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Awareness is not enough: Frequent use of water pollution information and changes to risky behavior

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Abstract: *Background*: Hazard information plays an important role in how risk perceptions are formed and what actions are taken in response to risk. While past studies have shown that information on water and air pollution is associated with changes to individual behavior, there is a need for examination of water quality information in the context of environmental disturbances. This study fills that gap by examining water pollution in an active industrial region of the United States – the Galveston Bay of Texas. *Methods*: Using original survey data collected in 2019 of 525 adults living in the Galveston Bay region, logistic regression is used to analyze the association of awareness and use of water pollution information on changes to outdoor activities and consumption of drinking water and/or seafood. Controls for chronic and acute exposure, environmental knowledge and experience, and demographics are included in the model. *Results*: The findings indicate that frequent checking of water quality information is significantly associated with action to reduce risk. *Conclusions*: There is a need for improvement in pollution data collection and development of a risk communication framework that facilitates the dissemination of this information in relevant, accessible, and credible ways.

Keywords: hazard mitigation, water quality, pollution information

1. Introduction

While much attention is paid to structural mitigation in reducing hazard risk, the role of hazard information in risk reduction is often overlooked. Yet, hazard information is critical to understanding and managing the risk people face. From the lens of risk as a product of exposure and vulnerability [1], hazard information can be understood as a resource influencing social vulnerability [2]. Where environmental hazard and monitoring information is lacking or difficult to access, interpret, or use –

as is often the case in race and ethnic minority communities – vulnerability is heightened [3]. From the lens of risk as socially and culturally constructed, hazard information is interpreted by individuals in relation to their worldviews as well as experience [4-6]. People carefully weigh multiple influences of risk on their well-being and develop coping strategies in response; then they re-evaluate the stressor, available resources, and coping strategies in relation to changes in the characteristics, conditions, and context of the stressor and their own coping abilities [4, 7-8]. In this iterative process, external information is important to the initial risk assessment and development of coping responses [9]. Hazard information, therefore, is an important factor influencing perceptions of and responses to risk.

Reducing risk is the aim of hazard mitigation, which "takes the form of advance action designed to eliminate or reduce the long-term risk to human life and property from natural and man-made hazards" [10]. Brody and Atoba [11] categorize hazard mitigation to include strategies that: *avoid* through retreat and relocation, *resist* through structural mitigation, *accommodate* through the creation of spaces and infrastructure that can absorb the impact of periodic hazard, or *build awareness* through education and information. Past research has found mitigation in the form of hazard education can build awareness. For example, education has been an essential tool for near-source mitigation of the National Tsunami Hazard Mitigation Program, and surveys of residents in the states of California, Oregon, and Washington demonstrated the campaigns raised awareness [12]. However, the education programs did not change individual behaviors. Residents prescribed action to reduce tsunami risk as a government, not personal responsibility. This calls into question if building awareness is sufficient for hazard mitigation - does risk reduction relies on behavioral adaptations?

Multiple studies have found hazard information awareness to be associated with changes in behavior. Wen, Balluz, and Mokdad [13] analyzed changes in behavior related to awareness of air quality alerts. Using data from a national survey of U.S. adults conducted in 2005, they found the prevalence of change in outdoor activity increased to 68% (from 16%) and 75% (from 31%) – among individuals without and with lifetime asthma – when accounting for awareness of air quality reports as well as individual perception of air quality. Similarly, a study conducted by Reams and colleagues [14] of residents of the upper Industrial Corridor of Louisiana found that individuals who are aware of air quality forecasts – and check them often – were more likely to change their behavior in order to limit their exposure to environmental risk. Additionally, the analyses indicated that higher levels of knowledge and concern about environmental hazards and more recent experience with storms, floods and other disruptive environmental events encourage individuals to take action to make themselves safer. A subsequent study by Reams and Irving [15], focused on the industrial corridor of Orleans and St. Tammany Parishes in Louisiana, supported these findings. Analyses of a survey of 550 residents suggested that individuals who were aware of air quality forecasts - and checked them often - were more likely to adopt exposure reducing behaviors by altering their outdoor activities on days with poor air quality. Studies of water quality advisories find congruent changes in behavior, including decreases in surfing and beach-going following advisories for fecal contamination of coastal waters [16] and general compliance with boil water advisories [17-18].

The present study extends this line of inquiry to examine risk reducing behaviors related to awareness of water pollution in the context of environmental hazards in the Galveston Bay region of Texas. As a center of oil and gas and transportation industrial activity, Galveston Bay can be considered a testbed for interactions between society, the environment, and industry. Residents of the area surrounding the Bay face both chronic exposure to water pollutants as well as acute exposure related to man-made, environmental hazard events – two of which are examined in this study: the Deer Park Intercontinental Terminals Company facility chemical fire (March 17, 2019) and a barge collision in the Houston Ship Channel involving oil tankers (May 10, 2019). Human-induced emergencies and disasters such as these are commonplace. As illustrated in Figure 1, the incidence of oil and chemical spills is rampant, affecting coastlines and waterways across the U.S. The data, capturing incidents reported to the National Oceanic and Atmospheric Administration from 1968-2020 [19], also demonstrates an increase in these environmental disturbances over time.

