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Using Historical Maps for Contaminated Site Identification and Prediction, and Environmental Justice Implications: A Case Study in Grand Rapids, Michigan

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USING HISTORICAL MAPS FOR CONTAMINATED SITE IDENTIFICATION AND PREDICTION, AND ENVIRONMENTAL JUSTICE IMPLICATIONS: A CASE STUDY IN GRAND RAPIDS, MICHIGAN

by

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As the production of synthetic chemicals has grown in the past centuries to increase production, lower costs, and generally make our lives more convenient, detecting and understanding the environmental impacts of these compounds has lagged significantly behind their mass production and wide-spread use. To combat this trend, sources of these contaminants, especially those that have been removed from the landscape, need to be quickly identified to make mitigation and remediation efforts more effective. In this study, historical Sanborn maps are used to extract and digitize historical site/land use in Grand Rapids during the early 1900s through the practical application of GIS software and analytic tools. This data was combined with historic and current demographic and socioeconomic data to search for evidence of past or present environmental injustice in the city. Evidence of environmental injustice in low income communities in the early 20th century was identified through spatial statistics, as well as a geographic similarity in past and present areas of environmental concern, but little evidence was found for current environmental injustice in the area of study. The data was also used to build a searchable database of industrial areas and potential contaminated site locations that will be available for public use to educate and empower residents, businesses, and policy makers in the city of Grand Rapids.

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1. INTRODUCTION

The presence of synthetic chemicals in our environment is an unfortunate reality and in some instances, a necessary risk. In the past few centuries, scientists have increasingly been creating these materials, making better and more effective products, speeding up production and yield in industry, and also generally making our lives more convenient, safe, and healthy. Unfortunately our understanding of the environmental impacts of these chemicals and compounds has lagged significantly behind their mass production and wide-spread use, and as history shows, most firms often do not realize the harmful effects of these compounds until *after* they significantly impact health and safety. This is why, as the list of these chemicals grows longer, there is an increasing need to preemptively identify and mitigate the sources of these contaminants before they are released into the environment; and when they are, to understand who is at the most risk.

Identifying and controlling current producers of these known contaminants presents many complications, but at the very least identification and monitoring of potential polluted locations is possible. It is a very different situation for contaminant sources that have been abandoned, rebranded, or torn down and completely removed from the landscape. Environmental specialists with the Michigan Department of Environment, Great Lakes & Energy (EGLE) in Grand Rapids that focus on issues concerning contaminated sites have acknowledge this gap in the data and recognize the benefit of using historical industrial information to help map potential contamination locations in the city. Grand Rapids has been industrialized since its incorporation thanks to a strategic location along the Grand River and nearby Lake Michigan and has struggled in recent decades with city-wide environmental contamination issues.

The purpose of this thesis is to assess the potential use of historical geographic data as a source for sites of environmental contamination and the use of said data as evidence of environmental injustice through the practical application of Geographic Information System (GIS) software and tools. The research focuses on the city of Grand Rapids, Michigan with the aim to produce a searchable database of these locations for future use in environmental site management of the city. The methodology is based on that applied by previous researchers with success in similar applications. Evidence of environmental injustice will be based on the statistically significant spatial correlation of industrial or contaminated sites and common demographic characteristics such as race, income, or immigrant status. The ultimate goal of this project is to develop an interactive map-based website and StoryMap to effectively inform and empower the local and regional communities of Grand Rapids regarding historic industrial contamination sources in their city.

The remainder of this section states the problem that this thesis research aims to address and the specific questions that guide the research. Section 2 provides background information on the industrial history of Grand Rapids, highlights current and emerging contaminants in Michigan, and introduces the Sanborn Map Company that produced the maps used in this research. Section 3 reviews several literature sources on past research, including the use of historical maps as data sources, a review of some available resources for historical data, contaminated site management and redevelopment, and finally the use of GIS to identify patterns of environmental justice. The methodology used for this research is detailed in Section 4, summarizing the four main steps of the research, including dissemination. Section 5 reviews the results from the data collection and analysis and discusses the implications of these results. Finally, the research is summarized and final conclusions are stated in Section 6 along with some guidance and applicability toward future research.

Statement of the Problem

Every day, more knowledge and understanding are gained regarding environmental contaminants. Scientists and interest groups are constantly testing current and emerging contaminants to gather more data on the characteristics of these synthetic compounds and their effects on human and ecological health. As issues with these contaminants are identified, they are further regulated or actually banned from production, depending on the severity of the impact. This is already quite complicated for businesses and sites that are currently still manufacturing, but what about the hundreds, or more likely, the hundreds of thousands of historical industrial sites that have been removed from the landscape by time and redevelopment? In order to identify the type of risk in certain areas, it is necessary to know the actual type of industry, if any, was located on a given parcel. This information is useful for predicting the location of potential contaminated sites and for quickly locating potential source sites when a new contaminant of concern is identified.

This specific project was developed based on a need for historical industrial site information to predict and prioritize potential environmental contaminant sources in Grand Rapids, Michigan. Through review of historic building and land use types, a database is created showing these potential sources. This is clearly beneficial to businesses and landowners but is also an opportunity for transparency and public engagement. Sharing this information with the public will enable residents, business owners, and policy makers to better understand the risks in their area and hopefully empower them to use this knowledge in further city planning and redevelopment.

Research Questions

1. How can historical maps be used as geospatial data sources for environmental contamination prediction and mitigation prioritization?
2. How does Geographic Information System (GIS) software enable better historical data collection and is it an effective tool for educating and empowering residents?
3. Using these tools and data, is there any evidence of past or current environmental injustice in Grand Rapids, Michigan?

2. BACKGROUND INFORMATION

In order to address these research questions, contextual understanding is needed on three main subjects: (1) the industrial history of the city of Grand Rapids, (2) the phenomena of emerging contaminants and an example case in Michigan, and (3) the purpose, publication, and spatial and temporal coverage of Sanborn fire insurance maps.

From Furs to Furniture: The Industrial History of Grand Rapids

Prior to the arrival of Europeans, the area that is now Grand Rapids was occupied as long as 2,000 years ago by the Hopewell peoples. Millenia later, around 1700 AD, the people of the Three Fires (Ottawa, Chippewa and Potawatomi Indians) established villages along the natural resource-rich Grand River, with settlements spanning from Grand Haven to Lansing. A century later, a fur-trading post was established by French-Canadians in the area in the early 1800s and by 1821, the United States solely controlled the land south of the Grand River, displacing or relocating the Native Americans to accommodate new European arrivals. Detroit-born Louis Campau was one such arrival who built a trading post and blacksmith shop along the Grand River and in 1831, purchased what is now the entire downtown business district of Grand Rapids. The city was officially incorporated in 1850, and quickly became the major manufacturing city on the western side of the state (GRHS, 2013; Experience GR, 2019).

At the time of its incorporation, with a population around 1,500 and an area of four-square miles, the city of Grand Rapids was already home to one furniture factory and multiple small private furniture shops. The location of the city along the Grand River provided hydro-generated power for the factories and transportation for logs from the old growth forests upstream, the latter leading to the city becoming a major lumbering center in the late nineteenth century. At the height of the lumber boom, Grand Rapids was home to over forty furniture companies. An international exhibition in Philadelphia in 1876 established Grand Rapids as a leader in the production of fine furniture (GRHS, 2013). Given this timeframe, the maps chosen for the historical portion of this research were published in 1912 through 1913 as they are the most extensive volume and represent this industrial era well.

In addition to industrial activities related to the furniture and automotive industries, Grand Rapids was home to multiple gypsum mines from the late nineteenth century through the early to mid-twentieth century (GRHS, 2013). Although case-specific and depending on the local lithological chemistry, contamination of groundwater from gypsum mining activities is generally insignificant (Omoti *et al.*, 2016), however the mines still pose other risks. Sinkholes can form when highly soluble evaporite rocks, such as gypsum, dissolve and cause damage to overhead infrastructure and safety risks to residents (Martinez *et al.*, 1998). According to local news sources, a section of US 131 freeway in Grand Rapids was rerouted in the 1990s due to noticeable sinking as a result of gypsum mining. Additionally, in 2018, a sinkhole was discovered above an old gypsum mine on the west side of Grand Rapids (Rothwell, 2018; Atlas Obscura, 2001). The physical and environmental impacts of gypsum mining will not be discussed in this research, but the locations will be included in the digital products.

Emerging Environmental Contaminants

Humans have a long history of realizing 'too late' that some materials or ingredients have significant detrimental effects on health. Marie Curie spending hours a day with her radium samples, elementary schools covered in lead paint, and fields annually blanketed with DDT – all these things were either legal or not fully regulated because they were assumed to be safe. These events also have another similarity – the safety hazard, once identified, always came as a surprise. These problems are rarely (if ever) caught and addressed before harm has already been done to humans, animals, or the environment. Over time, these compounds are studied and added to the list of priority pollutants with known health effects and regulations are set based on the severity of their impacts. Prior to this, they all start as contaminants of emerging concern (CECs) or simply 'emerging contaminants', a term used to describe pollutants that *may* cause human or ecological health impacts but are not currently regulated by any environmental or health laws (Bai *et al.*, 2018). A subsequent issue of CECs is that once they are identified, sources still need to be located. A relevant and timely example of this is the PFAS crisis in Michigan.

PFAS are a large class of synthetic chemicals used widely for their temperature resistance, water repellency, and friction reduction characteristics and are used in items such as cookware, firefighting foam, food packaging, and textiles. PFAS have recently emerged as a public health and global environmental threat due to being extremely persistent (often referred to as "forever chemicals"), highly mobile, toxic at extremely low doses, and have been linked to cancer, kidney and liver damage, hormone disruption and much more (NRDC, 2019; Matheny, 2019). Although there is evidence of concern with worker exposure to the chemicals as early as the 1970s, these compounds continue to be produced, however now mostly limited to firefighting foam, and federal advisories and limits for the contaminant are still just recommendations and not enforceable under current laws (NRDC, 2019; ITRC, 2017).

