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The Geography of Watershed Toxicity with Industrial Activity

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Abstract

The nonpoint-source pollution (from stormwater runoff) is a persistent, ubiquitous environmental challenge, rarely linked to the formerly industrial and currently blighted sites impacting the watershed as a whole-river, creek, stream, and lake. This shortcoming is particularly prevalent in the legacy, post-industrial city, characterized by abandoned industrial sites slated for cleanup. We develop a GIS-aided procedure to (a) map the whereabouts of industrial sites, and (b) identify site-specific pollutants also found in waterbodies in proximity. For our case study, we map industrial sites in various stages of cleanup per U.S. Environmental Protection Agency classification-brownfield, superfund, and national priority list (NPL).

It turns out, the 3/4-mile buffer zones centered on industrial sites with water permit also contain water quality monitoring stations, thereby meeting the spatial search criteria of proximity of the industrial site to the waterbody (river, creek, and lake) as well as to the station that gauge's water quality. Interactive spreadsheets identify industrial site pollutant quantity and type in common with waterbodies. Thereby, the watershed environmental quality holistically linked to industrial activity is monitored, with implications for site-specific physical design interventions that mitigate pollutants and toxin runoff in waterbodies and promote public health.

Keywords: Industrial Activity; Nonpoint Source Pollution; Watershed Toxicity; Environmental Impact; GIS

Abbreviations: NPS: Nonpoint Sources; CWA: Clean Water Act; PCBs: Polychlorinated Biphenyls; EPA: Environmental Protection Agency

Highlights

- **a)** The nonpoint source pollution (NPS) is a persistent, ubiquitous environmental challenge.
- **b)** NPS is rarely linked to toxic industrial sites, impacting the watershed quality holistically.
- **c)** A GIS-aided procedure maps the whereabouts of toxic industrial sites in proximity to waterways and water quality monitoring stations.
- **d)** We find industrial site pollutants also present in waterways in proximity, identified by type and quantity with interactive spreadsheets.
- **e)** Findings indicate monitoring industrial activity and waterbodies holistically, with site-specific physical, landscape interventions that mitigate pollutant and toxin runoff, promoting public health.

Introduction

Nationwide more than 85% of the U.S. rivers and streams, and 80% of reservoirs and lakes are polluted by Nonpoint Sources (NPS). (Lei et al. 2021, USEPA [1] & US Geological Survey [2]); Xie et al. [3] for a global survey of the NPS). Nonpoint source pollution results from rainfall or snowmelt moving over and through the ground, picking up and carrying pollutants like sediment, oil, and nutrients, which are then deposited into water bodies. This type of pollution is significant as it harms aquatic ecosystems, affects water quality, and contributes to harmful algal blooms and ocean acidification Zhao et al. [4], USGAO 2022 & USEPA [5]. The Clean Water Act (CWA), notably amended in 1987, addresses NPS pollution through the Section 319 Nonpoint Source (NPS) Program. This program assists states, territories, and tribes in implementing measures to prevent and manage NPS pollution, although managing these diffuse sources remains a challenging task USEPA [6] & USEPA [7]. Daniels & Daniels [8] note, notwithstanding the Clean Water Act, “in 2000, about 40 percent of America’s waterbodies were still not fit for drinking or swimming; and about four out of every five U.S. residents were living within ten miles of a polluted lake, river, stream or coastal area." Xie et al. [3] global bibliometric analytical survey.) Memphis and Shelby County is home to many abandoned industrial properties that impact the watershed CRA, 2023; Lewis [9]. Recent research on the impact of industrial blight Banai & Ploderer [10]; Banai & Momeni [11] provided the impetus to explore the environmental impact of industrial activity in proximity to waterbodies in Memphis, Shelby County Tennessee.

The historic location of industry in proximity to waterbodies and floodplains is a generally known urban form, albeit rarely conceptually considered as a determinant of the analytic methods' spatial criteria in mapping the nonpoint source pollution in the watershed. Furthermore, the nonpoint-source pollution targeted particularly to the formerly industrial and currently blighted sites slated for clean up or remediation in a legacy city impacting the watershed is rarely recorded in the literature. What specific type and quantity of the industrial site contaminants with various EPA remediation classification is linked to the waterbodies in proximity, and what are the environmental consequences?. In the section that follows we develop a mapping procedure to identify the type and quantity of pollutants that are in abandoned or active industrial sites and the nearby waterbodies-river, creak, and lake. Our GIS-aided mapping of industrial sites is enabled by data available in the public domain from the U.S. later below. We organize data on pollutants in waterbodies and indusial sites interactively by spreadsheets linking pollution data from industrial sites by current EPA-designated status and the water bodies. We start with a brief review of observational methods of analysis and mapping of NPS pollution in the watershed.