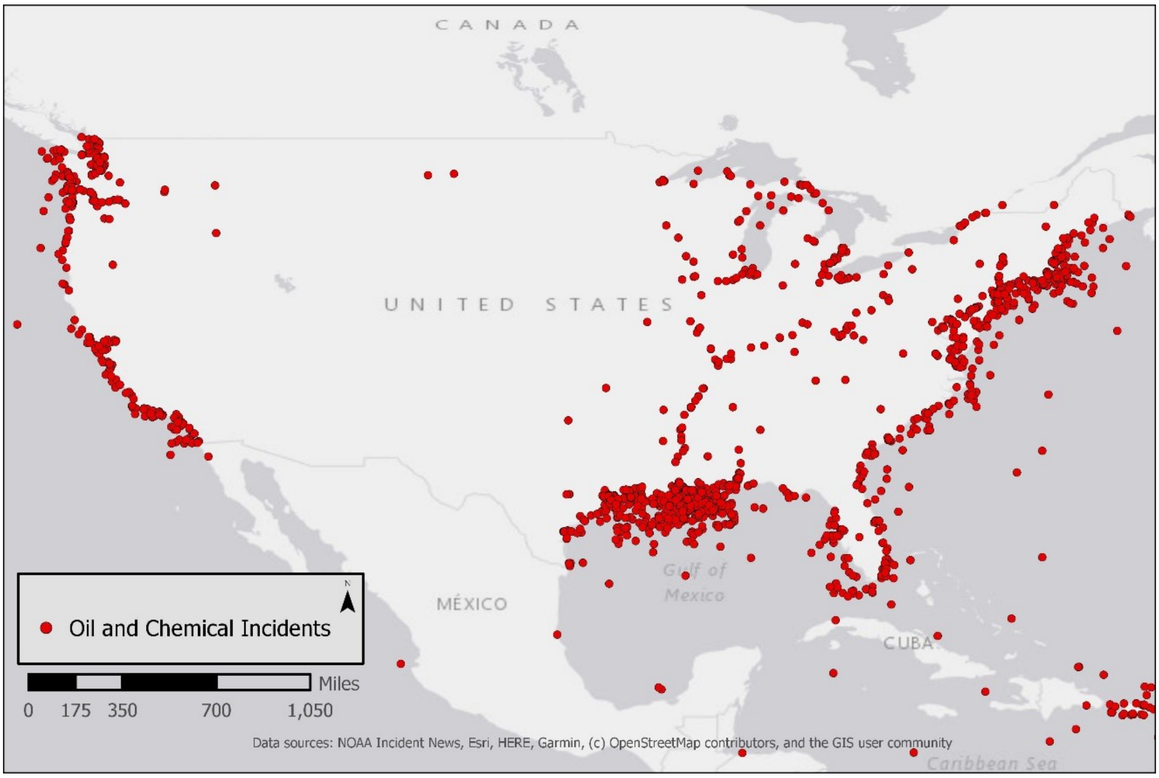

Figure 1. This map was developed using the NOAA Incident News Raw Incident Data downloaded on September 18, 2020 and ESRI's Light Grey Canvas Basemap.

Given the chronic problem of environmental disturbances affecting water quality, understanding how water pollution monitoring information in this context is associated with individual action to reduce risk is imperative. To our knowledge, past studies have not addressed awareness and use of water quality information among a representative population and in relation to multiple types of behavioral adaptation. The present study fills this gap by using survey data of 525 adults living in the area around Galveston Bay to test the hypothesis: *Individuals who are aware of water pollution monitoring and check it frequently will be more likely to change their behavior to activities that may put than at risk than those who are not aware of pollution monitoring or check it infrequently.*

2. Background: Water Pollutants in the Galveston Bay Watershed

2.1. Galveston Bay Socioeconomic & Environmental Attributes

The Galveston Bay region is the fifth largest metropolitan area in the U.S. and home to three major ports, including the Port of Houston - the second largest U.S. port in terms of tonnage [20]. The region is economically driven by energy, manufacturing, aeronautics, transportation, and healthcare industries. Access to Galveston Bay and the Gulf Mexico attracted a robust petrochemical industry including 10 oil refineries, processing approximately 40 percent of the state's total crude oil production and 14 percent of the total capacity in the U.S. [21]. Galveston Bay also produces about one third of the commercial fishing income for the state of Texas and is widely used for recreational fishing, birding, and boating [22]. Half of the population of Texas lives in the Galveston Bay watershed [23] with nearly 5.1 million people living in the three counties adjacent to the bay (Chambers, Galveston, and Harris) [24].

The Galveston Bay watershed consists of approximately 62,160 km^2 of land and water, with a mere 1,554 km^2 covered by the Bay. The Galveston Bay estuary is a hydrodynamically shallow (2.1 meters) system [25] that is heavily influenced by wind and freshwater inflows from the Trinity and San Jacinto Rivers [26] as well as various creeks and bayous. The metropolis of Houston and its associated suburban communities occupy the western side of the Bay, while the eastern side remains largely agricultural and undeveloped. Galveston Bay supports a diverse number of fish, wildlife and wetland plants. It provides ecosystem *goods* including food and shells, ecosystem *services* including storing and cycling essential nutrients, absorbing and detoxifying pollutants, maintaining the hydrologic cycle, and moderating the local climate [27-28]. Although habitat loss and fragmentation continue, regulation of groundwater withdrawal has slowed subsidence [29]. For humans, services include also providing sites for employment, recreation, and tourism. The vast majority of water quality concerns are concentrated in the western, urban tributaries of the Bay where municipal, industrial, and urban development is most pronounced [30-31]. The Bay comprises a major route for oil tanker traffic (as it connects the northern Gulf of Mexico with the Houston Ship Channel), and the Bay's coastline harbors major oil refineries. Over 8,000 vessels annually use the Houston ship channel enroute to the Ports of Houston, Texas City, and/or Galveston [32-33].