The PFAS contamination is Michigan's most serious and widespread environmental crisis since the early 1970s. Seventeen streams, rivers, lakes and ponds throughout the state already have "do not eat" fish advisories due to contamination. Since the synthetic chemical is relatively new, coming into wide use in the 1980s, locating direct sources for this contaminant has been generally successful. Wolverine Worldwide leather tannery, 3M, DuPont and other chemical companies have been blamed for most of the contamination as they released these chemicals, purposefully or inadvertently, into the environment for decades (Matheny, 2019). During statewide testing, PFAS were identified in more than 100 of Michigan's public water systems and was found to be more concentrated in western Michigan. This trend is also seen in the density of contaminated sites across the state (Figure 1).

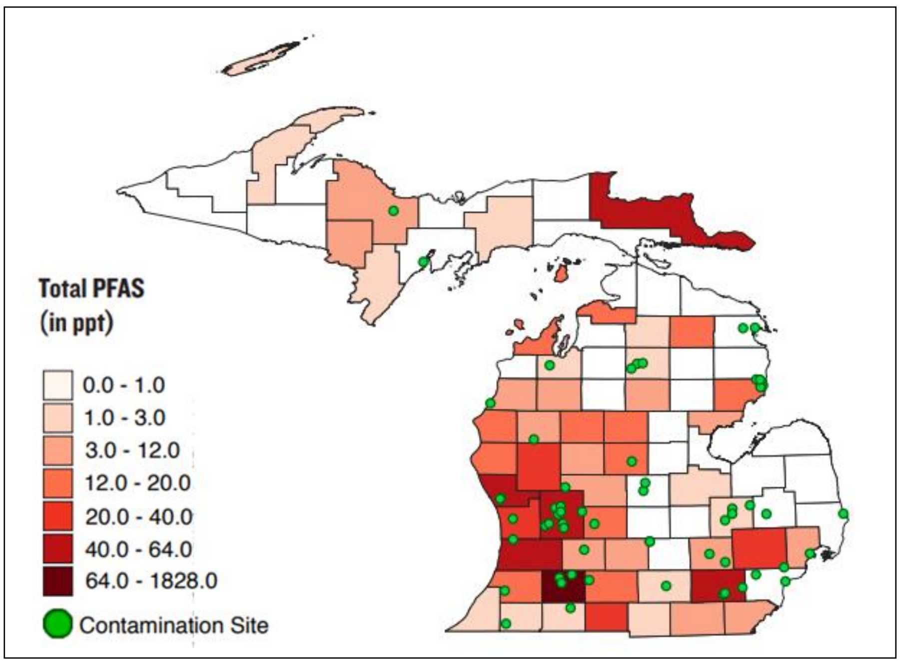


Figure 1: PFAS Detections in Michigan. Source: NRDC (2019)

The crisis has led to better understand of the manufacturing history of PFAS, as well as the past and current uses of the chemicals, which in turn has allowed for faster and easier identification of potential sources, release mechanisms, and pathways of PFAS (ITRC, 2017). As PFAS is a relatively new chemical, it will not be included in the research for this project, but rather this crisis stands as an example of the need to have a database of industrial locations so that when a new emerging contaminant is identified, potential contaminant sources can quickly be identified, located, and targeted for testing and remediation. On a timescale of a few decades, it is likely that contaminant sources will still be present, even if no longer in use, when a new emerging contaminant is identified. However, on longer timescales, such as a century in the case of this research, several of these sources have been removed from the landscape.

The Sanborn Map Company

The Sanborn Map Company has published maps and atlases for more than 12,000 municipalities in the United States. Although consummate and productive map makers, with coverage of the United States, Canada, and Mexico dating back to the mid-1800s, the company has been mostly unknown except to a small group of American map users. This is likely due to the fact that their maps are highly specialized and prepared exclusively for fire insurance purposes. These maps show the size, shape, and construction materials of buildings and were designed to assist insurance agents in determining the degree of hazard associated with specific properties. As such, these maps include details such as fire walls and the presence of sprinkler systems, but also include a wealth of information that can be applied to topics outside of fire protection and insurance. All structures and features are identified by building/feature type, such as dwellings, stores, cemeteries, and schools, and list the activities that take place at those facilities, such as varnishing and staining at furniture factories (LOC, 2019). This information can therefore provide details on social and industrial trends of the area, highlighting where housing, industry, or recreation was concentrated.

At the peak of the company's production in the late 1800s and early 1900s, the Sanborn maps were lauded for their accuracy and the breadth and technical quality of information, however the Great Depression in the 1930s and major changes in the insurance industry in the 1960s eventually rendered the maps obsolete. Recently, the company's best customers are municipal governments and parties with engineering and architectural interest in properties, although their use continues to increase within several research fields as they become digitally available and widely accessible (LOC, 2019).

In the next section, past research and literature is reviewed on the use and sources of these types of historical fire insurance maps for data collection, the management and redevelopment of contaminated sites, and how GIS can be used to study environmental injustice and inform policy making related to a diverse range of issues.

3. LITERATURE REVIEW

Contaminated site management is a delicate process that is rife with financial liability and the possibility of severe impacts to human and ecological health. Current and new industrial sites are subject to rigorous standards of health and safety assessments in order to protect neighboring areas and residents. The reality, for virtually all urban areas in the US and elsewhere, is that many environmental issues effecting human and ecological health are symptoms of previous industrial processes and guidelines. The regulation of the use of certain substances is dependent on the knowledge of the risk of harmful effects of that compound, which is often discovered and researched only after initial negative side effects have been identified. New emerging contaminants associated with previous industrial sites are regularly discovered. In order to effectively guide and empower residents, businesses, and policy makers, local environmental data must be accurate, accessible, and up-to-date. Utilizing the most applicable data sources and appropriate data analysis methods can lead to better understanding of potential impacts and liabilities, both for human health and for effective contaminated site management and redevelopment.

The city of Grand Rapids has a long history of manufacturing and provides a practical case study for the use of Geographic Information Systems (GIS) in identifying and predicting contaminated sites based on historical geographic data. The city's history of income and demographics, particularly how these factors might relate to prior industrial land parcels, can also illuminate imbalances regarding environmental justice.

This literature review will address three areas related to the potential use of historical maps for contaminated site identification and prediction to address issues related to environmental justice. The first section will address research related to the use of historical maps as sources of geographic data that can be used to address socially-just land redevelopment issues. The second section will focus on research concerning contaminated site management and redevelopment. The third section will discuss studies investigating environmental justice and how this complex topic has been addressed using GIS. Additionally, two relevant sources of historical geographic data available for the city of Grand Rapids and potentially useful for this project will be discussed.

Historical Maps as (Big) Data Sources

Entrenched in the digital age, with GPS and Google Maps at everyone's fingertips, it may seem that humans know everything there is to know about where things are and how to find them. The seemingly apparent truth of this notwithstanding, where things *are* is rarely a good indicator of where they *were* or what was there before. The flow perspective on cities and urban systems suggests that nothing is static, not even the built environment (Dijst, 2013). As cities exist in a constant state of flux, georeferencing historical maps allows for features to be made into searchable data and measurable vector GIS layers and can help analyze, model, visualize, and understand the spatiotemporal attributes of natural and social systems (Dijst, 2013; Rumsey and Williams, 2002).

Digitization of effective and widely accessible historical geography resources - based on rare and fragile print sources – can potentially take maps common to the collector-quality, coffee-table atlas market, to other interpretive historical geographies (Holdsworth, 2003). In addition to holding information retained by no other source, particularly those features that may have changed, been removed, or been replaced by modern development, historical maps are fundamental to the reconstruction of past places and provide a view into the attitudes and world views of those who made them while reflecting the state of technology or scientific understanding at that time (Rumsey and Williams, 2002). Stirling (2003) stresses that historical map resources should be considered for use when trying to establish the history of a property, dependent on project budgets and timing, as there is an increasing availability of historic maps in digital format. Using these maps in conjunction with additional standard historical sources such as census data paints a more robust picture of a site's history and potential.

Map regression, an analytical technique used by researchers whereby a modern map of a location is analyzed and then joined to progressively older maps of the same location, is a useful method to combine environmental studies. In a study of naval encounters by Hewitt (2018), detailed historical maps from the 1066 Battle of Hastings depict the campaign area at the time of conflict. The broad events and timelines are not debated, however one critical aspect still under debate is the characteristics of the presumed Norman landing point. The claim of most historians that the landing site at Pevensey was likely reached by open water and the battle was therefore relatively uneventful, is debated given the most typical historical interpretations which focus on the contemporary landscape which has an open bay. Using map regression, Hewitt (2018) questions the broadly held assertion that the Pevensey area was an open bay which ships accessed easily and suggests that the landing itself was likely far more difficult than historians initially suggested. Geographical reconstruction in conjunction with traditional historical archival research provides the greatest benefits for recreating a historical landscape through analysis of the evolution of the territory, urban areas and historic buildings. San-Antonio-Gómez *et al.* (2014) use georectified historical maps of the Real Sitio de Aranjuez, Spain in combination with orthophotos from 2005 to graphically reconstruct certain heritage artifacts that no longer exist, so as to 'see' the town and its territory at three moments in history: 1775, 1835 and 2005.

Hewitt's (2018) use of historical geographic data to expand upon, or even correct false long-held claims is part of a recent trend made possible by new GIScience methods and technologies. Maps created by Ray (2002) based on historical socio-economic data (demographic, genealogical, and legal material) indicate that during the Salem witch trials, accusers were more likely to come from top tax bracket households living further from the village center than the accused. In fact, several of the accusations were rooted in property disputes that had taken place years before. Ray's 2002 study linked every available document, image, and piece of demographic and genealogical information to every person involved, with their location in place and time providing essential information (Ray, 2002). Similarly, Holdsworth (2003) uses antique black and white maps of the Islamic empire overlaid on recent locations of conflict to build deeper historical frames for understanding religious tensions in the region.