Methods and Materials

Our case study focus is like those that aim to examine the impact of NPS pollution in the watershed like a bay or river Saba & Su [12]; Hoogestraat 2015; Celen et al. 2022; Lin et al. [13]. By pointing to upland activities as sources of pollutants the relevance of spatial mapping tools like GIS which we also use is realized Saba & Su [14]. Spatial mapping tools like GIS augment multicriteria analysis methods that streamline or structure the multiple drivers of NPS pollution Corwin et al. [15]; Loague et al. [16]; Siverturn &Prause, 2003; Guo et al. [17]; Liu et al. [18]; Eisakhani et al., 2009). However, spatial analytical methods of tracking NPS pollution rarely pay attention to where industry is historically legally permitted to locate in the region in relation to the waterbodies in proximity. Thereby, industrial sites (source pollution) particularly the former industrial and currently blighted, designated for clean-up as "brownfield" or Superfund sites are plausibly considered as a driver of NPS pollution in the waterbodies and floodplains in proximity. Our approach is a GIS-aided mapping that locates industrial sites in proximity to the waterbodies. GIS is a spatial analysis and visualization tool applied in a wide variety of fields.

It is used as a watershed assessment tool (Naranjo [19]; Miller et al., 2007; Loague et al. [16]; Liu et al. [18]; Kim et al. [20]; Liu et al. [18]. GIS assisted interactive mapping tools for NPS on the web adopted by local (state) environmental protection agencies serve a variety of general purposes including local community capacity building, funding, showcasing exemplary, "inspirational," restoration and proactive action plans that prevent, monitor, and/or mitigate NPS pollution in the watershed (MassDEP, NJDEP, TCEQ). However, what industrial pollutants are also found in waterbodies requires site-specific mapping that generic, web-based NPS tools do not provide. Furthermore, the watershed impact of NPS pollution is rarely inclusive of the watershed's connected waterbodies holistically. Our GIS-aided, interactive spreadsheet fills this void in the literature, identifying the industrial site pollutants also found in the waterbodies--river, creek, stream, lake--as a connected ecosystem. The GIS spatial buffer tool described below is particularly useful in a Boolean search with multiple criteria and site attributes. It turns out, 3/4-mile buffer zone centered on EPA-designated industrial sites also contains the location of the sites with water permit as well as water quality monitoring stations.

Thereby, the spatial search criteria of the proximity of the industrial site to the waterbody (river, creek, and lake) as well as to the station that gauge's water quality are met. Industrial sites that impact water resources require a permit from TDEC (Figure 2, and Figure 3). The significance of the ¾ mile distance search for targeted, EPA-industrial sites among the sites that impact water resources (watershed) is indicated. The extent of spatial search is determined by the type of pollutant that is mapped. For example, Ma & Tong [21] use a 1-km distance in mapping air pollution impact (for similar GIS and Web-integrated applications, see also Giglione et al. [22]; Hochstein & Szczur [23]; Vieux & Needham [24]. The ¾ mile buffer centered on industrial sites encompass water quality monitoring gauges that likely register the impact of industrial site activity with NPS pollution in proximity. Pollutants in industrial sites that are also found in the waterbodies in proximity are highlighted by type and proportion within interactive spreadsheets by each body of waterway analyzed with available data-river, creek, and lake. Our GIS-aided procedure is a simple tool to aid environmental monitoring and public decision making that aims to improve the quality of the watershed in conjunction with the state of industrial site remediation in the city and the region. We conclude with a discussion of the environmental and public health consequences of pollutants.

Data and Mapping Methodology

The methods applied to the problem of NPS pollution in the watershed are a wide variety of deterministic, probabilistic, sce-

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nario-based, simulated, and GIS-aided techniques (e.g. USEPA [25], Clement et al. [26]; Lee & Jones-Lee [27], Kaushal et al. [28], Hoogestraat 2015, Altenburger et al., Celen et al. 2022). Primary data collection is a common feature. Our method of mapping NPS pollution in the watershed linked to industrial activity is developed with environmental data available in the public domain, outlined below, illustrated with a case study of Memphis and Shelby County Tennessee (Figure 1). A GIS aids in mapping the whereabouts of industrial sites based on U.S. EPA classification. The historical location of industry in proximity to waterbodies is a clue in the selection of the geographical extent. A second clue is a legal (permit) one- "water resources permit for industrial sites" data from Tennessee Department of Environment and Conservation (TDEC). Thus, we include waterbodies, floodplains, and (site) permits as map features. We give an outline of steps taken in retrieving, preparing data and mapping watershed toxicity with industrial activity.

