the Baytown neighborhood ($p = 0.0045$) and participants who identified as Black/African American ($p = 0.0185$) had greater concentrations of exposure than their respective reference groups (Table 5). Similar to BHT, BHA is an antioxidant used as a preservative in foods, cosmetics, and pharmaceuticals (García-García and Searle, 2016; Thakore, 2014).

3.3.13. Bis(2-ethylhexyl) phthalate (BEHP)—No flood related exposure determinants were associated with BEHP in the univariate analysis (Table 3). However, multiple demographic variables were associated with BEHP including ADI, race/ethnicity, age group, and neighborhood (Table 4). In summary, the fourth ADI quartile had the highest concentration, and Latino participants had higher concentrations of exposure than those who identified as Black/African American and white, and youth had higher concentration in their wristbands versus seniors. Lastly, participants from East Houston had higher concentrations in their wristbands than participants from the Baytown, Bellaire-Meyerland, and Addicks neighborhoods (Figure SI-13). When adjusted in the multiple regression model ADI ($p = 0.0255$) and identifying as Latino ($p = 0.0185$) were the only significant variables (Table 5). BEHP is used as a plasticizer and is used primarily in medical equipment (Bouattour et al., 2020), but it also has uses in consumer goods including furniture materials, cosmetics, and personal care products (EFSA Panel on Food Contact Materials et al., 2019; Rowdhwal and Chen, 2018). As previously acknowledged, participants from the Bellaire-Meyerland neighborhood largely worked at Baylor College of Medicine and higher concentrations in that neighborhood could be explained by occupational exposure. The larger trend suggested by the multiple regression model indicates that there is some source of exposure that increases as socioeconomic status increases, except with Latino participants. This could be from multiple reasons including occupational exposure, housing material and industrial production nearby.

3.3.14. Triclosan—The only statistically significant finding in the univariate analysis for triclosan was the flood related variable, living situation post-flood (Table 3, Table 4). Individuals who moved post-flood had higher concentrations of exposure than those who stayed living in a flooded home (Table SI-7). No significant regression model could be created for triclosan. Triclosan is an antibacterial and antifungal agent used in a variety of consumer products including toothpaste, hand-sanitizer, and mouthwash (Goodman et al., 2018). It's estimated that 75% of the USA population is exposed to triclosan through consumer goods and personal care products (Weatherly and Gosse, 2017)

3.4. Comparison of EDC exposure frequencies

High rates of exposure to endocrine disrupting chemicals have previously been reported in studies that utilized silicone wristbands as passive samplers (Dixon et al., 2019; Poutasse et al., 2022). Dixon et. al., 2019 compared chemical exposure from eleven studies done across three continents including the pilot study conducted immediately after Hurricane Harvey and found that 13 of the 14 chemicals detected in over 50% of the samples were pEDCs (Dixon et al., 2019). A full comparison of detection frequencies to all EDCs evaluated in this study to Dixon et. al., 2019 reveals that four compounds had comparable exposure frequencies (i.e. DEP, DBP, DIBP, and BHT), seven compounds had higher detection frequencies in this current study (i.e. BBP, lilial, benzophenone, TPP, 2,4-di-tert-butylphenol, BHA, and Triclosan) indicating increased EDC prevalence in Houston, TX surrounding Hurricane Harvey, and two compounds had lower detection frequencies in this current study (i.e. BS and BEHP) (Table 2).

3.5. Environmental Justice Implications

Our findings highlight the significance of evaluating the unique contributions of disasters to environmental justice concerns. Environmental justice implications surrounding natural disasters were first researched following Hurricane Katrina (Allen, 2007). Like Katrina, there were significant concerns after Hurricane Harvey regarding the disproportionate impacts of hurricanes on low-income communities of color (Phillips, 2018). In all disasters, it is essential to examine whether socially disadvantaged (i.e., racial/ethnic minority or lower socioeconomic) individuals are more adversely impacted. In the case of Hurricane Harvey, not only were neighborhoods with minority and low socioeconomic residents more likely to have a greater extent of flooding (Chakraborty et al., 2019; Smiley et al., 2022) they were also disproportionately affected by pollutant counts (Bodenreider, 2019; Phillips, 2018) including petrochemical releases (Flores et al., 2021).