Temporal studies by Cunfer (2002) of dust storms indicate that drought and high temperature are superior explanatory variables for predicting the location of dust storms as compared to estimates of land use patterns during the Dust Bowl. Land use-centric explanations were favored for decades by New Deal officials (and persist in history textbooks to the present). The standard argument is that the dust storms were caused by poor land management by homesteaders flooding the region in the early 1900s. The counter argument by Cunfer, is based on analyses of historical maps and data, including county boundaries, agricultural and soil surveys, and weather stations for all 280 counties of the Dust Bowl region, which were merged with wind erosion models to counter the previous paradigm (Cunfer, 2002).

The combination of historical social and cultural data with environmental data, as seen in Cunfer (2002), can shed new light on natural landscape-human interactions for multiple time periods. Goldewijk and Ramankutty (2004) created land cover layers for as early as 1700 using a "hindcast" modeling technique to extrapolate data from 1992 backwards by interpolating historical cropland inventory data. These layers were compared to land cover data for 1990. Their estimates indicate that cropland areas expanded fivefold between 1700 and 1990, mostly at the expense of forests, while grazing land area expanded six-fold, mostly at the expense of natural grasslands during the same period. These patterns match general patterns of economic development and European settlement (Goldewijk and Ramankutty, 2004).

The benefits of historical geographic data in historical research is clear. However, data collection and integration processes associated with GIScience analyses are not without complications. Gregory (2002) makes the point that a digital representation of a paper map is at best of equal quality to the original, so in order to distinguish between the different types of error and inaccuracy, some specialized nomenclature must be established. *Error* is the difference between reality and the digital representation of it. *Accuracy* is the closeness of results to values accepted as true. *Precision* is the number of decimal places given in a measurement. *Quality* refers to the fitness for the purpose of the data, and *uncertainty* is the measure of the doubt or distrust associated with the data. Sources of errors include scanning, digitizing and geo-referencing locational errors, the user's involvement with the data capture process (minor positional errors when placing points), and coordinates measured from a map and locations of the reference points, so that every location on the layer will be slightly distorted (Gregory, 2002).

Historical reconstructions of social or natural processes also often require comparisons of maps derived from different sources, each of which will bring their own specific sources of errors (Petit and Lambin, 2002). Rumsey and Williams (2002) emphasize that the stretching and skewing that occurs while georeferencing historical maps to match modern coordinate systems, changes to lines, shapes, distances and aesthetics, can cause the resulting map to lose value as a cultural artifact. For effective use, paper maps must be scanned at very high resolution and brought into GIS as graphic images, with georeferencing based on common control points from modern and accurate digital maps, and appropriate mathematical algorithms applied to effectively warp the historical map to fit modern landscapes (Rumsey and Williams, 2002).

In recent years, fire insurance maps issued by the Sanborn Map Company have been advertised as an untapped source of historical site information. Sanborn maps are excellent sources of historical land use information, but many other less known national and local companies issued fire insurance maps between the 1870s and 1950s (Stirling, 2003). Regardless of the exact source, these maps present a different set of challenges to georeferencing than small scale maps of ancient origin because they are based on field measurements that were collected in a consistent manner so their geometric accuracy should not vary across the mapped area (Piekielek, 2017). These maps cover small geographic areas and will not suffer significant distortion when placed into projected map space. Out of 202 randomly selected maps, one hundred thirty-eight map sheets were successfully georeferenced (extensive land use conversion was the most common reason the remaining 64 map sheets could not be georeferenced) and route mean square error (RMSE) for map sheets of cities and towns that were laid out on a right-angle grid was found to be lower than for those that depicted cities and towns that were laid out with irregular angles (Piekielek, 2017).

Useful quantitative geospatial data on large scale historical maps based derived from high quality field measurements are often largely inaccessible due to their analog format. Recently, strategies used in georeferencing historical maps are transitioning from a focus on individual research projects, to the production-scale creation of quantitative datasets across large geographic areas. However, in the absence of a central governing body for historical maps establishing georeferencing standards, it seems more likely that best practices will come from researchers and practitioners most familiar with specific historical map series and georeferencing techniques (Piekielek, 2017).

Historical Map and Photo Resources and their Potential

As demonstrated by Stirling (2003) and Piekielek (2017), fire insurance maps created by the Sanborn Map Company are an indispensable and highly accurate and detailed source of historical qualitative and quantitative geospatial data. The Grand Rapids Public Library (GRPL) houses a digital collection of Sanborn Fire Insurance maps - large-scale maps with detailed drawings of the built environment of urban areas produced for insurance agents to use in quoting fire insurance policies - for the city of Grand Rapids, Michigan in 1874, 1878, and 1912. The maps are digitized using French Lumiere technology, the highest geometrical accuracy available, by the W.E. Upjohn Center for the Study of Geographical Change at Western Michigan University and are available for the proposed research (GRPL, 2019).

Slonecker *et al.* (2010) and Holdsworth (2003) confirm through their research that in addition to historical maps, historical photos provide social knowledge and information of physical conditions of an area, often as the only remotely sensed data source prior to satellite imagery availability. Starting in 1936, during the Great Depression, the building permit office of Grand Rapids used stimulus funds from the US Department of Labor to pay people to collect photos and address information of residential, commercial, and industrial properties throughout the city. Exact coverage is unknown and only a portion are available digitally, although all are publicly available at the City Archives and Records Center in Grand Rapids (City of Grand Rapids, 2019). These sources may prove invaluable for this proposed research and contact has already been initiated with the appropriate personnel for acquisition.

Contaminated Site Management and Redevelopment

Contaminated site identification, management and redevelopment using GIS is still an emerging field as more information is revealed every day about the characteristics and dangers of current and past industrial processes and how these factors relate to contemporary land use. A critical worldwide environmental problem is human and ecological exposure to hazardous (ignitable, corrosive, reactive, or toxic) wastes from agricultural, industrial, military and mining activities. These wastes often include heavy metals, hydrocarbons and other organic chemicals (Slonecker et al., 2010). After rapid, unmitigated growth, particularly post World War II, the US industrial legacy has left the nation with thousands of contaminated land parcels, known as brownfields, that must be rehabilitated and reintegrated into productive urban land inventories (Rydant and Smith, 2001). The range of historic operations at current brownfield sites in the United States include activities related to: metal smelting, oil refining, warehousing, transportation, as well as the manufacture of leather, paints, plastics, metals and fire-proofing materials. All of these activities are linked to the production and release of suspected or recognized toxicants such as heavy metals, chlorinated hydrocarbons, and polycyclic aromatic hydrocarbons (Litt and Burke, 2002).

Many of these activities are, historically, linked to urban land use. Urban redevelopment requires bringing vacant industrial and commercial land to productive use. However, given the socio-economic status of most brownfield areas, increased health surveillance and disease prevention strategies are needed whereby the proper information technologies can help identify risks, ensuring the right of communities to know about potential harmful health effects existing within their environments. Such information can also inform national, regional, and state environmental health policies, program evaluations, and long-term planning strategies (Litt and Burke, 2002).

Site identification of potential hazardous properties and their specific characterizations traditionally requires extensive field sampling and laboratory analysis. However, new and emerging remote sensing techniques show promise for site characterization (visual interpretation of morphological characteristics of production, storage, disposal, transport and effects on the natural environment) that can also provide critical information to the hazardous waste cleanup process and compliance in remediation cases at much lower cost (Slonecker et al., 2010). The United States EPA reconstructed a record of waste handling and disposal history (including uncontrolled waste disposal site boundaries, points of access and adjacent land use) that goes back to the 1930s in some areas using historic aerial photographs, the only remotely sensed data source that can be used to identify conditions from that time onwards (Slonecker et al., 2010). Rydant and Smith (2001) create a framework for site identification based on historical records, urban morphology, hazard assessment and an eight-stage methodology. The method is applied to a case study of Keene, NH, producing a historical map of environmental contamination showing precise areas, or polygons, of potentially polluted land through the creation of a GIS-based spatial inventory of relict hazards. This approach allows estimation of the potential size of an accumulated hazard at a given site and insight on the pathways of toxins and pollutants that may be found at any given site.

Once identified, sites must be prioritized so as to use redevelopment funds effectively. Power et al. (2009) developed a Risk-Ranking Methodology (RRM) to prioritize investigation and management efforts for Crown Contaminated Sites (historic and abandoned mine sites on provincial lands in British Columbia), using a risk-based preliminary site investigation to gather key information about the sites. Data are summarized according to several attributes aimed at characterizing potential health and ecological risks, identifying human and ecological exposure pathways. These data are then used in a workshop setting to evaluate relative rankings among sites and to identify subsequent management actions for each site (Power et al., 2009). Following the identification and prioritization of brownfields, managing site redevelopment can be problematic and expensive. The economics of urban growth should be considered in light of concerns of land value, spatial change and land use planning and design since many former industrial sites are being redeveloped and regenerated for alternative uses, such as brownfields in high-value urban areas (Wu and Qin, 2018).

Environmental Justice and GIS

In reality, the short and long-term health effects on humans associated with current and past contaminated sites can be devastating. More important is to understand the social and political systems in place regarding policies associated with mitigation and redevelopment of contaminated sites and the uneven impacts of these efforts on certain communities over others. For example, Maantay (2007) found that people living within defined proximity buffers (which vary depending on facility type) to main sources of air pollution emissions in the Bronx, New York are up to 66% more likely to be hospitalized for asthma (unless they lived near truck routes where rates were only 17% higher), are 30% more likely to be poor, and 13% more likely to be a minority than those living outside the buffers. The Commission for Racial Justice (1987) identified an inordinate concentration of hazardous waste facilities in Black and Hispanic communities, particularly in urban areas, revealing that the issue of race is an important variable in the problem of the development of uncontrolled toxic waste sites. The average minority percentage of the population in communities with toxic waste facilities in 1987 was found to be twice the average minority percentage as compared to communities without such facilities (24% vs. 12%). The report identified Michigan as a state with occurrences of environmental racial injustice. Although the highest occurrences were on the eastern side of the state, counties and cities in western Michigan were also highlighted, including Grand Rapids' Kent County (Commission for Racial Justice, 1987).