Data Acquisition and Preparation

I. Obtained water resources permit data (2024) and water monitoring stations data (2024) from the Tennessee department of Environment and Conservation (TDEC). Industries that impact water resources with storm water discharge require a permit from the Tennessee Department of Environment and Conservation (TDEC). Surficial hydrology (surface waters, streams, rivers, lakes, reservoirs, and wetlands) is gauged in water quality monitoring stations (TDEC).

II. Retrieved industrial location address data from TDEC information resource page (2020).

III. Performed geocoding with latitude and longitude from the addresses of the location of the industries with EPA status and water resources permit.

GIS Operation

a. Displayed the geocoded data for water resource permits by importing XY data into the GIS software and exported these as point features.

b. Created a ¾-mile buffer zone around each industry location to assess the proximity of water monitoring stations and water resources permits. The spatial search with ¾ mile buffers encompasses industrial sites near waterbodies, permitted location of industry, and water quality monitoring station. (Figure 1).

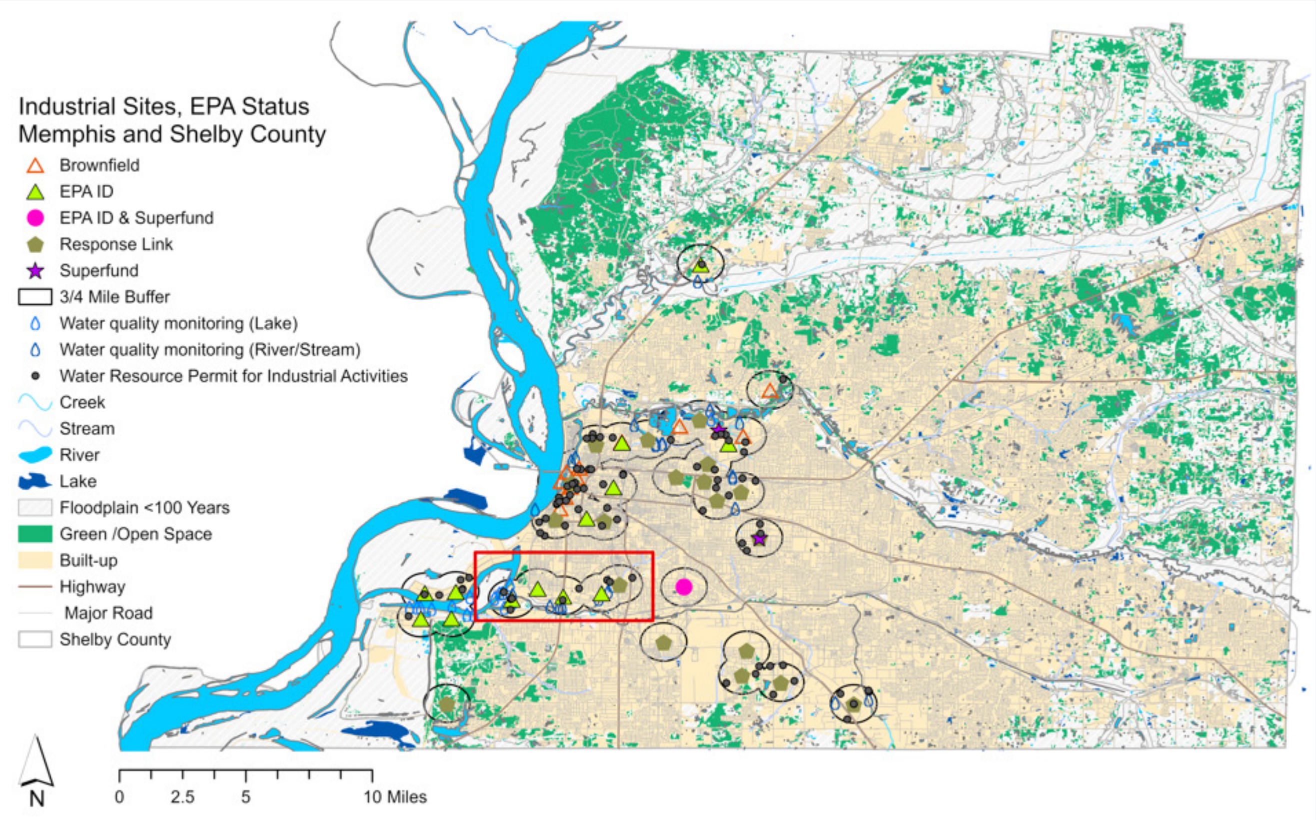

Figure 1: The Geography of Watershed Toxicity in Memphis, Tennessee. EPA sites are designated by Brownfields, Superfunds, EPA ID or Response Link ID.