2.2. Oil Spill Pollutants in Galveston Bay

While the immediate impacts of oil spills is relatively well understood, much less is known regarding the long-term effects of oil residues that persist in the environment [34-35]. Long-term population and ecosystem-level impacts of oil pollution are expected to depend on hydrocarbon bioavailability and the intrinsic physiology of afflicted organisms. For example, twenty years after the 1989 Exxon Valdez oil spill, surveys of fouled sites around Prince William Sound, Alaska demonstrated the continued presence of subsurface oil in up to 29% of sites surveyed [36-37]. Similarly, sediments and biota in the aftermath of the BP Deepwater Horizon (DwH) oil spill in the Gulf of Mexico have been shown to act as reservoirs for spilt oil [38]. A recent report examining the fate, behavior, and associated toxicity of DwH oil residues on GoM beaches showed persistence of high molecular polycyclic aromatic hydrocarbons (or PAHs), a class of chemicals that occur naturally in crude oil and gasoline, on oiled beaches at toxic levels [39-41]. Therefore, regardless of factors influencing hydrocarbon longevity in oiled sediments or beaches, their long-term environmental persistence can be a major contributor of chronic toxicity in exposed organisms [37, 42-43]. Specifically, the coastal ecosystems of Galveston Bay remain a high priority for environmental monitoring studies as there is continued concern for long-term oil pollution [44-45].

In the Galveston Bay, there were an average 275 of oil spills each year during the 1998-2014 time period [46], with significant spills (>168,000 gallons) taking place from time to time [47]. Seventy five percent of all reported spills were attributed to Bunker C and heavy fuel oils, diesel fuel, and petroleum products of an unknown nature. Fifty seven percent of reported spills were from vessels, while 39 percent of spills could be traced to land-based facilities. The propensity of oil-derived PAHs and 'legacy' industrial pollutants including polychlorinated biphenyls (PCBs) to bio-concentrate in organisms, bio-accumulate across food webs, and exert toxicity has led to environmental monitoring efforts to quantify their levels in various ecosystems [48-51]. Sediments and biota act as reservoirs and refuges for these pollutants in the environment. Such sequestration ensures their long-term persistence, contributing to chronic toxicity in exposed organisms [37, 42-43]. Studies continue to show high levels of PCBs and dioxins in sediment of the Houston Ship Channel [52-53]. Another study noted a strong gradient of PCBs levels were found in Galveston Bay, with sources pointing towards the industrialized portion of the Houston Ship Channel [54]. The same study found a parallel gradient in contamination was also noted in the water, sediment and fish samples, with PCBs level in Gulf killifish (Fundulus grandis) correlating strongly with that found in the sediment. Dioxins and related furans are created through the combustion of chlorinated hydrocarbons. Recent studies suggest that dioxins continue to be released into the environment in and around the Houston Ship Channel and Clear Creek, including at the Superfund site [52, 55-58]. Since 1990, PCBs, dioxin, and organochlorine pesticides have been identified as pollutants of concern in seafood consumption advisories issued in the Lower Galveston Bay watershed by the Texas Department of State Health Services [29, 58].

2.3. Other Sources of Pollution in Galveston Bay

When human activities disrupt the essential functions of ecosystems, the assimilative capacity of the natural system can be exceeded, and the normal flow of goods and services provided by healthy ecosystems can become impaired [59]. In the Galveston Bay this was particularly evident after Hurricane Harvey when the flooding flushed an unprecedented volume of nutrients and contaminants into the bay in a very short amount of time [60]. The largest number of fish kills in Texas occurred from 1951 to 2006 in Galveston Bay [61]; these were associated primarily with low dissolved oxygen and harmful algal blooms, often thought to be symptoms of environmental degradation.

Atmospheric deposition and land-based activities (residential, industrial and agricultural lands) that reside within the watershed are thought to diminish water quality. Fertilizers and pesticides from lawns, pet waste, herbicides, and oil and grease from roads and parking lot runoff from the land, On-site Septic Facilities (OSSF), and various and contaminants enter the water [29, 62-67). Improperly maintained and highly clustered OSSFs are contributing to increased nutrient loadings in the watersheds surrounding Galveston Bay [67]. An increase of overall low intensity development in the Bay's watersheds is likely to increase total phosphorus as a result of increased nonpoint source loadings from fertilizer [65], thereby lowering the nitrogen to phosphorus (N:P)ratio. Such changes to N:P ratio have been shown to change the phytoplankton community composition in the past [68].

2.4. 2019 Environmental Hazards in Galveston Bay

In 2019, two environmental disturbances occurred in less than two months that spilled approximately one million gallons of oil derived products into Galveston Bay. The first occurred on March 17, 2019 at approximately 10:30 AM when a storage tank caught fire at the Intercontinental Terminals Company (ITC) facility in Deer Park, Texas due to a mechanical failure [69]. The tank contained naphtha enriched with butane, a highly flammable liquid used in the production of gasoline [70]. The fire eventually spread to ten other 80,000 barrel storage tanks before being extinguished three days later. These additional storage tanks held stock feeds for gasoline production including xylene and pygas, which contain concentrations of carcinogenic benzene [71]. Local reports state that the fire produced a black plume of smoke visible for 30 miles and a smog-like haze across at least six counties [72]. On the third day of the fire, elevated benzene levels led to a one-day shelter-in place order in the Deer Park area [73]. Days later on March 22, a dike wall partially collapsed at the facility allowing chemicals to be released into Tucker Bayou and the Houston Ship Channel; however, no evidence of benzene was found in local drinking water. The effort to extinguish the fire produced 21 million gallons of waste water mixed with tank products and firefighting foam [71].

Less than two months later on May 10, 2019 at approximately 3:20 PM, the 775-foot tanker MV Genesis River collided with the tug Voyager pushing two barges in the Houston Ship Channel near Bayport, Texas. One barge capsized and the other was heavily damaged leaking approximately 11,276 barrels (473,600 gallons) of product over five days [74]. Each barge contained approximately 25,000 barrels of reformate used in the production of gasoline which can have high concentrations of carcinogenic benzene [75]. The Genesis River took on water, but did not spill any fuel or cargo. Residents of Seabrook, Clear Lake Shores, Kemah, Baycliff and San Leon were told to avoid fishing and coming in contact with the water [76]. A strong "gasoline smell" was reported across several cities; however, the Texas Commission on Environmental Quality and US Coast Guard air monitoring showed no concern for public health related to this smell [77]. Water sampling in some areas did show some elevated levels of known human carcinogen benzene [75], and there were reports of a large fish kill following the spill [74]. By May 15, 2019, both barges were removed from the ship channel and normal vessel traffic resumed [74]. Federal, state and local personnel participated in rapid cleanup operations both near the collision and along the coast, utilizing eight skimmers and over 20,000 feet of containment boom. The fishing advisory was lifted on May 24 after water testing no longer showed high levels of contaminants from the event.