While this study found increased exposure to EDCs in minority racial/ethnic groups and low-income neighborhoods following Hurricane Harvey, it is necessary to distinguish whether Hurricane Harvey lead to increased exposure to EDCs, or whether these socially disadvantaged populations had preexisting disproportionate exposure to EDCs. The results

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from this study indicate that demographic variables including race/ethnicity appear to have played significant roles in a participant's exposures to EDCs. However, based on the current literature, in non-disaster scenarios EDC exposure profiles differ by race/ethnicity (Chan et al., 2021; James-Todd et al., 2012). Possible sources for those EDCs include personal care products, household goods, or industrial manufacturing. Chemical industries, including those which produce EDCs, are more likely to be located in low-income communities of color (Collins, 2011; Kyle Crowder and Liam Downey, 2010), and it has previously been shown that neighborhoods with a higher percentage of people of color and higher income inequality have greater exposure to air pollution in Houston, TX (Chakraborty et al., 2014). With this information alone, it is difficult to determine whether the inequality in EDC exposure was preexisting, and/or if inequality in EDC exposure was exacerbated by Hurricane Harvey.

The overall impact of Hurricane Harvey on personal chemical exposure in a longitudinal panel has been studied (Samon et al., 2022) and can be utilized to distinguish whether Hurricane Harvey lead to increased exposure to EDCs, or whether these socially disadvantaged populations had preexisting disproportionate exposure to EDCs. A longitudinal panel of the Houston-3H project was evaluated for differences in chemical exposure between when this study occurred and one-year later in a non-disaster scenario (Samon et al., 2022). Utilizing pairwise analysis it was found that chemical exposure in the Houston metropolitan area was higher immediately after Hurricane Harvey than it was one year later. Additionally, it was found that 10 of the 13 EDCs studied here were statistically higher immediately after Hurricane Harvey. Lastly, it was found that covariates associated with exposure in this study (i.e., neighborhood, race/ethnicity, ADI, and age) were not significant when evaluating the differences in chemical exposure across timepoints in the longitudinal panel (Samon et al., 2022). Cumulatively, this information signifies that while Hurricane Harvey was overall associated with increased chemical exposure in the Houston metropolitan area, including increased exposure to EDCs, certain subpopulations including communities living on the fence line to industry, minority populations that identify as Latino or Black/African American, and youth have higher levels of baseline chemical exposure. Evidence also largely suggests that one subpopulation's chemical exposure was not impacted by the hurricane more than any other subpopulations. This research provides evidence that Hurricane Harvey exacerbated existing environmental inequalities in EDC exposure by associating personal exposure to EDCs with known adverse health effects after Hurricane Harvey with minority racial/ethnic groups and low-income neighborhoods.

3.6. Limitations

Due to the rapid response nature of disaster research, the Houston 3H project had several limitations, several of which have been previously reported(Oluyomi et al., 2021). Briefly, participant recruitment was targeted to specific communities, which may have introduced selection bias and limited generalizability. This study relied on questionnaire data, an inherent limitation with questionnaires include recall bias as well as incomplete responses. This is especially true in disaster scenarios where participants may be stressed and time limited (Hussain et al., 2009). We were unable to study several variables regarding flood exposure (i.e., flooding in frequently visited places aside from home), particularly among

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individuals with a high ADI (Oluyomi et al., 2021), due to missing information. Several of the variables studied also had unequal sample sizes among groups. Ideally, an equal distribution would have been desired, however the statistical analysis chosen didn’t rely on equal sample size (Fan et al., 2011; Slinker & Glantz, 1988). Lastly, a prevalent limitation in disaster research is the time that sampling occurred in relation to when the disaster occurred. Due to logistics the samples were collected more than a month after Hurricane Harvey hit Houston and this may explain the lack of correlation between the flood related variables and exposure to EDCs. However, at the time the study was conducted Houston was still in a post-disaster scenario, which was evident by ongoing clean-up efforts and persistent flooding (Nicole, 2018; Oluyomi et al., 2021).