Analysis and Mapping

a) Utilized the ArcGIS Pro's Selection by Location tool to identify and review all water monitoring stations and water resource permits within the ¾-mile buffer zones (Figure 2).

b) Compiled and arranged the findings to prepare the final map, clearly marking the buffer zones and relevant features.

Brownfields are locations that have industrial or commercial sites where any future use is affected by environmental contamination. EPA IDs are the ID numbers of sites designated for cleanup that are in process or complete. Response Link IDs are numbers for sites that the EPA has designated for the removal of waste. Superfunds are sites that have a fund set up to establish financing cleanup of environmental contamination.

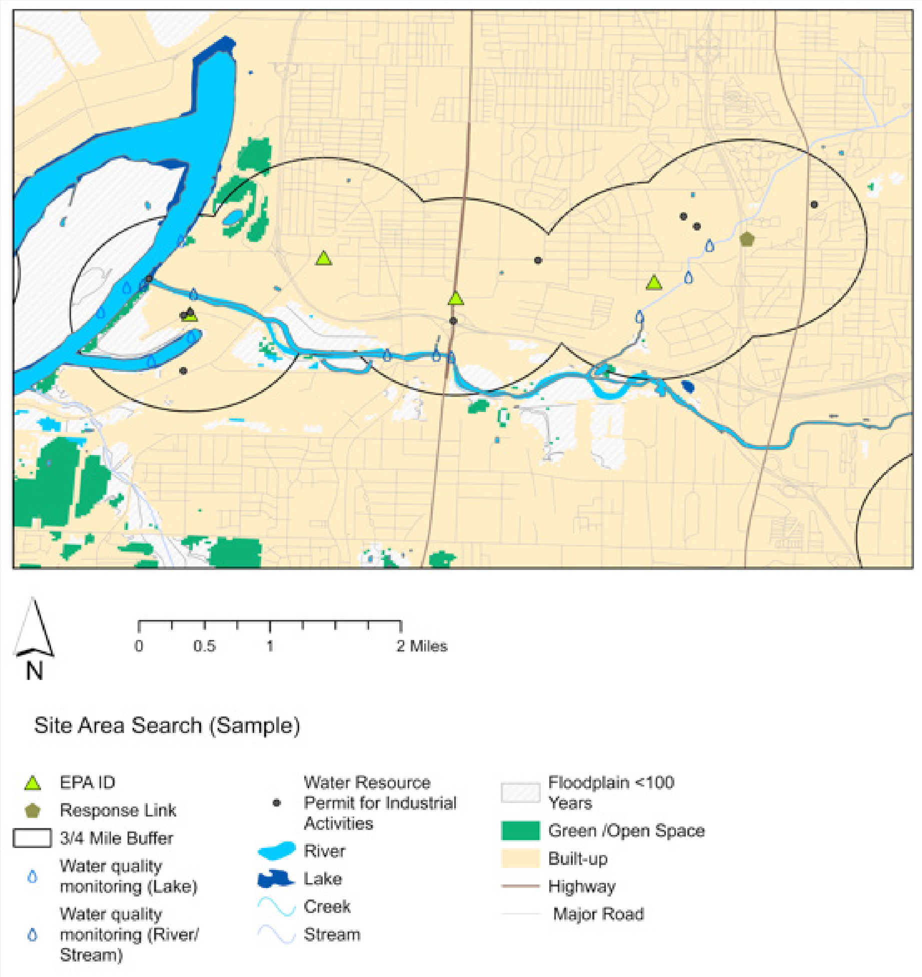

Figure 2: The GIS search with ¾ mile buffers centered on EPA-designated industrial sites (EPA ID, and Response link) near waterbodies encompass industrial sites with a water permit (shown in bold point), and water quality monitoring stations (water drop symbol). (see sample selection box, Figure 1). The sites with water resources permit near the two EPA-classified sites are active hazardous waste treatment, storage, and disposal (TSD) facility (Rivergate Rd, Memphis, TN 38109); inactive (188 E Industrial Ave, Memphis, TN 38109); and inactive undergoing environmental remediation (901 E Bodley Ave, Memphis, TN 38106).