In all, the Deer Park fire is estimated to have released ~696,990 gallons of oil-contaminated water and ~1.5 million gallons of flame retardants [78]. Whereas, the barge spill is estimated to have released ~378,000 gallons of gasoline into Galveston Bay [75]. At present, the extent of oil leak into the surrounding waters is not fully known. The magnitude of these disturbances is suspected to have a significant impact on the local and national economy due to a partial closure of adjacent waterways of the Houston Ship Channel, and estimates of economic impacts ranging from $0.5 – $1 billion [79]. The ecological impacts of both disturbances are not fully known at this time. In the immediate aftermath of the Deer Park fire (on 3/23/19), the Texas Commission on Environmental Quality (TCEQ) released a water quality report. Their chemical analysis of waters in the immediate vicinity of the fire found oil-derived hydrocarbon levels to far-exceed their regulatory mandated health-protective concentrations [80]. Initial public concern was mainly over the release of volatile organic compounds, including benzene [81]. However, subsequent analytical chemical analyses showed the absence of volatile organics (including benzene) in water samples taken from the vicinity of the fire [82]. Continued concerns for human exposure due to the consumption of contaminated fish and shellfish from the Houston Ship Channel led to a moratorium on sea food consumption immediately following the spill [83]. However, concern remains for the exposure of aquatic biota to oil-derived hydrocarbons, and likely long-term human health effects as related to sea food consumption.

2.5. Health Impacts of Pollutants in Galveston Bay

The International Agency for Research on Cancer (IARC) [84] classifies heavy oil and related contaminants as carcinogens that may directly increase risk of cancers through several pathways: stress, immunosuppression, or endocrine disruption. Oil contains several chemical compounds including benzene, toluene, xylene, gasoline, and naphthylene which can dissolve or deform cell membranes and kill cells. Immediate health effects of crude oil on human health has been documented to include: irritation to the skin or skin disorders; irritation to the nose, throat, and lungs; headaches; nausea; drowsiness; fatigue; loss of coordination; labored breathing; or irregular heartbeat [85]. Safety information on crude oil indicates that prolonged exposure or repeated contact should be avoided and that vapor, mist, or liquid may be harmful if inhaled [85]. Extra caution should be taken since vapor from crude oil may not be detectable by human odor perception.

Exposure to oil has been studied in lab animals and humans to a lesser extent. Skin tumors in lab animals demonstrate the carcinogenic effects of prolonged exposure and repeated contact with crude oil and associated substances [85]. Human health studies of oil exposure, especially those studying long-term health consequences are limited with only seven studies on the health effects on humans exposed from the 39 largest oil spills globally [86]. Recent research on short term human health effects conducted in the Gulf of Mexico following the Deepwater Horizon oil spill (DWHOS) report lower respiratory tract, inflammation of the eyes and throat, nausea, headache, low back pain, psychological impacts (e.g. depression) among exposed populations [87]. A study of women and their children's health found that among women in Southern Louisiana, physical-environmental exposure such as working on oil clean-up, coming into contact with oil, or damage to property or where you fish as well as economic exposure such as experiencing negative financial consequences from the oil spill were both associated with higher self-reported physical health impacts including burning in nose, throat, or lungs; sore throat; wheezing; headaches; watery, burning, itchy eyes or nose [88].

Further, exposure to the DWHOS was a predictor of higher rates of poor mental health in the same cohort of women [89]. The Gulf Long-term Follow-up (GuLF) Study, a cohort study following the health of DWHOS clean-up workers and volunteers found that working on the spill for more than 180 days and stopping work due to the heat were associated with greater risk of nonfatal myocardial infarction [90] and that high amounts of total hydrocarbon exposure or stress on the job were associated with increased prevalence of depression and PTSD [91].

3. Materials & Methods

3.1. Survey Sample

To assess the association of pollution information and changes in behavior of residents of the Galveston Bay region, we launched an online survey of adults, aged 18 years or older, residing in a total of 51 zip codes surrounding Galveston Bay. The survey sample area is shown in Figure 3 in relation to the Deer Park chemical fire and the barge collision; Galveston beach is also highlighted in the figure. The survey was in the field May 28 - July 14, 2020 and collected responses from 525 individuals. All survey participants gave their informed consent for inclusion before they participated in the study, and the survey protocol was approved by the Texas A&M University Institutional Review Board (reference number IRB2019-0646M).