Using silicone wristbands as an exposure assessment tools also has its limitations. Silicone wristbands capture an individual’s dermal and inhalation exposure(O’Connell et al., 2014) and currently cannot be compared to known reference values. Thus, it is unknown whether the amounts of EDCs seen in this study exceed the acceptable risk level. Additionally, the uptake rates of the EDCs studied into silicone wristbands are unknown, and the inability to calculate a normalized value may be biasing the results.

4. Conclusions

Wristbands sampled personal exposure to a wide range of chemicals following Hurricane Harvey, but the most frequently detected chemicals were identified as EDCs. Several demographic and flood related variables obtained from participant questionnaires were evaluated and a trend emerged where individuals who had a high ADI were more likely to live in the Houston neighborhoods along the fence line of industry, identify as Black/ African American or Latino, and were more likely to continue living in a flooded home without remediation. How the variables studied are related to EDC exposure are specific to individual EDCs, but several variables were repeatedly significant in the regression analysis. Individuals with higher EDC exposure were more likely to identify as Black/African American or Latino, live in the neighborhoods of Baytown or East Houston, or be less than 19 years old. While this study focused on exposure to EDCs following Hurricane Harvey, there is not sufficient evidence in this study alone r to demonstrate that EDC exposure was associated with the hurricane. However, when incorporated with existing evidence finding increased chemical exposure following Hurricane Harvey including increased exposure to EDCs, it can be inferred that minorities, particularly individuals that identify as Latino or Black/African American or individuals living in low-socioeconomic neighborhoods are generally disproportionately exposed to higher levels of EDCs. These findings have important public health and environmental justice implications, since social inequalities in EDC exposure may lead to disparate longterm health outcomes in those populations. More research is needed on whether EDC exposure was driven by consumer goods, or proximity to industrial sites. Government response to impending flooding should additionally include increased monitoring of EDCs near industrial complexes.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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Abbreviations

ED	Endocrine disruptor
EDC	Endocrine disrupting chemical
pEDC	Potential endocrine disrupting compounds
ADI	Area deprivation index
BBP	Butyl benzyl phthalate
DBP	Di-n-butyl phthalate
BEHP	Bis(2-ethylhexyl) phthalate
DIBP	Diisobutyl phthalate
DEP	Diethyl phthalate
BHT	Butylated hydroxytoluene
BHA	Butylated hydroxyanisole
TPP	Triphenyl phosphate
LOD	Limit of detection
LOQ	Limit of quantitation
VIF	Variance inflation factor
Houston-3H	Houston Hurricane Harvey Health

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HIGHLIGHTS

- Silicone wristbands characterized exposure to 16 EDCs following Hurricane Harvey.
- Exposure to flood-waters minimally impacted EDC exposure.
- ADI was associated with bis(2-ethylhexyl) phthalate exposure.
- Increased exposure to EDCs was associated with race and where a person lives (neighborhood).