While the goal of most environmental justice studies are the same, the demographic and socioeconomic factors used to study the topic can vary and depend on the focus and interest of the authors. Based on existing research, race and income are the two most common factors used in environmental justice analyses, as seen in Vaz *et al.* (2016), Kreider (2020), and Graham *et al*. (1999). Other studies, such as those conducted by Orum *et al*. (2014) and Clark *et al*. (2014), focused on more demographic and socioeconomic factors including household income, race, education attainment, poverty status, and age. The availability of many of these data in digital format allows for the use of the information in GIS-based analysis.

Although race and income are often the focus of studies on environmental injustice, they are not necessarily the defining factors and siting may be similarly dependent on socioeconomic characteristics of the resident population. In a study of Buffalo, New York, Krieg (2005) found no significant evidence of "environmental racism" - the disproportionate impact of environmental hazards on people of color communities - based on data from the TRI and other EPA regulated facilities. This is echoed in historical geographic and demographic data for Baltimore (limited to 1935 and later, given the city's industrial history) developed by Litt and Burke (2002) that indicates these types of sites are often initially concentrated in white, working class neighborhoods with lower educational attainment and higher mortality rates (respiratory disease, cancers and heart disease) than state and national averages, and higher poverty levels caused in part by wealthier residents leaving the area as economic and physical conditions declined. Similarly, Krieg (2005) found no strong evidence for environmental racism in the city of Buffalo, but it did show that people of color were more likely to live in low-cost housing areas and ecological hazard impacts to people in these areas are sometimes more severe than the same impacts on medium-to high-cost housing areas.

These correlations have been made clearer and more powerful through the use of GIS. Maantay's (2007) methods of environmental justice assessment are examined with GIS, analyzing the locations, financial status, and demographic characteristics of those affected to assess the spatial correspondence between asthma and air pollution in the Bronx. Pulido (2000) uses GIS to analyze past patterns in Los Angeles of white Americans moving away from older industrial cores, showing that suburbanization and decentralization of city areas lead to the development and modern-day continuation of racism, environmental racism, and white privilege. Understanding these concept formations is important for modern day policy making (Pulido, 2000). While 'space' has received considerable attention, 'spatiality' - the relationship between social space and society - has not, and spatial discussions instead typically center on issues of distance, location, and scale, to the detriment of greater attention to race as one of the key social forces shaping American cities. As more information is collected on the follow-up effects of the Great Depression and World War II, the question is no longer as vague as "do waste facilities and environmental hazards develop in communities of color or do people of color tend to develop near hazardous areas?" but rather "does state and legislation make it easier for whites to move out of the central cities to cleaner neighborhoods over time while inner cities - where industrial and waste facilities still remain - increasingly register higher concentration of minorities?" (Pulido, 2000). GIS is an indispensable tool that is used not only to identify these spatial disparities in environmental injustice, but also in planning and policy making regarding contaminated site management and redevelopment.

Summary

Previous research indicates that historical maps and photos are indispensable sources of social knowledge and information about past physical conditions of an area. Combining geographical reconstruction with historical documentation and environmental data can provide a practical recreation of a historical cultural and physical landscape for a longer period of time as compared to contemporary map products. Collecting historical geographic data can be problematic when attempting to properly geolocate landmarks between various sources. The quality and uncertainty of georectified data needs to be considered when integrating this type of data for time-series studies for research purposes. Human and ecological exposure to hazardous wastes at contaminated sites is a critical environmental problem at local and global scales. Identification and characterization of these sites can require extensive field sampling and laboratory analysis, however advances in remote sensing technologies are new excellent options to collect critical information on remediation and compliance to be used during site management and prioritization. The social impacts of these contaminated sites are dependent on the social and political systems in place and lead to uneven effects felt differently in different communities. Understanding these patterns is important for modern day policy making and planning. GIS offers new methods to identify these imbalances and inform contaminated site management and redevelopment planning. The following section will detail the methodology, informed by and borrowed from previous and similar studies, that was used for this research.

4. METHODOLOGY

The methodologies used for this project are grouped into four chronological steps: (1) collection and preparation of historical maps, (2) extraction and collection of location, attribute, and demographic data, (3) geospatial data analysis, and (4) development of an ArcGIS Online (AGOL) web application.

Historical Map Preparation

Sanborn Fire Insurance maps from 1912 and 1913 were downloaded from ProQuest's Sanborn Maps Geo Edition™ website through the Western Michigan University Library. These maps are the most comprehensive set of historical maps produced near the turn of the century and cover the majority of the city of Grand Rapids during this time frame based on historic city limits. This source was also chosen as most of the maps are georeferenced and significantly reduce the amount of time for map preparation. Details on exact methodology were not readily available, however based on descriptions from ProQuest and the accuracy of location based on ground-truthing, it is most likely that the technologies used were a mix of manual and automatic georeferencing (ProQuest, 2020). All georeferenced maps were downloaded as GeoTIFFs and any remaining maps that were not georeferenced were downloaded as high-resolution JPEGs. The JPEGs were georeferenced using ArcMap's Georeferencing tool and control points were based on ESRI Topographic, Streets, and Imagery basemaps. In instances when the location and/or name of streets identified in the Sanborn maps had changed since the maps were produced, the volume's index sheet was used to find the approximate location and then georeferencing was completed based on cross streets and the map sheet's spatial relation to neighboring sheets (Figure 2). All map sheets that fell outside of the historic city limits were not included.

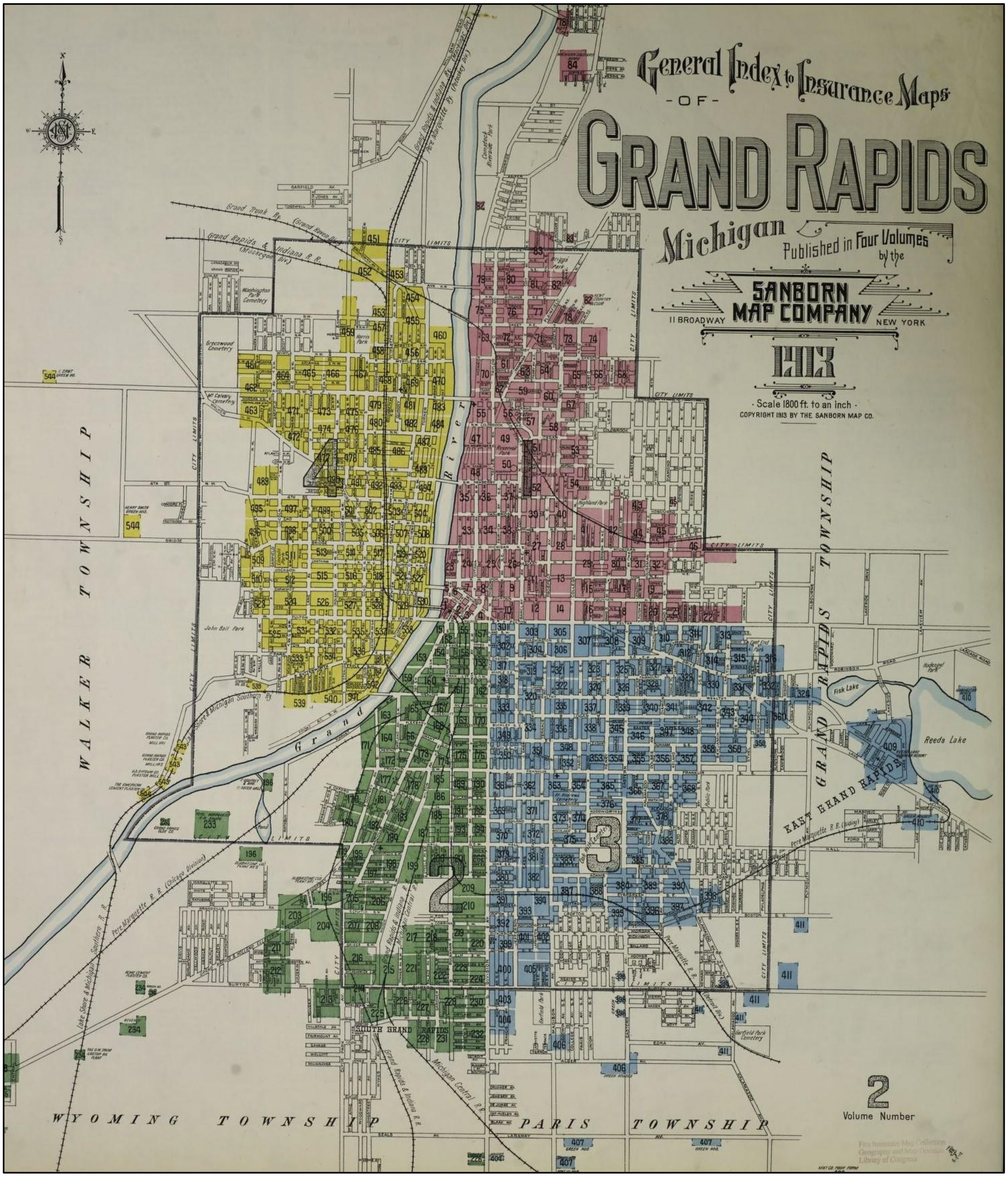


Figure 2. Index map sheet for Grand Rapids Sanborn maps published 1913 (ProQuest, 2020)

After a complete review of the georeferenced maps, some limited skewing and stretching of the Sanborn Fire Insurance maps was identified, similar to Piekielek's (2017) findings that the small geographic areas covered by these types of maps do not cause significant distortion during georeferencing. However, due to automated or hasty georeferencing techniques, several maps were not precisely located or overlapped. Some of these issues are also likely caused by the more artistic layout of the Sanborn maps that may over exaggerate the width of the streets compared to the parcels, making accurate georeferencing impossible without significant stretching or shrinking of different parts of the same map sheet. For the purpose of this research, these inaccuracies were acknowledged and accepted and are discussed in further detail in the Results and Discussion section.