Results

Pollutants Identified in Industrial Sites in common with Waterbodies

What pollutants in industrial sites (e.g., Superfund, National Priority List) are also found in waterbodies-River, Creek, Lake? We developed spreadsheets that display pollutants data identified by industrial sites by EPA classification interactively in common with the water bodies (Figure1) EPA site classification). For brevity, we highlight results from Cypress Creek, excluding other waterbodies, which we also observed. Polychlorinated Biphenyls (red color) is linked to a Brownfield, in parentheses. Cyprus Creek is highlighted since it is a source of flooding in the abutting city neighborhood (Table1). For perspective on toxicity, compare Superfund and brownfield site contaminant type and quantity. These are the former industrial sites that are abandoned (blighted), designated for the clean-up of the toxic waste before the site is redeveloped. In brownfield, we find PCB: 25.5 mg/kg (25,500 ug/kg) (5.71%); Lead: 400 mg/kg (400,000 ug/kg) (89.57%); Arsenic: 11 mg/kg (25,500 ug/kg) (5.71%); Metals: 10 mg/kg (10,000 ug/kg) (2.24%), (EPA 2024). In Superfund, Lead: 43 mg/kg 43,000 ug/kg (81.09%); Asbestos: 0.0400000 ppb (0.04 ug/kg) (~0%); Soil Bioavailability: 10000 ug/kg (18.86%); Dioxin: 15 ug/kg (0.0283%); Radiation: 2.4 pCi/g (EPA 2013) (Table2). The pollutants identified in our industrial sites and waterbodies are linked to a wide-ranging impact, including environmental/economic/public health/marine life, groundwater, crops or farming also observed in the literature (Harrington et al. [29]; Clement et al. [26]; Luo et al. [30]; Allan et al. [31]; Hoogestraat 2015; Merrit, 2017; Spearing-Bowen & Schneider, 2017; Ghosh et al., 2022; Feng et al., 2023; Li et al., 2010; Lin et al., 2023) (Figure 4).

Table 1: Excerpt from spreadsheet of contaminants by industrial sites and waterbodies--Cypress Creek. Pollutants in waterbodies (River, Stream, Creek, Lake) in common with industrial sites (EPA ID, Response Link ID, and Brownfield).

Creek	Water Pollutant	Industrial Sites
Cypress Creek	Sedimentation/Siltation, Ammonia, Un-Ionized, Dissolved Oxygen, **Arsenic**, Escherichia Coli (E. Coli), Phosphorus, Dissolved Oxygen, **Endrin**, Aldrin, **1,2- Dichloroethane**, **Dieldrin**, **Chlordane**, **Polychlorinated Biphenyls (Pcbs)**, **Pesticides**, **Nitrate/Nitrite** (Nitrite + Nitrate As N)	Chromium, **Pesticides**, (Response Link Id), Bis(2-Chloroethyl) Ether, Naphthalene, Butyl Benzyl Phthalate, Bis(2- Ethylhexyl)Phthalate, **1,1-Dichloroethane** (EPA ID), 2-Butanone, 4-Methyl-2-Pentanone, Acetone, Benzene, Chlorobenzene, **Chlordane** (Response Link ID), Ethylbenzene, Methylene Chloride, Styrene, Toluene, Vinyl Chloride, Xylenes, Mibk, Pentachlorophenol, **Arsenic**, Barium, Beryllium, Cadmium, Chromium, Mercury, Nickel, Asbestos, Anthracene, Benzo(B)Fluoranthene, Benzo(Ghi)Perylene, Benzo(K)Fluoranthene, Benzo[A]Anthracene, Benzo[A]Pyrene, Chrysene, **Nitrate/Nitrite**, Indeno (1,2,3-Cd)Pyrene, **Endrin**, Phenanthrene, Pyrene, Alpha-Chlordane, Ddt, **Dieldrin**, Alpha-Chlordane, Ddd, Dde, Ddt, Endosulfan Sulfate, Isophorone, 1,2,4-Trimethyl Benzene, Indeno(1,2,3-Cd) Pyrene, Tetrachloroethene, Trichloroethene, Cyanide, **Polychlorinated Biphenyls** (Brownfield), Beryllium, Iron, Lead, Thallium, 2-Methylnaphthalene, Aroclor-1242, Aroclor-1248, Aroclor-1254, Aroclor-1260, Pcbs, Dioxin, Nickel, Zinc, Copper, Aroclor-1242, Aroclor-1248, Aroclor-1254, Aroclor-1260, Pcbs, Dioxin, Nickel, Zinc, Copper.

Pollutant data for industrial sites in common with the rest of major water bodies in Memphis are available upon request. They include Nonconnah Creek, McKellar Lake, and Mississippi River.