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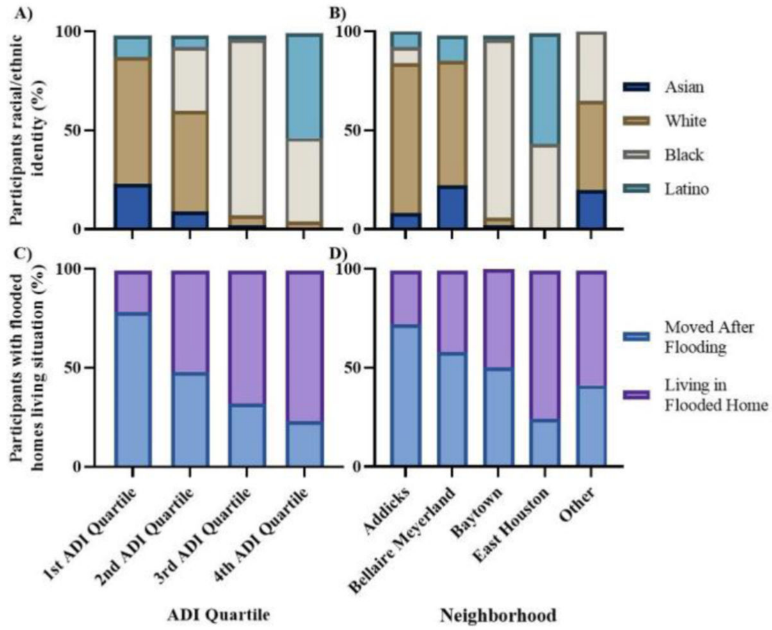

Figure 1.

Distribution of race/ethnicities (A-B) among A) ADI quartile and B) neighborhoods, and distribution living situation post flood if house flooded (C-D) among C) ADI quartile and D) neighborhoods.

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Table 1.

Participant demographic & environmental characteristics (n = 172)

Characteristics	N	%
Sociodemographic		
Gender		
Female	125	73%
Male	47	27%
Age Group		
Youth (5–19)	18	11%
Adult (20–64)	119	69%
Senior (>64)	35	20%
Race/Ethnicity		
Asian	15	9%
Black/African American	66	38%
Latino	33	19%
White	53	31%
Multiracial	5	3%
Area Deprivation Index (quartiles)		
1st Quartile (−16. − 64.2)	43	25%
2nd Quartile (64.3 – 106.2)	43	25%
3rd Quartile (106.3–114.2)	42	24%
4th Quartile (114.3–120)	44	26%
Neighborhood		
Addicks	25	15%
Baytown	47	27%
Bellaire-Meyerland	37	22%
East Houston	43	25%
Other	20	12%
Flood related exposure Home Flooding		
Yes	143	83%
No	29	17%
Flood Clean-Up Participation		
Yes	115	67%
No	46	27%
Living Situation if House Flooded		
Moved after house flooded	68	40%
Stayed living in flooded home	75	44%
Did not flood	29	17%
Amount of Home Flooding		
Zero	30	17%
< 1 ft	34	20%

Characteristics	N	%
1 – 2 ft	44	26%
> 2 ft	46	27%
Time Spent in Flooded Home		
0	30	17%
1–3 hr	40	23%
4–6 hr	28	16%
7–12 hr	30	17%
>12 hr	31	18%

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Table 2.

Detected EDCs exposure frequencies post-Hurricane Harvey compared to detection frequencies seen in a previously reported wristband study (Dixon et. al., 2019).

Analyte	Number of Detections	% Detection	% Detection Dixon et al. 2019
Butyl benzyl phthalate	165	96%	66%
Di-n-butyl phthalate	161	94%	93%
Diethyl phthalate	157	91%	95%
Lilial	147	85%	75%
Benzophenone	145	84%	64%
Diisobutyl phthalate	142	83%	85%
Triphenyl phosphate	137	80%	52%
Butylated hydroxytoluene	132	77%	79%
2,4-di-tert-butylphenol	113	66%	13%
Benzyl salicylate	84	49%	73%
Butylated hydroxyanisole	82	48%	19%
Bis(2-ethylhexyl) phthalate	49	28%	84%
Triclosan	45	26%	15%
Di-n-hexyl phthalate	30	17%	9%
Dicyclohexyl phthalate	21	12%	9%
4-tert-butylphenol	12	7%	8%
Di-n-octyl phthalate	10	6%	10%
Deltamethrin	3	2%	0%
Dipentyl phthalate	1	1%	0%
Bisphenol A	1	1%	0.38%

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Table 3.

Summary of the statistical findings for the non-parametric analyses done using either the Wilcoxon or Kruskal Wallis test and the modified survivability analyses evaluating associations between concentrations of EDCs and flood related exposure determinants.