Figure 3: Map of Surveyed Area in Relation to Environmental Hazards

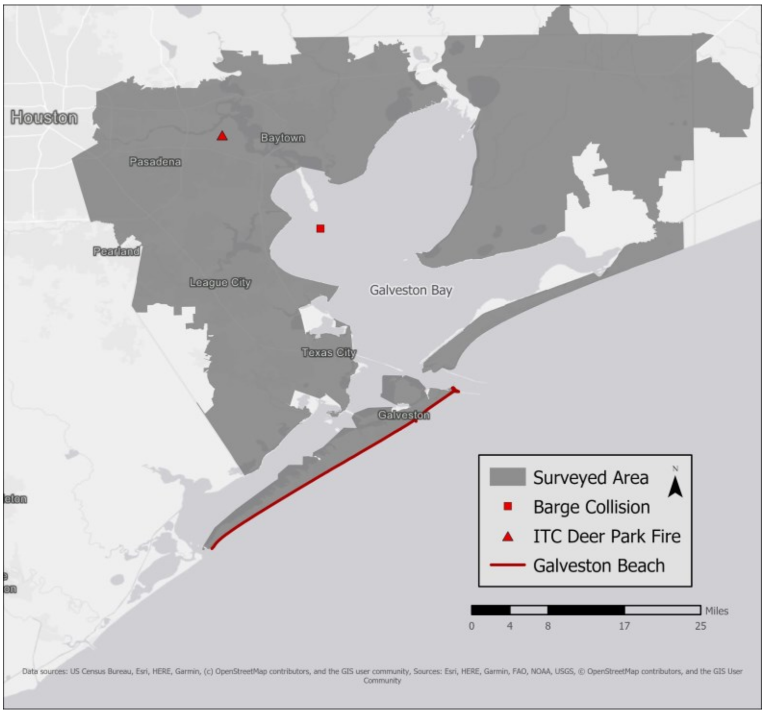

Figure 2. Shaded area corresponds to zip codes sampled in the survey, in relation to the 2019 environmental hazard events and Galveston beach. Map developed using U.S. Census Bureau 2019 TIGER/Line Shapefile of zip code tabulation areas and ESRI's Light Grey Canvas Basemap. Zip code tabulation areas correspond with the zip codes designated for the survey sample. Locations for the ITC Deer Park Fire and Barge Collision were drawn based on event reports [69, 74]. Galveston Beach was drawn according to generalized beach access points published by the Texas Parks and Wildlife Department [92].

Survey respondents were recruited by Qualtrics to fill quotas on sex, age, and race. The quotas represent overall population characteristics of residents in the zip codes sampled, determined by 2018 U.S. Census Bureau data [93]. There were differences between the sample and population proportions with skews towards more females (60.76% in the sample versus 50.45% in the population), younger adults (42.29% of 18-34 year olds in the sample compared to 33.65% in the population), and white (43.05% in the sample versus 35.90% in the population) individuals in the sample. Given these discrepancies, a sample weight was calculated to adjust the sample to population parameters for sex, age, and race/ethnicity using a “raking” or iterative proportional fitting method [94]. While there are no strict rules on trimming survey weights – and many surveys use different trimming procedures and threshold points [95], we adopt the procedure used in other studies [e.g., 96] to trim observations three times smaller or three times larger than the median weight value. Accordingly, a total of 6.86% of the observations were trimmed. While applying the weight to the quota-based sample adjusts the sample to make it more representative of the population, there are unknown biases introduced into the survey estimates [97]. This is due to the non-probability sampling frame because measures of precision (i.e., response rate, margins of error) are not available with such a sampling approach. See

Appendix A for a table reporting the sample proportions with and without the weight applied, compared to population proportions.

3.2. Measures

To measure the dependent variable of interest - change to behavior - survey respondents were asked two questions: 1) "Have you ever changed your planned outdoor activities for the day due to poor water quality conditions in Galveston Bay?" and 2) "Have you ever changed your use or consumption of drinking water and/or seafood due to poor water quality conditions in Galveston Bay?" Response options included "yes," "no," or "don't know." Observations with responses of "don't know" were dropped from the analysis. To assess the key independent variable of interest - awareness and frequency of use of pollution information - the survey asked respondents: "Are you aware of any pollution monitoring of the water quality of Galveston Bay?" Response options included "yes," "no," "don't know." For those respondents that indicated "yes," they were asked a follow-up question: "And how often do you check the water quality rating of your community? Do you check it…" Response options included: "don't know," "never," "seldom," "sometimes," "occasionally," and "everyday." See Table 1 for tabulations of responses by measure.

Table 1. Tabulations of Variables Analyzed in Regression Models

Variable	Category	Prevalence
Change outdoor activities (no[1])	yes	44.21%
Change consumption (no)	yes	36.26%
Water quality monitoring (not aware)	never check	6.15%
	seldom check	6.62%
	sometimes check	8.89%
	occasionally check	7.36%
	everyday check	4.07%
Fish, swim, visit Galveston Bay (never)	once a year	12.18%
	a couple of times a year	19.77%
	multiple times a year	18.52%
	once a month	11.59%
	multiple times a month	15.73%
	once a week	8.97%
	multiple times a week	4.81%
Eat locally caught seafood (never)	once a year	3.83%
	a couple of times a year	14.77%
	multiple times a year	22.22%
	once a month	12.22%
	multiple times a month	15.72%
	once a week	8.33%
	multiple times a week	5.90%
Concern for health (not at all)	not at all - a little	4.32%
	a little	9.55%
	a little - a moderate amount	8.34%

	a moderate amount	18.15%
	a moderate amount - a lot	11.50%
	a lot	15.81%
	a lot - a great deal	10.07%
	a great deal	14.30%
Environmental hazard knowledge (not at all)	slightly	22.81%
	moderately	34.79%
	very	18.88%
	extremely	11.36%
Pollution experience (none)	at least one event	91.26%
Sex (male)	female	50.40%
Age (18-34 years)	35-44 years	18.00%
	45-64 years	33.40%
	65 years and older	14.90%
Latino (no)	yes	47.60%
African American (no)	yes	10.90%
Education level (high school or less)	some college	21.02%
	Associate's or Bachelor's degree	36.68%
	post-graduate degree	9.79%

[1] Referent category of the variable noted in parentheses. Survey weight applied to tabulations.