Table 2: Common pollutants in waterbodies (river, lake, creek) and industrial sites (Superfund, Brownfield, EPA IDs, Response Links), and pollutant quantities.

Pollutant Type	Water Body Pollutant Quantity	Site Pollutant Quantity
Mercury	0.01 ug/l (Wolf River), 0.0563 ug/l (Mississippi), 0.0424 ug/l (Wolf River), 0.394ug/l (Loosahatchie River), 0.0715 ug/l (McKellar Lake)	0.07 µg/l (EPA IDs)
Lead	0.484 ug/l (Wolf River), 0.979 ug/l (Wolf River), 0.0999 µg/l (Loosahatchie River)	43 µg/l (Superfund), 400 µg/l (Brownfield), 23 µg/l (EPA IDs)
Chlordane	0.02 µg/l (Wolf River), 0.00005µg/l (Mississippi), 0.01 µg/l (Nonconnah Creek), 0.0922 µg/l (Wolf River), 0.035 µg/l (Loosahatchie River), 0.0055 µg/l (McKellar Lake), 0.00138 µg/l (Cypress Creek)	_
Dioxin	0.44 ng/kg (Mississippi), 5.5 ng/kg (Nonconnah Creek), 0.9 ng/kg (Wolf River), 0.3979 ng/kg (McKellar Lake), 0.019 ng/kg (Loosahatchie River)	15 ug/kg (Superfund), 20.9 ppt (Response Link IDs)
Arsenic	5 ug/l (Cypress Creek)	11 µg/l (Brownfield)
Endrin	0.013 µg/l (Cypress Creek)	_
1,2-Dichloroethane	_	_
Dieldrin	0.024 µg/l (Cypress Creek)	_
Pesticides	_	14.7 ng/g (Response Link IDs)
Nitrate/Nitrite	0.757 mg/l (Cypress Creek)	_
Copper	2.15 ug/l (Nonconnah Creek)	_
PCBs	_	25.5 ng/g(Brownfield)