EDCs	Home flooding		Clean-up participation		Flood amount in home		Time in flooded home		Living Situation	
	p-value[a]	p-value[b]	p-value[a]	p-value[b]	p-value[a]	p-value[b]	p-value[a]	p-value[b]	p-value[a]	p-value[b]
Butyl benzyl phthalate	0.401	0.515	0.128	0.162	0.515	0.837	0.464	0.569	0.854	0.735
Di-n-butyl phthalate	0.945	0.687	0.148	0.754	0.697	0.689	0.949	0.909	0.187	0.335
Diethyl phthalate	0.158	0.440	0.207	0.136	0.282	0.639	0.216	0.466	0.454	0.858
Lilial	0.977	0.955	0.482	0.260	0.581	0.486	**0.0169** *	0.0559	**0.0012** **	**0.0038** **
Benzophenone	0.218	0.414	0.829	0.792	0.824	0.972	0.819	0.970	0.253	0.723
Diisobutyl phthalate	0.871	0.829	0.138	0.0896	0.523	0.735	0.604	0.667	0.356	0.621
Triphenyl phosphate	0.510	0.597	0.785	0.665	0.178	**0.0327** *	0.0845	0.189	**0.0009** ***	**0.0006** ***
Butylated hydroxytoluene	0.845	0.715	0.285	0.229	0.728	0.649	0.271	0.309	0.474	0.510
2,4-di-tertbutylphenol	0.0974	0.165	0.984	0.799	0.443	0.566	0.557	0.586	**0.0450** *	**0.0268** *
Benzyl salicylate	0.600	0.618	0.912	0.882	0.605	0.672	0.672	0.551	0.0763	**0.0196** *
Butylated hydroxyanisole	**0.0025** **	**0.0013** **	0.914	0.968	**0.0147** *	**0.0075** **	0.0858	0.0769	0.466	0.669
Bis(2-ethylhexyl) phthalate	0.471	0.525	0.543	0.660	0.486	0.468	0.483	0.527	0.143	0.200
Triclosan	0.585	0.772	0.294	0.446	0.552	0.750	0.176	0.162	**0.0232** *	**0.0178** *
ΣEDCs	0.250	-	0.385	-	0.392	-	0.0592	-	0.0554	-

[a] non-parametric analysis using either the Wilcoxon or Kruskal Wallis test

[b] modified survivability analysis.

* **Bold** ($p < 0.05$)

** **Bold** (<0.01)

*** **Bold** ($p < 0.001$)

**** **Bold** ($p < 0.0001$).

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Table 4.

Summary of the statistical findings for the non-parametric analyses done using either the Wilcoxon or Kruskal Wallis test and the modified survivability analyses evaluating associations between concentrations of EDCs and demographic exposure determinants.