Data Extraction and Collection

Once all the relevant Sanborn maps had been georeferenced, they were brought into ArcMap for data extraction. A new point layer was created with attribute fields for building/feature type (i.e. Housing, Store, Industrial/Factory, School), subtype (i.e. Dwelling, Apartment, Auto Shop), any onsite features, any special materials used in construction, and the company or owner name. A coded domain was created for the building/feature type field to standardize the collection of data and limit the variety of entries. This was an iterative process as maps covering different portions of the city introduced new or more appropriate feature categories. This was also done to facilitate the creation of feature type groups for the interactive AGOL web map. A point was created for every feature on each map, however for some larger buildings or facilities, a point was created for each room or smaller area that differed in use or type from adjacent areas. For example, when collecting a point for a dwelling, a single point would be placed in the center of the structure (e.g., the equivalent of a centroid placed manually within each polygon). When collecting a point for a large woodworking factory, points would be created for the engine room, the varnish room, and the lumber piles at the site. Once a point was created, attribute information about the feature was recorded in the corresponding fields depending on the data presented in the maps (see Figure 3) and the applicability of the data toward the research questions (i.e. environmental factors).

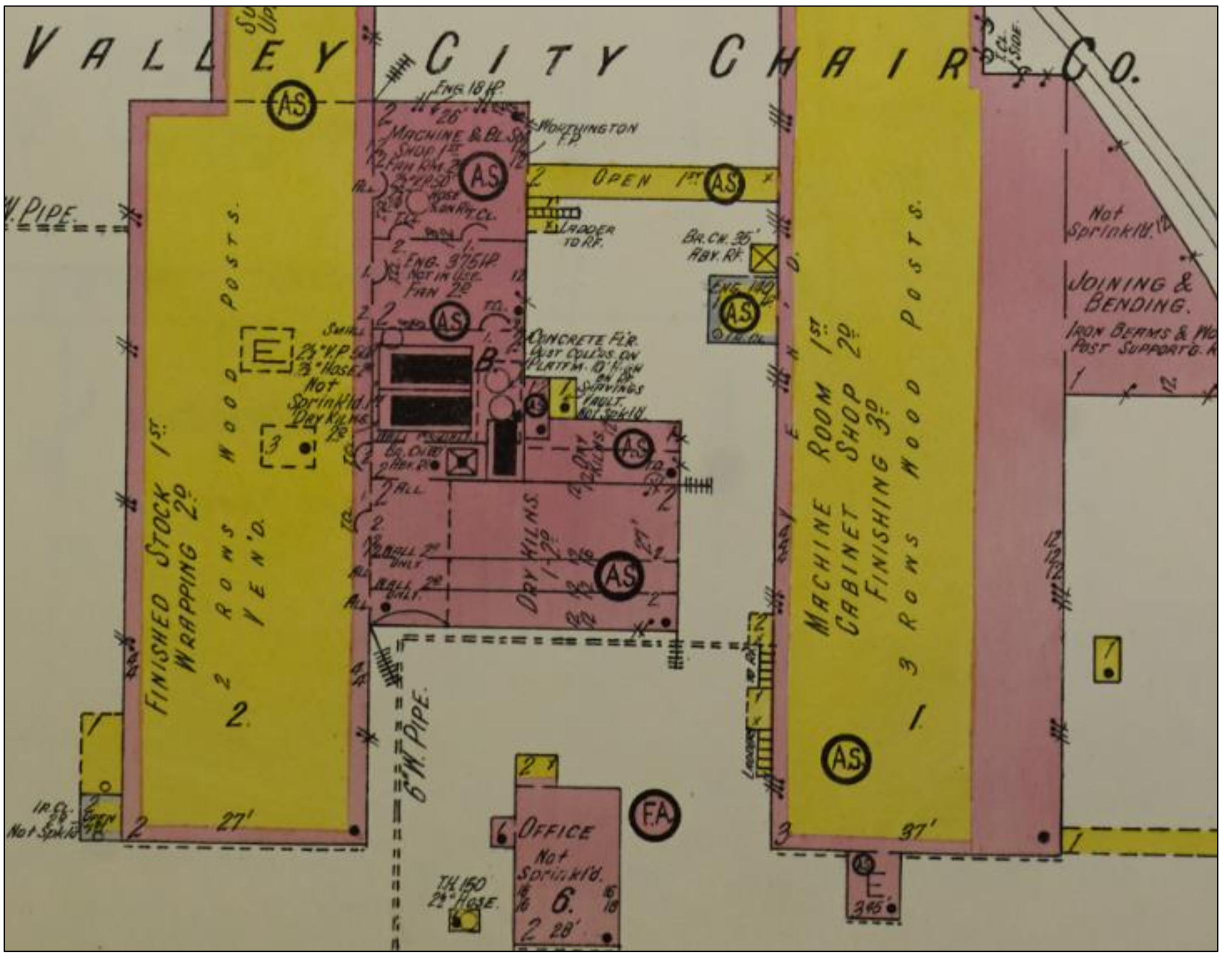


Figure 3: Image clip from Sanborn Fire Insurance Map. Source: LOC (2019)

This was repeated for all the map sheets within the 1912/1913 city limits. No data were created within empty parcels; however it is unknown if these parcels were in fact vacant or if the structures were not included by the cartographers. This trend mainly occurred in the outer edges of the city limits and likely does not impact the research as industrial activity was concentrated closer to the city center.

In addition to the points, a polygon layer was created. Polygons were drawn around large facilities or other physical features of interest. No data was collected with the polygons as they will only serve as visual feature boundaries and all the data will be associated with the point(s) within the polygon. When applicable, some natural features such as ponds were collected so that the presence and location of these features was available during analysis. Once all the data points were collected, the data was merged into a single feature class and standardized. An additional field was created to identify the sites of potential contamination. Classification was made by type of contaminant (i.e. Gas, Coke, Varnish) at the site, dependent on feature type and site use, and based on known health effects of different industrial activities (Syms, 2004).

Current environmental data for the city was collected from the EPA through the Environmental Justice Screening and Mapping Tool (EJSCREEN). This dataset includes the following environmental indicators: National Scale Air Toxics Assessment Air Toxics Cancer Risk, National Scale Air Toxics Assessment Respiratory Hazard Index, National Scale Air Toxics Assessment Diesel PM (DPM), Particulate Matter (PM2.5), Ozone, Lead Paint Indicator, Traffic Proximity and Volume, Proximity to Risk Management Plan Sites, Proximity to Treatment Storage and Disposal Facilities, Proximity to National Priorities List Sites, and Wastewater Discharge Indicators, and is a robust and popular tabular and geospatial data resource for environmental justice research (Grier *et al*., 2019). This data, available only at the census block scale, was downloaded directly as a geodatabase and was brought into ArcGIS for analysis.

Current demographic and socioeconomic data for the city was retrieved from the U.S. Census Bureau. The factors chosen for this research were median household income, percent of minority residents, unemployment rates, percent of non-English speaking households, and education attainment (percent of population under 26 with less than a high school education). This choice was based on several other environmental injustice studies that focus on these five (or fewer) factors, the most common being race and income. Excluding unemployment rates, these factors also reflect the data used by the EPA in environmental justice reporting (EJSCREEN). Demographic and socioeconomic data available through the U.S. Census Bureau and other state, county, or city databases present thousands of different factors that could be used depending on the focus of the study. As this research focuses on overall trends, these five main factors were considered suitable. The most recent comprehensive data for most topics was from 2017, so this year was chosen to represent the current demographic and socioeconomic status of the city. For percent of minority residents and education attainment, percentages were not included in the original data and were calculated by dividing the number of residents by the total population. The smallest scale available for these data layers was census tracts, so a shapefile of census tracts for the city was collected along with data tables for the five demographic and socioeconomic factors. ArcMap was used to join the data tables with the shapefile to create a geographic visualization of this data. Although the current city limits of Grand Rapids have expanded, the data from 2017 was also limited to the city boundaries of Grand Rapids from 1912/1913 to standardize the scale of the analysis. The environmental indicator data from EJSCREEN (census blocks) was also adjusted to match the scale of the demographic and socioeconomic data from the U.S. Census (census tracts). In order to accomplish this, the values in all census blocks within each tract were averaged and that value was reattributed to a census tract polygon.

To prepare the final data for analysis, all the vector layers were rasterized using the Feature to Raster tool in ArcGIS. The census data was in decimal degrees, so the output cell size was set to 2.5×10^{-4} (~80 feet) to match the cell size that will be used for the data extracted from the Sanborn maps. For this type of data, rasterization should not significantly impact the data as it is not continuous, but rather each census polygon has one value depending on demographic or socioeconomic factor. When rasterizing, any cells within this polygon are all attributed the same value. It is possible that there will be cells that contain portions of two or more polygons and data may be lost. This is not of high concern for this research as it is focused on citywide trends, but consideration should be taken during smaller-scale research applications.