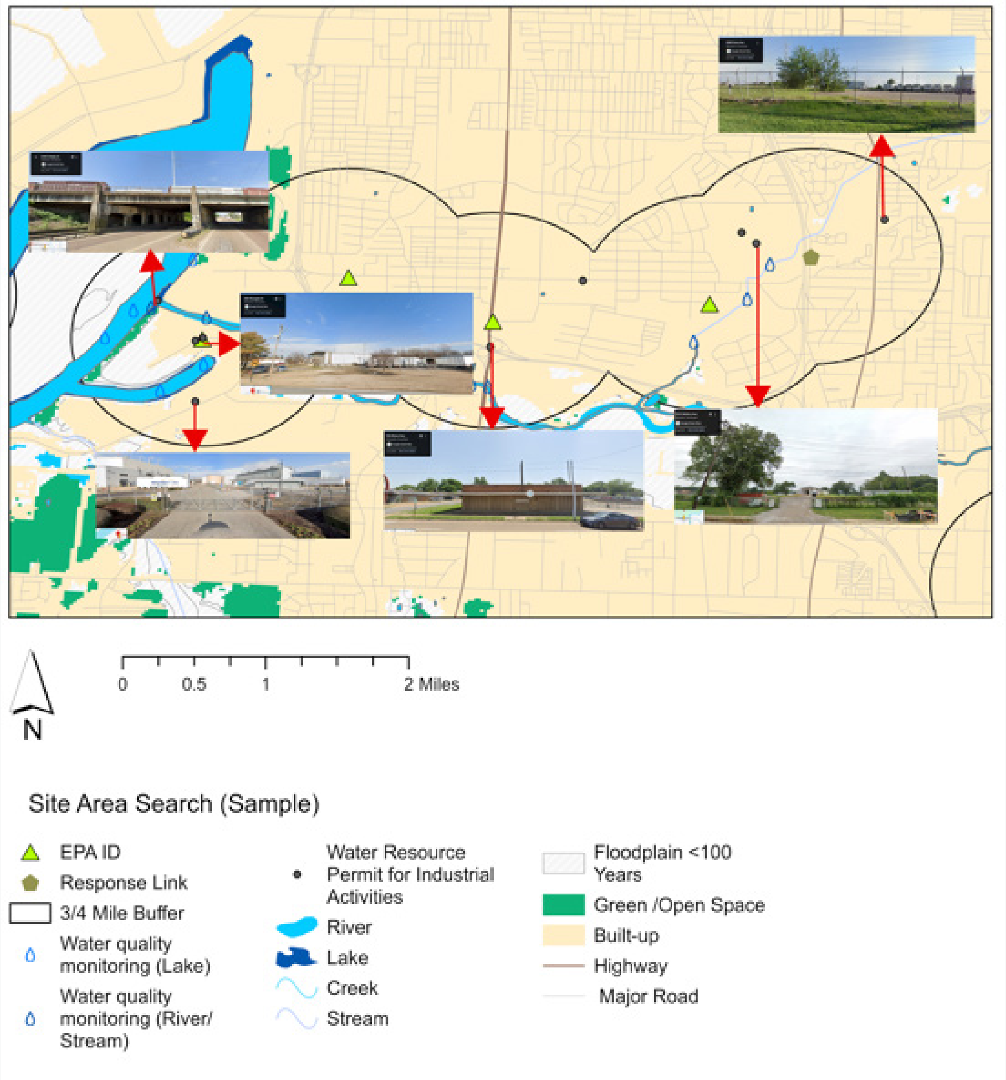

Figure 3: Street views of the sites with water resources permit (shown in bold point) are near the two EPA-classified sites (Google Street View). The sites include active hazardous waste treatment, storage, and disposal (TSD) facilities (Rivergate Rd, Memphis, TN 38109); inactive (188 E Industrial Ave, Memphis, TN 38109); and inactive undergoing environmental remediation (901 E Bodley Ave, Memphis, TN 38106). Note locations of water quality monitoring stations (shown with water drop symbol).

Figure 4: Environmental Consequences of Pollutants: a) Warnings are posted at the Wolf River about the potential toxicity of fish caught there, a legacy of Velsicol Blow [36]; b) Valero released toxic gas into the air and unburned oil into Nonconnah Creek (Tatum 2021); and c) Retired Allen Fossil Plant contains coal ash in a pond next to McKellar Lake, contaminating groundwater and destroying quality of the local ecosystem Sells 2020).

Potential Toxic Elements

We highlight toxicity of NPS pollutants observed in our data by associated impacts recorded in literature.

a) Heavy metals like, cadmium (Cd), chromium (Cr), copper (Cu), iron (Fe), manganese (Mn), nickel (Ni), potassium (K), phosphorus (P), sodium (Na), sulfur (S) and zinc (Zn)

a. Aquatic and terrestrial environments (water and soil) (Abbas et al, 2023)

b) Polycyclic aromatic hydrocarbons (PAHs)

a. Public health (high cancer risk) (Allan et al. [31])

c) Metal pollution

a. Environmental, public health, and economic consequences (Byrne et al.,2020);

d) Chlorinated ethene and ethane

a. Environmental, public health, and economic consequences (Clement et al. [26])

e) Dense nonaqueous phase liquid (DNPL)

a. Environmental (biodegradation) (Feng et al., 2023)

f) Biochemical

a. Freshwater flora (Ghosh et al., 2022)

g) Chlordane

a. Public health (Harrington et al. [29])

h) Lead (Pb) and copper (Cu)

a. Local ecosystems(fishery) Hoogestraat (2015)

i) Nitrate

a. Public health, risk of preterm birth (Lin et al., 2023); forest, agricultural, and urbanized watersheds (Kaushal et al. [28])

j) Polycyclic aromatic hydrocarbons

a. Environnent (soil, plant, air) (Li et al.,2010)

k) Mercury (Hg), lead (Pb), arsenic (As), cadmium (Cd), chromium (Cr), Copper (Cu), nickel (Ni) and zinc (Zn), Brown Field

a. Environmental (Liu et al., 2011); bioaccumulation in fish (Lee and Jones-Lee [27])

l) Cadmium, copper, and lead in soil, industrial site

a. Environmental and public health (Luo et al. [30])

m) Polychlorinated Biphenyls (PCBs)

a. Fish (Merrit, 2017)

n) Arsenicus, cadmium, lead, copper, and mercury

a. Air pollution, dust storms, human health, agriculture, and ecosystems (Just how dangerous is Great Salt Lake dust? (Retrieved December 5, 2024)

o) Lead, zinc & chromium

a. Groundwater toxicity, drinking water pollution (Spearing-Bowen & Schneider, 2017)

Further research plausibly identifies the contaminant thresholds type and quantity in waterbodies and industrial sites for safekeeping of the ecosystem.