Chronic exposure to poor environmental conditions has been connected to behavior modifications in a study of air quality [98]; similarly, it is thought that acute exposure to environmental emergencies and disasters encourages adaptations to reduce risk [99]. Accordingly, the model controls for chronic and acute pollution exposure through multiple measures. Chronic exposure to water pollution in the Galveston Bay is measured by responses to two survey questions that replicate survey items in past studies [15, 100]: 1) "How often would you say you fish, swim, or visit Galveston Bay?" and 2) "How often do you eat locally caught seafood?" Response options included: "never," "once a year," "a couple of times a year," "multiple times a year but not monthly," "once a month," "multiple times a month but not weekly," "once a week," and "multiple times a week." A third question was asked about frequency of Galveston beach. However, the variable was highly correlated with frequency of swimming, fishing, and visiting Galveston Bay; therefore, it was not included in the model.

Assessment of acute exposure to water pollution focused on the recent environmental hazard events and asked respondents to rate their concerns about health related to these events. Two questions were posed: 1) "How concerned were you about the effect of the Deer Park Fire on your health and the health of your household?" and 2) "How concerned were you about the effect of the barge collision in Galveston Bay on your health and the health of your household?" Response options included: "not at all," "a little," "a moderate amount," "a lot," and "a great deal." Prior to these questions, respondents were asked if they were aware of these events. Regarding the Deer Park chemical fire, 58.86% said they were aware of this event, and 50.48% were aware of the barge collision. For those that were not aware or said they were not sure, brief descriptions of the events and pictures from local media were shown to respondents (see Supplemental Materials, Figure S1). This should have aided recall for some respondents; therefore, the self-reported indicator of health concern to measure acute exposure to the two environmental hazard events should reasonably capture if individuals thought they were physically exposed or experienced anxiety or stress over the event. Due to a high correlation between health concern for each environmental hazard event, the measure of acute exposure included in the model represents the averages concern for the two events. The resulting variable has nine categories, ranging from no concern to "a great deal" of concern.

In addition to chronic and acute pollution exposure, environmental hazard knowledge and prior experience with pollution are controlled for in the model as these have been found to be associated with action to reduce risk [14-15]. To measure environmental hazard knowledge, a question replicating items of past studies [15, 100] was posed in the survey: "How knowledgeable do you feel you are about actions to take in the event of an environmental hazard? An environmental hazard is the risk of damage to the environment from air pollution, water pollution, toxins, and radioactivity." Response options included: "not knowledge at all," "slightly knowledgeable," "moderately knowledgeable," "very knowledgeable," and "extremely knowledgeable."

The survey also presented respondents with a list of pollution types and events, asking: "In your lifetime, have you ever personally seen or experienced the following in or around Galveston Bay?" These included: "tar balls on the beach," "trash and other debris in the water," "trash and other debris on the beach or coastline," "dead fish on the beach or coastline likely due to contamination," "smell of oil or other chemicals," "smell of sewer," and "sheen of oil or other chemicals in the water." Responses that indicated experience with at least one of these is considered to represent pollution experience while responses of "none of these" indicates no experience with pollution. Finally, controls are included for sex (male or female), age (18-34 years, 35-44 years, 45-64 years, and 65 years and older), Latino ethnicity (no or yes), African American race (no or yes), and education level (high school or less, some college, Associate's or Bachelor's degree, or post-graduate degree).

3.3. Method

Logistic regression was used to model change in outdoor activities (Model 1) and change in consumption of drinking water or seafood (Model 2) due to poor water conditions in Galveston Bay as explained by awareness and frequency of use of water quality monitoring information, while controlling for: chronic water pollution exposure (fish, swim, or visit Galveston Bay; visit Galveston beach; and eat locally caught seafood), acute water pollution exposure (health concern related to the Deer Park chemical fire and health concern related to the barge collision of May 10, 2019), environmental hazard knowledge, pollution experience in and around Galveston Bay, sex, age, race and ethnicity, and education level. Logistic regression is appropriate when the dependent variable is a binomial response variable and when modeling the impacts of multiple explanatory variables on the response variable [101]. Goodness of fit of the models was assessed using the F-adjusted mean residual test, which was developed for testing the fit of logistic regression models using survey data and validated using National Health Interview Survey data [102]. The results are explored using marginal effects at specified values because they appropriately express both the non-linearity and conditional effects of the results [103].

4. Results

The results of the logistic regression analyses are presented in Table 2 as marginal effects representing the discrete change in the likelihood of altering behavior to outdoor activities (Model 1) and consumption of drinking water and seafood (Model 2) due to poor water quality conditions in Galveston Bay. Marginal effects like these, expressed at specified values of the independent variables, should be interpreted in relation to the referent category. Note that demographical controls variables are omitted from the table; Table S1 in the Supplemental Materials provides a table reporting the coefficients and standard errors of all variables in the logistic regression models.

Table 2. Logistic Regression Results: Marginal Effects[1]