Data Visualization and Analysis

The collected and categorized data was used to create multiple maps visualizing industrial and social trends of the city of Grand Rapids during the early 20th century. Focusing on building/feature type, two maps were created; one displaying the locations of all sites identified as industrial or factories and one depicting the concentration of this site type across the city. The latter was done using the Kernel Density tool in ArcMap that produces a continuous surface citywide from the input of discrete spatial features. This tool was chosen to show the distribution of these sites across the city and a kernel density produces a smoother distribution, allowing for better analysis of general trends over abrupt hotspots. The default value (~ 80 feet) was used for output cell size, as it results in a manageable file size and is sufficient for visualizing trends on a citywide scale, area units were square miles, output values were densities, and the method was planar. The processing extent was set to match the 1912/13 city limits so that the resulting raster would cover the same area as demographic data for correlation analysis (default extent will only go as far as where points exist). This step is appropriate in this research since it is known that no features of this type are located in the larger extent. For similar research where this is unknown, this may not be appropriate as it can lead to inaccurate analysis. These two maps were also created focusing on locations that were identified as potential contaminated sites. Concentration categories (i.e. low, medium, high) were used as this research is more concerned with trends than exact values. As data on income by location was not available for the city of Grand Rapids in the early 1900s, the housing type data collected from the historic maps was used to create proxy maps of low and high income areas for the time frame. For analysis, the highest weight was given to the 'Tenements' housing type as it represented the lowest income residents, followed by 'Boarding House', 'Flat/Apartment', and 'Dwelling' with the lowest weight as it generally would represent the highest income residents. The Kernel Density tool was run twice more on the dataset, once for low income and once for high income and density maps were created showing the geographic trends in income based on housing type during the 1912/1913 period.

In order to ascertain if there are statistically significant correlations between the historical presence of an industrial or contaminated site and historic or current demographic and socioeconomic trends, spatial statistics analysis was run using R, a statistical programming language, through RStudio. The *cor.test* function was used (available in the *stats* package) to test for association between the raster pairs using the Pearson correlation coefficient. Correlation values range from -1 to +1, indicating negative and positive linear correlations, respectively, while a value of zero indicates the raster layers are independent of each other (ESRI, 2020). The program was used to produce a correlation matrix for historic industrial sites, historic potential contaminated sites, historic low income based on housing type, historic high income based on housing type, current environmental indicators by census block and by census tract, current median household income, current minority percentages, current unemployment rates, current primary spoken languages, and current level of education attainment. This was done by testing each pair separately and recording the correlation coefficient and significance. The Band Collection Statistics tool in ArcMap was also considered for use in analysis. This tool creates correlation matrices for sets of raster layers based on how the cell values from one raster layer relate to the cell values of another raster layer, representing the measure of dependency between the layers. Very similar correlation coefficients were found using this method as to the *cor.test* in R, but the tool does not provide p-values to measure statistical significance and therefore was not sufficient for the research requirements.

Web Application and StoryMap Development

ArcMap and ArcGIS Pro software was used to create an AGOL web application. The web application includes all the point data collected from the Sanborn maps. The data is categorized in different ways so that the user may choose to view the data per their specific interests, such as by building/feature type or by whether or not the location is a potential contaminated site. These groups are further categorized by contaminate type (i.e. Gas, Chemical, Metal) to facilitate the user targeting the data of interest. The points are also interactive within the map and can be clicked on to open an info box for each point listing the associated data for that feature. Due to file size and possible copywrite issues, no historic maps were included, although weblinks to the maps are provided on the web application. This web application was used to build an ArcGIS StoryMap that contains additional and more in-depth information on the purpose and goal of the project, details about the data collection and Sanborn Fire Insurance Maps, and guidance for interpreting the results and the actions that are available to residents based on this information. The next section reports the results of the methodologies used during research and discusses the implications of the results as they apply to the research questions.

5. RESULTS AND DISCUSSION

Data Extraction and Collection Results

A total of 384 Sanborn fire insurance maps, published between 1912 and 1913 in four volumes, were downloaded from ProQuest's digital database. Approximately thirty maps were georeferenced from JPEG or GeoTIFF that was not properly georeferenced. Limited amounts of map overlap or misplacement was encountered, however this level of error was considered minor as the exact location of the contaminate within the parcel or the structure cannot be known, so these points should be considered as generalized locations or center points of industrial sites or buildings/structures that may be contaminated rather than the exact source point. Over forty thousand points were collected from the four volumes of map covering the majority of area within the 1912/13 city limits. Once the data points were collected and merged, there was a final total of 41,646 points to be used during analysis (Figure 4). Of these points, approximately 23,000 represent housing structures, ~14,800 represent other residential-related structures (sheds, personal garages, or stables), and ~1,500 represent industrial sites or factories. The final ~2,000 points represent all other feature/structure types including public buildings, schools, shops and stores, and places of worship. The industrial sites and factories were concentrated near the center of the city running north to south along the Grand River and southwest of the city running east to west. Most of these locations were near or abutted a railroad track or a train depot/station. In addition to the points, 309 polygons were digitized around facilities and other larger areas of interest including cemeteries and gravel pits.

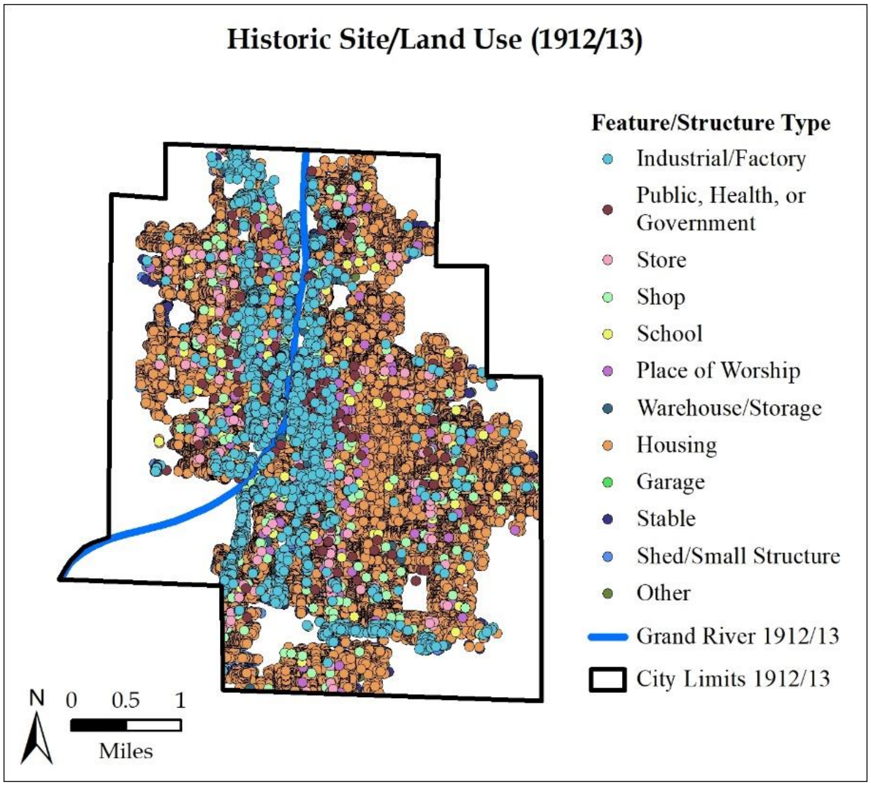


Figure 4. Historic site and/or land use based on feature type (1912/13)

Once the data was organized and standardized, the new field for potential contaminant type was filled based on data from the feature type, the listed onsite activities, and any special materials used. This list included, but was not limited to, asbestos, ash, blacksmith, boiler, coal, laundry/chemical, pharmaceutical/chemical, gas, varnish, veneer, paints, tannery, and lumber. For analysis purposes, these categories were not analyzed separately or ranked; any type of contaminant was considered a potential contaminated site. These specific categories are used in the digital products linked to this thesis. Maps displaying the demographic and socioeconomic data retrieved from the U.S. Census Bureau can be seen in Figures A1 through A5 (see Appendix). Figure A6 in the Appendix displays the environmental indicator data retrieved from EJSCREEN. Tables A1 and A2 include retrieved data from the U.S. Census Bureau and EJSCREEN for all census tracts and census blocks, respectively.

Data Analysis Results

The results of the Kernel Density analysis for the historic industrial or factory sites is displayed in Figure 5. The trends in concentration of historic industrial sites match well to the point locations of these sites, however more minute density patterns are clear showing higher concentrations near the center of the city and multiple clusters along the Grand River.

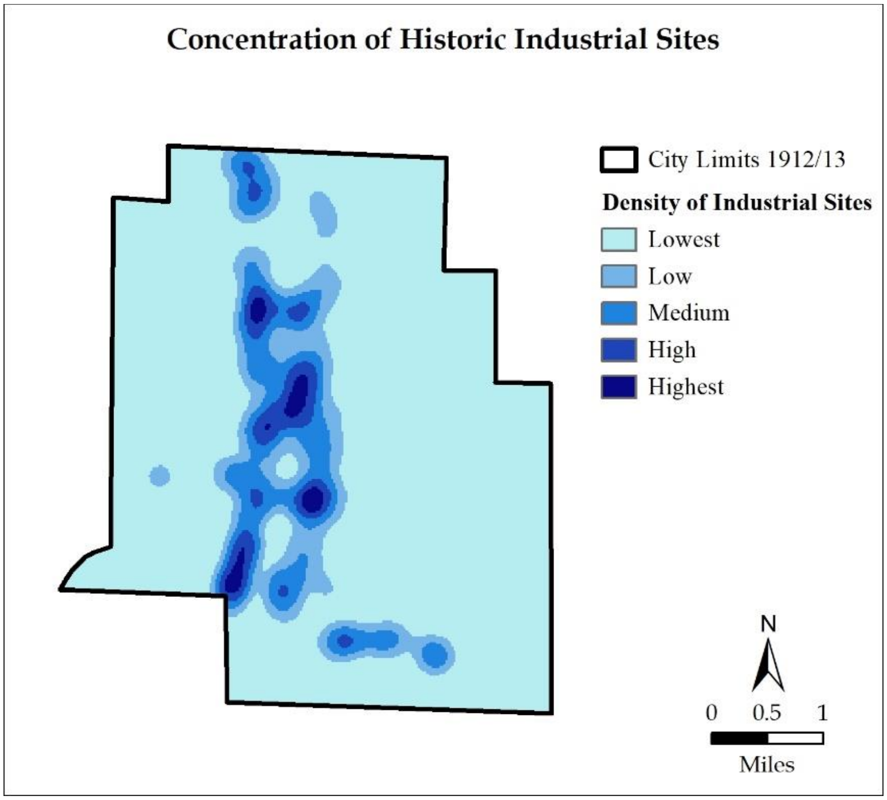


Figure 5. Density map of locations of historical industrial sites (1912/13)

Although the industrial areas do generally fall along train lines, the highest density areas are not collocated specifically with large train depots or stations. The current day locations of these high density industrial areas are at the crossing of the Grand River with Pearl Street NW and the intersection of Highway 131 and Wealthy Street SW. The results of the Kernel Density analysis for the historic potential contaminated sites is shown in Figure 6. The highest density areas for historic potential contaminated sites also occurs near the crossing of Pearl Street NW and the Grand River, although it extends further to the southeast into the historic downtown and shopping district where stores and shops (such as auto mechanics, painters, or small tanneries) that do not qualify as industry or as factories would still be of environmental concern.