EDCs	ADI		Race/Ethnicity		Gender		Age group		Neighborhood	
	p-value[a]	p-value[b]	p-value[a]	p-value[b]	p-value[a]	p-value[b]	p-value[a]	p-value[b]	p-value[a]	p-value[b]
Butyl benzyl phthalate	0.265	0.461	**0.0284** *	0.105	**0.0472** *	0.138	0.177	0.197	0.121	0.538
Di-n-butyl phthalate	0.992	0.883	0.377	0.109	0.316	0.803	0.391	0.426	0.469	0.100
Diethyl phthalate	0.138	0.608	0.128	0.857	0.514	0.535	0.834	0.558	0.122	0.468
Lilial	<**0.0001** ****	<**0.0001** ****	<**0.0001** ****	<**0.0001** ****	0.553	0.632	**0.0276** *	**0.0173** *	<**0.0001** ****	<**0.0001** ****
Benzophenone	0.223	0.273	0.0546	0.0098 **	0.338	0.992	0.0558	0.0622	0.182	0.0773
Diisobutyl phthalate	0.559	0.710	0.0510	0.213	0.603	0.424	**0.0114** *	**0.0190** *	**0.0312** *	**0.0318** *
Triphenyl phosphate	0.110	0.329	0.546	0.538	0.366	0.753	**0.0002** ***	<**0.0001** ****	**0.0253** *	0.0783
Butylated hydroxytoluene	**0.0012** **	**0.0004** ***	**0.0002** ***	<**0.0001** ****	0.357	0.619	0.113	0.0610	**0.0001** ***	**0.0003** ***
2,4-di-tert-butylphenol	0.055	**0.0386** *	0.124	0.183	0.127	0.539	0.734	0.749	**0.0194** *	**0.0131** *
Benzyl salicylate	0.518	0.423	0.452	0.294	0.268	0.148	0.906	0.778	0.229	0.0901
Butylated hydroxyanisole	<**0.0001** ****	<**0.0001** ****	**0.0088** **	**0.0245** *	0.477	0.410	0.156	0.161	<**0.0001** ****	<**0.0001** ****
Bis(2-ethylhexyl) phthalate	**0.0123** *	**0.0044** **	**0.0081** **	**0.0031** **	0.676	0.739	0.0641	**0.044** *	<**0.0001** ****	<**0.0001** ****
Triclosan	0.0602	0.123	0.679	0.412	0.768	0.955	0.331	0.0695	0.404	0.509
ΣEDCs	<**0.0001** ****	-	<**0.0001** ****	-	0.160	-	**0.0170** *	-	<**0.0001** *	-

[a] non-parametric analysis using either the Wilcoxon or Kruskal Wallis test

[b] modified survivability analysis.

[*] **Bold** (p < 0.05)

[**] **Bold** (< 0.01)

[***] **Bold** (< 0.001)

[****] **Bold** (p < 0.0001).

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Table 5.

Multiple regression analysis for the assessment of determinants of exposure for EDCs.

EDCs	Variable		ß (95%CI)	p-value
Butyl benzyl phthalate R^2 = 0.0730	Race	Black/African American	88.3 (6.80, 170)	**0.0339** *
		Latino	93.8 (7.74, 180)	**0.0329** *
		White	38.7 (−29.5, 107)	0.264
		Asian	reference	
	Neighborhood	Baytown	33.5 (−43.6, 111)	0.392
		East Houston	11.6 (−65.6, 88.8)	0.767
		Bellaire-Meyerland	50.5 (−10.1, 111)	0.102
		Unclassified	60.2 (−11.0, 131)	0.097
		Addicks	reference	
Di-n-butyl phthalate R^2 = 0.0603	Race	Black/African American	−74.5 (−136, −1.2)	**0.0176** *
		Latino	−59.2 (−124, 5.45)	0.0724
		White	−43.4 (−93.9, 7.11)	0.0917
		Asian	reference	
	Neighborhood	Baytown	−2.55 (−60.6, 55.5)	0.931
		East Houston	−3.03 (−61.8, 55.8)	0.919
		Bellaire-Meyerland	−50.6 (−95.9, −5.28)	**0.0289** *
		Unclassified	−31.3 (−84.9, 22.3)	0.250
		Addicks	reference	
Diethyl phthalate R^2 = 0.0474	Race	Black/African American	96.2 (3.61, 189)	**0.0418** *
		Latino	18.4 (−85.3, 122)	0.726
		White	38.5 (−55.9, 133)	0.422
		Asian	reference	
Lilial R^2 = 0.175	Neighborhood	Baytown	105 (9.76, 200)	**0.0309** *
		East Houston	150 (49.5, 251)	**0.0037** **
		Bellaire-Meyerland	19.6 (−71.6, 111)	0.6722
		Unclassified	9.39 (−94.5, 113)	0.858
		Addicks	reference	
		ADI Score	0.61 (−0.411, 1.62)	0.241
	Age	Youth	−72.3 (−163, 18.0)	0.116
		Senior	−40.6 (−109, 27.7)	0.242
		Adult	reference	
Diisobutyl phthalate R^2= 0.111	Neighborhood	Baytown	50.0 (1.31, 98.7)	0.0442
		East Houston	44. (−4.27, 92.7)	0.0736
		Bellaire-Meyerland	35.2 (−15.2, 85.6)	0.170
		Unclassified	95.7 (37.7, 154)	**0.0014** **
		Addicks	reference	
	Age	Youth	69.1 (17.6, 120)	**0.0088** **