	Model 1 OUTDOOR ACTIVITIES			**Model 2 CONSUMPTION**		
	dy/dx	*CI lower*	*CI upper*	*dy/dx*	*CI lower*	*CI upper*
Water Quality Monitoring (not aware)						
never check	-1.39%	-0.236	0.208	-0.21%	-0.176	0.172
seldom check	-11.17%	-0.330	0.107	-10.38%	-0.279	0.071
sometimes check	9.59%	-0.075	0.267	0.18%	-0.164	0.167
occasionally check	14.59%	-0.046	0.337	**25.86%**	0.085	0.433
everyday check	**25.92%**	0.047	0.471	**32.71%**	0.101	0.553
Fish, swim, visit Galveston Bay (never)						
once a year	0.79%	-0.193	0.208	-12.86%	-0.367	0.110
a couple of times a year	9.07%	-0.095	0.276	-7.48%	-0.314	0.164
multiple times a year	18.52%	-0.019	0.389	2.86%	-0.215	0.272
once a month	0.92%	-0.203	0.222	-6.61%	-0.313	0.181
multiple times a month	13.36%	-0.079	0.346	3.28%	-0.216	0.282
once a week	0.44%	-0.227	0.236	-4.71%	-0.321	0.227
multiple times a week	18.12%	-0.082	0.444	-1.48%	-0.340	0.310
Eat locally caught seafood (never)						
once a year	0.86%	-0.278	0.296	5.03%	-0.243	0.343
a couple of times a year	-5.20%	-0.213	0.109	2.51%	-0.145	0.195
multiple times a year	-4.68%	-0.204	0.110	0.76%	-0.156	0.171
once a month	-10.77%	-0.296	0.081	3.39%	-0.160	0.228
multiple times a month	4.64%	-0.136	0.229	2.67%	-0.147	0.200
once a week	-6.91%	-0.272	0.133	-2.66%	-0.224	0.171
multiple times a week	-20.59%	-0.425	0.013	-5.32%	-0.261	0.155
Concern for health (not at all)						
not at all - a little	-3.18%	-0.352	0.289	11.02%	-0.177	0.397
a little	3.99%	-0.197	0.277	1.28%	-0.223	0.249
a little - a moderate amount	-3.82%	-0.278	0.202	6.59%	-0.179	0.311
a moderate amount	6.19%	-0.170	0.294	12.77%	-0.118	0.373
a moderate amount - a lot	1.01%	-0.232	0.252	1.01%	-0.231	0.252
a lot	11.85%	-0.118	0.355	10.41%	-0.137	0.346
a lot - a great deal	16.26%	-0.086	0.411	5.89%	-0.181	0.299
a great deal	**26.60%**	0.017	0.515	19.98%	-0.039	0.439
Environmental hazard knowledge (not at all)						
slightly	9.16%	-0.100	0.283	10.59%	-0.063	0.275

moderately	7.21%	-0.113	0.257	11.77%	-0.040	0.276
very	-4.09%	-0.236	0.154	9.92%	-0.076	0.274
extremely	19.54%	-0.042	0.433	14.59%	-0.058	0.350
Pollution experience (none)						
at least one event	**26.45%**	0.124	0.405	**32.87%**	0.229	0.429

[1] Note: Change in marginal effects from referent category, noted in parentheses, reported with confidence intervals. Bolded figures are statistically significant (p<0.05).

Considering first the primary explanatory variable of interest, the results support that individuals who are aware of water pollution monitoring and check it frequently are more likely to change their behavior than those who are not aware of pollution monitoring or check it infrequently. The marginal effects demonstrate the average individual who checks water quality information "everyday" is 25.92% (p=0.017) more like than someone who is not aware of water pollution monitoring to change their planning outdoor activities and 32.71% (p=0.005) more likely to change their consumption of drinking water and/or seafood when poor quality conditions in Galveston Bay are present. The average individual who checks water quality "occasionally" is associated with a 25.86% (p=0.004) higher likelihood of changing their consumption behavior, compared to someone with no awareness of water quality information.

The models account for chronic and acute exposure to water pollution. Of these measures, only the concern for health related to recent environmental hazards (the Deer Park chemical fire and the barge collision in Galveston Bay) are associated with changes in behavior that reduce risk. The marginal effects indicate that, on average, an individual who has the highest level of concern for their health and the health of their household is 26.60% (p=0.036) more likely than someone with no concern to change their outdoor activities due to poor water quality.

In addition to exposure, the model accounts for self-reported environmental hazard knowledge and experience with pollution events in and around Galveston Bay. While environmental hazard knowledge is not statistically significant, pollution experience is significantly associated with action to reduce risk. On average, individuals who have experienced at least one event in their lifetime are 26.45% (p=0.000) and 32.87% (p=0.000) more likely than someone who has never observed a pollution disturbance to change their outdoor activities and consumption of drinking water and/or seafood, respectively. Finally, of the demographic controls the results indicate that females are 10.66% (p=0.026) more likely than males to change their consumption behavior, and 45-65 year old adults are 17.35% (p=0.007) less likely than 18-34 year old adults to change their outdoor activities.

5. Discussion

5.1. Implications of Findings

The results support our hypothesis that individuals who are aware of pollution water monitoring and check this information frequently are more likely to take action that reduces their risk in terms of changing their outdoor activities and consumption of drinking water and/or seafood on days when water quality is poor. This is in line with past studies that have found awareness of air quality reports and frequency of checking them is associated with behaviors to reduce risk [12, 14-15]. These findings suggest risk-reducing behavior is sensitive to the frequency of checking water quality information. While occasionally checking water quality information is significantly associated with changes to consumption, it is not significantly associated with changes to outdoor activities. The findings also indicate that acute, but not chronic, exposure is significantly associated with changes to outdoor activities when water quality is poor. However, changes to consumption in relation to the 2019 environmental hazards is not evident. Additional data, particularly rich qualitative data from interviews and focus groups, would help explore how perceptions of risk are associated with acute exposure events and, in turn, affect the propensity to take different actions to reduce risk. There is some evidence that the fishing public often ignores fish consumption advisories due to discounting health risks that are associated with familiar and enjoyable activities [104]. Similar psychosocial processes involving de-amplification of risk may be occurring with recreational activities in the Galveston Bay.

5.2. Need for Pollution Monitoring & Risk Communication Framework

The findings of this study point to a need for pollution monitoring data that is current, accessible to the public, and communicated in a manner that induces responses. Although straightforward, meeting this need is challenging. Water pollution monitoring is complex and requires considerable expertise and effort (see Table S2 in Supplemental Materials for details on the process of water pollution analysis in relation to the Galveston Bay). Additionally, adequate environmental monitoring requires continuity, consistency, and adequate scale – requirements that entail significant and consistent investment of resources [105]. For this reason, there is a dearth of environmental monitoring information [106]. This is evident in the Galveston Bay where, with the exception of independent research, there is a lack of concerted water pollution monitoring. Water quality monitoring is mainly under the remit of state agencies and communicated through seafood advisories. Filling this information gap, not only in the Galveston Bay but globally, is a critical first step so that risk may be communicated effectively.