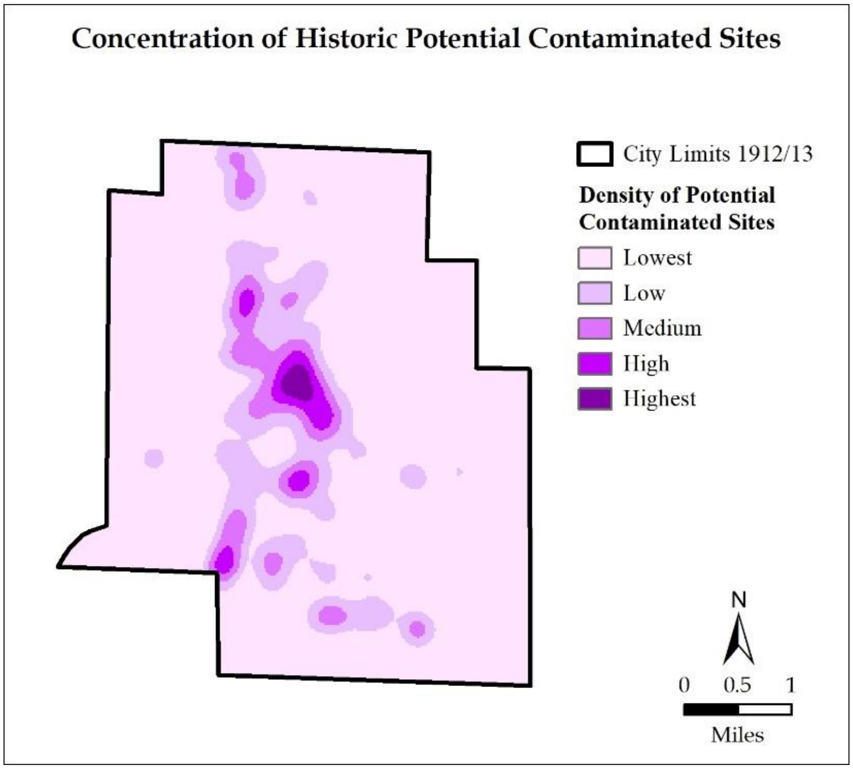


Figure 6. Density map of locations of potential contaminated sites (1912/13)

Regarding income, higher concentrations of low income housing are found near the center of the city, spanning both sides of the Grand River, with the highest low income housing, particularly tenements, also clustering in the downtown and shopping districts (see Figure 7). High income housing also shows areas of high concentration near the downtown and shopping districts but is much more widespread across the city, and is much denser in the southeast, south and north (see Figure 8).

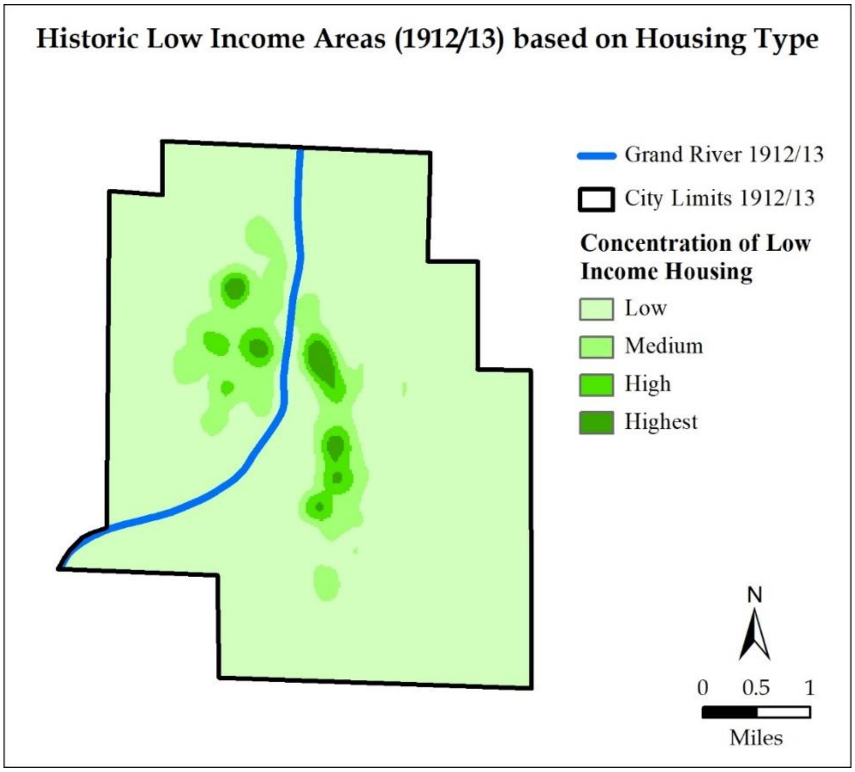


Figure 7. Concentration of low income housing based on housing type (1912/13)

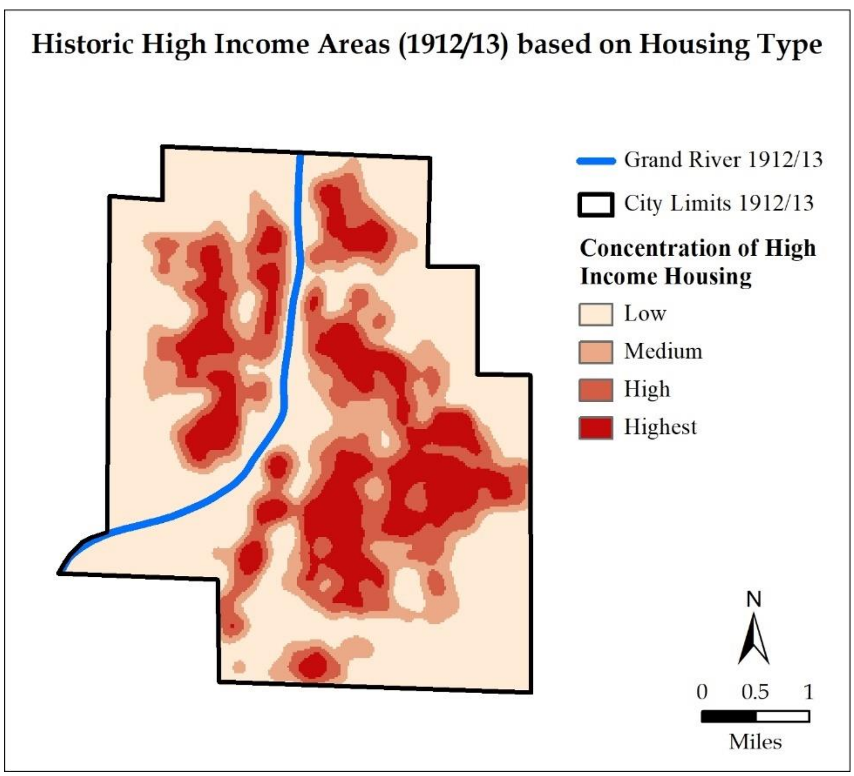


Figure 8. Concentration of high income housing based on housing type (1912/13)

The correlation matrix of the nine factors is shown in Table 1. The vast majority of the pairs had statistically significant correlations (>99%), the exceptions being percent non-English speakers and environmental indicators by census block (>90%), and unemployment rate and environmental indicators by census tract (>95%). Several strong correlations were found between practically all the current demographic and socioeconomic factors. Strong correlations were also seen between the historic potential contaminated sites, industrial sites, low income areas, and the current total environmental indicators. The strong correlation of the latter suggests that the general areas of contaminated sites, or at least areas of high pollution, have remained relatively the same over the past century. The strongest correlation between an environmental factor and a demographic or socioeconomic factor was found between the historic low income areas and the current total environmental indicators; however the correlation value was 0.49, so it is strong in relation to the other factors in the matrix, but still not perfectly correlated.