Discussion

Critical Pollutant Levels and their Environmental Impacts, Comparison with Standards

We identify contaminants in Superfund, Brownfield, and EPA ID sites that are also found in rivers, lakes, and creeks, including mercury, lead, arsenic, chlordane, dioxin, and polychlorinated biphenyls (PCBs).

a) Mercury Levels: River, creeks, and lake have mercury concentrations ranging from 0.01 to 0.0715 μg/l. The maximum mercury contamination limit (MCL) for drinking water is 2 μg/l, according to EPA recommendations Environmental Protection Agency [32]. Despite being below the drinking water guideline, these values pose as ecologically dangerous in delicate settings, such as aquatic food webs Zhao et al. [4]. According to research by Lei et al. (2021), mercury is bio-accumulative, meaning that even tiny amounts can cause major disturbances in aquatic environments. High-risk sites: Mercury values of 0.07 μg/l are reported at EPA ID sites, suggesting a possible environmental risk of bioaccumulation in nearby ecosystems.

b) Lead Concentration: With concentrations in waterbodies ranging from 0.484 to 0.979 μg/l, lead is another significant contaminant. Lead concentrations at Superfund sites can surpass the EPA's action standard of 15 μg/l for drinking water, with levels as high as 43 μg/l United States Environmental Protection Agency [33]. Remedial actions are necessary to stop ecological harm and human exposure to such high quantities. Even low levels of lead exposure can have serious negative effects on health, especially in children, where they can impair brain development Geological Survey [34]. Cleaning up lead-contaminated places frequently involves intricate socioeconomic factors, which emphasizes the importance of community engagement (Maxwell, Kiessling, & Buckley, 2020).

c) Arsenic Levels: Cypress Creek's arsenic values are 5 μg/l. While present levels of arsenic in drinking water are within acceptable bounds, continuous monitoring is necessary to make sure they do not exceed the EPA's MCL of 10 μg/l Tennessee Department of Environment & Conservation [35]. Even at low levels, continued exposure to arsenic can raise the risk of cancer and other chronic illnesses Zhao et al. [4].

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d) Chlordane and Dioxin: The range of chlordane values in different waterbodies is 0.01 to 0.0922 µg/l. Because chlordane is a persistent organic pollutant that persists in the environment for a long time and can bioaccumulate in fish and other aquatic species, its presence is especially alarming (Environmental Protection Agency, 2013). The U.S. Government Accountability Office's report from 2022 also emphasizes how legacy chemicals like chlordane still present hazards decades after they were initially used. Dioxin levels at Superfund sites can reach up to 15 µg/kg. According to the Environmental Protection Agency [34], dioxins are extremely hazardous and can harm the immune system, interact with hormones, and create issues with reproduction and development. In aquatic ecosystems, even minimal levels of dioxin can cause significant changes to the food web [36-78].

Industrial sites and waterbodies exhibit various levels of toxicity with environmental consequences. Findings on the NPS by contaminant type and quantity suggest site-specific monitoring and physical design interventions that mitigate the problem of the pollutant and toxin runoff from industrial sites that are historically located in or near floodplains in proximity to waterbodies [79-115]. The waterbodies studied-river, creek, and lake-are aquatic ecosystems with different strengths and vulnerabilities that should be further investigated when impacted by NPS pollution. Climate change with intense rain events exacerbates the NPS pollution problem linked to the industrial sites even further.

Having determined an association, further research plausibly investigates the structural causes of NPS pollutants targeted to the industrial and other land use types inclusively in various proximity to the waterbodies, combining GIS with methods briefly reviewed above. Land cover and topography, floodplains boundary, given industrial sites' historical location near water bodies, are fundamental layers determining the disposition of pollutants in the watershed. Furthermore, GIS-aided mapping tools facilitate socio-economic and demographic analysis at a high resolution, neighborhood level with readily available U.S. Census block data. If added as additional layers, then the combined socio-economic-demographic-ecological mapping reveals the vulnerability of the residential population at risk in various proximities to the waterways and industrial sites [116-120].

Conclusion

Our GIS-aided spreadsheets facilitate the monitoring of environmental quality in the watershed holistically linked to the industrial site activity. Thereby, we fill a void created with GIS-aided tools used by local (state) environmental protection agencies that serve a variety of general purposes including environmental monitoring and NPS pollution mitigation, however, do not specifically target industrial sites in various stages of remediation in the watershed's connected waterbodies. We identified contaminants in Superfund, Brownfield, and EPA ID sites that are also found in rivers, lakes, and creeks, including mercury, lead, arsenic, chlordane, dioxin, and polychlorinated biphenyls (PCBs). We determined the type and quantity of the industrial site contaminants with various EPA remediation classification in waterbodies in proximity. Furthermore, the observation of the industrial sites' toxicity in common with river, creek, and lake holistically highlights the property of the watershed as a connected ecosystem, and thereby the ubiquitous NPS pollution in that ecosystem. Hence also highlighted is the rationale for monitoring the environmental quality of that ecosystem holistically.

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