A coupled issue with lack of environmental monitoring information is the dissemination of this information to the public and policy-makers. It is important to approach information dissemination not as a process of filling information deficits, but as a process of contextualization in relation 'real world' experience [107]. In a study of awareness, use of, and attitudes toward air quality information in the United Kingdom, Bickerstaff and Walker [107] found that relevance is key. Air quality information was criticized by residents as being overly technical in language, ambiguous due to lack of description to ease interpretation of presentation of quality metrics, and not sufficiently specific with regards to spatial application. Additionally, air quality reports were consistently in conflict with direct personal experience. They explain [107] (p. 292):

> *Air-quality information is not passively received by a homogenous public body. Rather the material is contextualised and 'made sense of' in relation to the relevance to people's lives and the immediate and personal realities of physical encounters with air pollution. Where air-quality information and advice has little resonance with people's local experience, and where its credibility is challenged, it is quite reasonable to expect that it will be ignored or simply set alongside the many other demands on the public's attention arid understanding.*

Applying this to the issue of water quality suggests water pollution information should be provided on a relevant spatial scale (i.e., what is considered 'local') and in relation to observable water quality disturbances. Further, pollution information should be approached as a collaborative effort among data users and producers [106] and possibly incorporate local knowledge through, for example, crowd-sourcing platforms [108]. Additionally, pollution information should come from credible sources where trust is established in the relationships between the public and the organizations. Irwin contends that effective communication of risk recognizes that information sources "will be judged alongside the perceived credibility of the source and the possibilities for practical action which are opened up for its intervention" [109] (p. 102). Pollution information, therefore, should also be connected to practical actions to reduce risk. Future work should endeavor to create a risk communication framework that implements this aspects of pollution information formatting and dissemination.

5.3. Study Limitations

The current study is limited by its cross-sectional design that captures explanatory and outcome measures at the same time. Consequently, causal relationships cannot be established. The strength of this approach for examining the association of pollution information with actions to reduce risk outweigh this limitation as this study contributes to an area of research with few empirical analyses of water quality monitoring. Furthermore, the present cross-sectional analysis has provided additional information on the frequency of checking water quality information and changes to multiple types of behavior to reduce risk – critical information to move forward with further research in this area. The study is also limited by its reliance on online survey data, which limits recruitment and participation to individuals with access to online services.

Another limitation of this study is the reliance on a non-probability, quota-based sampling frame. Due to low response rates, high costs, and poor coverage of probability surveys, non-probability surveys are being increasingly used by researchers [110]. While quota-based sampling aims to match a panel to a set of population parameters and, therefore, enhances the representativeness of the sample, there is a critical disadvantage. Specifically, non-probability samples, including those using quotas, do not allow for calculation of margins of error that provide a measure of precision. This likely results in introducing unknown sampling biases into the survey estimates [97]. A study by Pew Research Center [111] concludes that such biases may be reduced through the use of survey weights. Accordingly, this study includes a weight that adjusts the sample on population parameters for sex, race/ethnicity, and age using an iterative proportional fitting method by [94]. This method is appropriate for managing the limitations of non-probability survey samples [110] but does not completely eliminate biases.

6. Conclusion

Hazard mitigation can take a number of forms; the present study has looked at one strategy of risk reduction – building awareness [11]. Building on the work of Reams and colleagues [14-15], this study examined how water pollution awareness and frequency of checking information is associated with changes to outdoor activities and consumption of drinking water and/or seafood when water quality is poor. The results of the present study are in line with prior research, finding that behavioral changes are associated with frequent checking of water quality ratings. The findings underscore that awareness is not enough to reduce risk; rather, changes in risky behavior is only associated with very frequent engagement with pollution information.

Critical to the contribution of this study is the context in which water pollution information and risk reduction activities were explored. As a hotspot of oil and gas and transportation industry activity, environmental disturbances - including 2019 events of a chemical fire and barge collision - often affect the Galveston Bay. Residents living around the Bay, therefore, are exposed to chronic and acute water pollution. It is under these conditions that the present study has found the frequency of checking water quality information to be significantly associated with changes to recreational and consumption patterns. This context has considerable implications for risk communicators, including researchers, environmental organizations, and policy-makers. Primarily the message is a cautious one – it is imperative to improve water pollution monitoring and the dissemination of this information so that risk is not ignored, normalized, or de-amplified. Investments are needed to make data collection more consistent, widespread, and on the appropriate spatial scale. Concerted efforts are also needed to share this information in ways that are perceived as relevant, accessible, and credible to the public. Only with these developments will the potential hazard information offers for risk reduction be realized.

Supplementary Materials: The following are available online at www.mdpi.com/xxx/s1, Figure S1: Environmental Hazard Events in Survey, Table S1: Logistic Regression Results, Table S2: Process for Detection of PAHs & PCBs in Water and Biota Samples.

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Appendix A

Comparison of sample and population proportions on sex, age, and race and ethnicity are given in Table A.1. Column 1 corresponds to the sample without a weight applied; column 2 to the sample with a weight applied; and column 3 to the population. The data analyzed in this study applies the survey weight (column 2).

Table A.1. Sample and Population Proportions on Sex, Age, and Race and Ethnicity

		1	2	3
Sex	Male	39.24	49.62	49.55
	Female	60.76	50.38	50.45
Age	18-34 years	42.29	34.20	33.65
	35-44 years	22.67	18.27	18.03
	45-64 years	28.00	33.31	33.38
	65 years & older	7.05	14.23	14.94
Race &	White	43.05	36.30	35.90
Ethnicity	African-American	9.33	10.87	10.90
	Latino	40.95	47.14	47.60
	Asian-American	4.00	3.75	3.70
	Other	2.67	1.93	1.90

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