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EDCs	**Variable**		**ß (95%CI)**	**p-value**
		Senior	19.6 (−19.3, 58.5)	0.321
		Adult	reference	
Triphenyl phosphate R^2 = 0.286	Amount of flooding in home	< 1 ft	−3.58 (−57.8, 50.7)	0.896
		1 – 2 ft	−22.5 (−75.6, 30.7)	0.404
		> 2 ft	2.50 (−53.1, 58.1)	0.929
		0	reference	
	Hours Spent in Flooded Home	1–3 hr	−43.2 (−99.1, 12.6)	0.128
		4–6 hr	−49.2 (−106, 8.01)	0.0914
		7–12 hr	−24.3 (−81.3, 32.6)	0.399
		>12 hr	−27.4 (−78.5, 23.6)	0.290
		0	reference	
	Age	Youth	121 (82.3, 160)	<0.0001 ****
		Senior	29.8 (2.44, 57.1)	0.0329 *
		Adult	reference	
2,4-di-tert-butylphenol R^2 = 0.141	Living	Living in flooded home	−4.79 (−10.5, 0.922)	0.0996
	Situation	Moved from flooded home	−1.9 (−7.68, 3.79)	0.504
		Did not flood	reference	
	Gender	Female	4.82 (0.591, 9.05)	0.0257 *
		Male	reference	
	Neighborhood	Baytown	2.81 (−5.45, 11.1)	0.503
		East Houston	−3.75 (−12.1, 4.57)	0.375
		Bellaire-Meyerland	3.71 (−2.69, 10.1)	0.254
		Unclassified	−2.96 (−10.6, 4.65)	0.443
		Addicks	reference	
	Race	Black/African American	−0.094 (−8.66, 8.47)	0.983
		Latino	−2.88 (−11.9, 6.18)	0.531
		White	−4.34 (−11.5, 2.84)	0.234
		Asian	reference	
Butylated hydroxyanisole R^2 = 0.337	Neighborhood	Baytown	11.1 (4.45, 17.7)	0.0012 **
		East Houston	−6.47 (−13.1, 0.181)	0.0565
		Bellaire-Meyerland	3.10 (−2.12, 8.31)	0.243
		Unclassified	6.53 (0.397, 12.7)	0.0371 *
		Addicks	reference	
	Race	Black/African American	6.45 (0.0534, 12.8)	**0.0481** *
		Latino	0.550 (−6.42, 7.52)	0.876
		White	−2.18 (−8.73, 4.37)	0.511
		Asian	reference	
Bis(2-ethylhexyl) phthalate R^2 = 0.0945	ADI		−0.46 (−0.87, −0.057)	**0.0255** *
	Living	Living in flooded home	23.8 (−9.45, 57.2)	0.159
	Situation	Moved from flooded home	−11.9 (−46.5, 22.7)	0.497

EDCs	Variable		ß (95%CI)	p-value
		Did not flood	reference	
	Race	Black/African American	31.7 (−18.0, 81.5)	0.209
		Latino	57.6 (5.92, 109)	0.0292 *
		White	22.5 (−18.4, 69.4)	0.254
		Asian	reference	
ΣEDCs R^2= 0.140	Race	Black/African American	278 (75.2, 480)	**0.0075** **
		Latino	294 (73.8, 515)	**0.0092** **
		White	−7.03 (−214, 200)	0.9466
		Asian	reference	

* **bold** (p < 0.05)

** **bold** (<0.01)

*** **bold** (p < 0.001)

**** **bold** (p < 0.0001).

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