Table 1. Correlation matrix of historical environmental data, current environmental indicators, and current demographic and socioeconomic factors

CORRELATION MATRIX

	Ind. Site (H)	Cont. Site (H)	EIs Block (C)	EIs Tract (C)	MHI (C)	% Minority (C)
Ind. Site (H)	1	0.915***	0.497***	0.387***	-0.257***	0.147***
Cont. Site (H)	0.915***	1	0.567***	0.432***	-0.276***	0.09***
EIs Block (C)	0.497***	0.567***	1	0.678***	-0.135***	-0.101***
EIs Tract (C)	0.387***	0.432***	0.678***	1	-0.081***	-0.105***
MHI (C)	-0.257***	-0.276***	-0.135***	-0.081***	1	-0.662***
% Minority (C)	0.147***	0.09***	-0.101***	-0.105***	-0.662***	1
Unemploy. (C)	0.190***	0.191***	-0.044***	0.005**	-0.58***	0.78***
% Non-English (C)	0.145***	0.092***	0.002*	0.077***	-0.37***	0.652***
% Less than HS (C)	0.021***	-0.035***	-0.127***	-0.158***	-0.448***	0.724***
Low Income (H)	0.325***	0.463***	0.483***	0.45***	-0.141***	-0.081***
High Income (H)	0.106***	0.238***	0.159***	0.115***	-0.13***	0.08***

	Unemploy. (C)	% Non-English (C)	% Less than HS (C)	Low Income (H)	High Income (H)
Ind. Site (H)	0.190***	0.145***	0.021***	0.325***	0.106***
Cont. Site (H)	0.191***	0.092***	-0.035***	0.463***	0.238***
EIs Block (C)	-0.044***	0.002*	-0.127***	0.483***	0.159***
EIs Tract (C)	0.005**	0.077***	-0.158***	0.45***	0.115***
MHI (C)	-0.58***	-0.37***	-0.448***	-0.141***	-0.13***
% Minority (C)	0.78***	0.652***	0.724***	-0.081***	0.08***
Unemploy. (C)	1	0.647***	0.539***	-0.043***	0.015***
% Non-English (C)	0.647***	1	0.596***	-0.111***	-0.044***
% Less than HS (C)	0.539***	0.596***	1	-0.256***	-0.091***
Low Income (H)	-0.043***	-0.111***	-0.256***	1	0.442***
High Income (H)	0.015***	-0.044***	-0.091***	0.442***	1

KEY

Ind. Site (H)	Industrial site based on facility type
Cont. Site (H)	Potential contaminated site based on facility use
EIs Block (C)	Total environmental indicators by census block
EIs Tract (C)	Total environmental indicators by census tract
MHI (C)	Median household income
% Minority (C)	Percent minority residents
Unemploy. (C)	Unemployment rate (16 years and above)
% Non-English (C)	Non-English speaking households
% Less than HS (C)	Education attainment (less than a high school diploma)
Low Income (H)	Low income households based on housing type
High Income (H)	High income households based on housing type
*, **, ***	<0.1, <0.05, <0.01 p-value (statistical significance)
(H)	Historical data from 1912/1913
(C)	Current data from 2017

Discussion

Historical maps often hold data that is not available in any other source and provide a glimpse into the social and cultural norms of the time. The Sanborn fire insurance maps over Grand Rapids in 1912/13 resulted in over 40,000 data points and approximately 100,000 items of data. Given that all these data are attached and linked to a location on the ground, no other historical document or data table could have been as productive. Additionally, even though these maps were designed and published with the sole intention of providing information relating to fire insurance, the variety and specificity of data included on the maps make them applicable to the environmental research field, among many others. Factories and producers in the same industry can be assumed to be using similar, if not identical, materials and practices. As such, reasonable assumptions can be made that a furniture factory, even if it does not specifically list it, is a potential source for varnish, stain, and wood treatment contaminants. This can also apply to auto shops, coal plants, and stores that sell paint, oils, and glues. If these facility and land use types can be located, producing maps of potential contaminant sources is a quick and easy task.

Historical maps fill an important knowledge gap regarding environmental contamination as environmentalism and the tracking of pollutants is still a relatively young practice, only going back a few decades. This means that this topic of data was not of high concern, if considered at all. As many toxic compounds are odorless, tasteless and colorless, easy and obvious detection is often impossible. Within the span of a century, and certainly anything beyond that, it is possible to have several iterations of land use at the same site, and as buildings are torn down, rebranded, or rebuilt, that history is completely removed from the landscape. Historical data, especially maps and photos, hold this lost information and through the process of extraction and digitization, it is made readily available to current researchers and environmental specialists. Despite the benefits, it is important to recognize and understand the limitations and biases of historical maps. The Sanborn maps are highly technical and are not linked to a particular political agenda, but they are still historical documents and should be approached as such.

The next step in this process is prioritizing testing and mitigation of contaminated sites. Since the industry and contaminant category are known, environmental specialists can target certain facility types before others depending on the contaminant of concern. This ties into the specific and indispensable role that GIS serves in this process. In addition to utilizing this technology to collect the data, when a contaminant of interest, such as an emerging contaminant, is identified and linked to a particular industry or facility, GIS can not only be used to quickly locate all such sites, but also to analyze their proximity to other important demographic and socioeconomic factors. For example, GIS can be used to help prioritize contaminated sites near to schools or residential areas over those that are farther from vulnerable communities. The final step in the process is data dissemination, which is also highly benefited by the use of GIS as it can provide an interactive platform to display the data so that users can retrieve only the data that is of interest to them. Environmental impact data on the state or city level can feel non-applicable to one's own situation, so having the ability to zoom down to the scale of a neighborhood, street, or even parcel, can empower residents and policy makers to understand their direct connection to these environmental processes. Achieving this through tabular data format would not only be extremely time consuming, it would be far less effective. Therefore, the research questions regarding the use of historical maps and GIS as they pertain to environmental data are clearly answered; not only do they provide access to historical data that likely exists in no other format, they also provide an unmatched platform for efficient and effective data collection, analysis and dissemination.

The final portion of this research relates to the question regarding evidence of past or present environmental injustice in Grand Rapids. The data collected from the historical maps successfully served to build citywide map of areas of environmental concern. For the purposes of this research, only two main categories were considered; industrial/factory sites and potential contaminated sites. However, the data extracted from the maps could be used to make several additional subcategories to build more targeted maps, such as contamination linked specifically to the furniture industry which would include any furniture factories, lumber treatment yards, and storage facilities for chemicals used in the woodworking process. Extracting demographic and socioeconomic data from the historical maps was not as straight-forward, particularly given the focus and theme of the maps being related to fire insurance. Despite this, the amount and detail of information including in the maps did provide insight into these social factors. Housing type was used as a proxy indicator for income. This is acknowledged as an assumption based on the likelihood that earning a higher income would result in living in a more expensive housing type, so the data was only used to analyze geographic income patterns on a city-scale level (for similar research, smaller scale use of the data would need to be carefully considered given the implied assumptions). Other demographic data was either not present or was not as easily retrievable on the Sanborn maps. Several churches, society, and club halls were identified as belonging to certain cultural groups (i.e. Polish, African American) which could indicate a higher percentage of residents of those demographics in the area, although there were no other indicators to support this assumption. Given this, no other historic social factor was used for analysis.

The suitability of the correlation matrix was tested by using the historical industrial sites raster and the historical contaminated sites raster as a test sample. Given that the vast majority of industrial sites would be linked to at least one type of contaminant, these two layers should have a strong positive correlation. This was confirmed with a correlation value of 0.915, the slight uncorrelation due to the fact that some non-industrial sites are considered contamination risks such as auto or mechanic shops. There was also a clear positive correlation between historic low income and industrial sites (0.325) and between historic low income and potential contaminated sites (0.463), indicating that generally the more industrial and potential contaminated sites there were in an area, the more likely that low income residents would live nearby. This trend is likely due to limited car ownership at the time, so most manual laborers would need to live or stay near industrial sites. This is also reflected in the high number of boarding houses across the city, and the fact that most tenements were located downtown. To corroborate this finding, high income housing was found to have lower, albeit not by much, correlation coefficients with historic industrial sites (0.106) and potential contaminated sites (0.238). The relationship is still positive however, which indicates that even higher income residents were more likely to live near industrial sites and potential contaminated sites, which is to be expected as they too would need to be closer to factories or the offices downtown. Therefore, given the data collected from the historical maps, there is evidence for environmental injustice in low income communities in Grand Rapids during the early 1900s.

The historic industrial sites had little correlation with the five current demographic and socioeconomic factors, although they were all positive relationships except for median household income. This means that in general, areas of historic industrial use are more likely to currently have higher percentages of minority residents, unemployment rates, percentages of non-English speaking households, and percentages of residents with less than a high school degree, and lower median household income. Given the low correlation coefficients (highest at -0.257), these really only represent minor trends and are not appropriate to build any theories on. Similar trends were seen with the historic potential contaminated sites that also showed that areas of historic potential contaminated sites are more likely to currently have higher percentages of minority residents, unemployment rates, percentages of non-English speaking households, and percentages of residents with less than a high school degree, and lower median household income. Again, the low correlation coefficients (highest at -0.276) do not allow for any definitive theory building. Current areas of high environmental indicators also did not show high correlations with most demographic and socioeconomic factors, although the relationships did show that areas with more environmental indicators see lower median household incomes and higher percentages of non-English speaking households, but also lower percentages of minority residents, unemployment rates, and percentages of residents with less than a high school education. However, since these correlation coefficients were also so low, the relationships are not considered for this research. A negative relationship with lower median household income was found in all of the different environmental indicators and demographic and social factors indicating that any of these conditions would result in a lower median income. Percent minority residents had a strong correlation to all other factors, particularly to unemployment rates (0.78) and percent of residents with less than a high school education (0.724) indicating that higher minority areas are more likely to have higher unemployment and more residents with lower education levels. Unemployment rates also had a strong positive correlation with percentages of non-English speaking households, indicating that communities with higher linguistic isolation are more likely to have high unemployment rates. Historic low income and high income showed a positive relationship with a correlation coefficient of 0.442, meaning that even though their distributions through the city differed, there is still a strong historical overlap of low and high income housing. This would be very interesting data to have for current conditions, but the format and scale of the current median household income does not allow for correlation analysis. Similar studies could benefit from this additional analysis.

A surprising correlation was found between historic industrial or contaminated sites and current areas with the highest environmental indicators. Although industry in the city of Grand Rapids has certainly changed over the past century, the areas of the most concern have not. Still, environmental impacts between the early 20th century and the early 21st century are not directly comparable given the vast differences in the data available and the factors considered. Detailed air quality data was not available from the historic maps, but it is likely that air quality was low given the amount of industry and lack of environmental standards at the time. It is possible that although industrial air pollution has decreased in the city, bus and personal vehicle traffic is now the cause for heightened air pollution levels in certain neighborhoods.

Scaling of data is a very important consideration for this type of research. A significant amount of data resolution was lost when the environmental indicator data was averaged to match the census tract scale of the other data. As seen in Figure A6 and A7, some census tracts included blocks with a low total number of environmental indicators and blocks with the highest total number of environmental indicators. When averaged, the smaller resolution data was lost and extremes in both directions were muted. These differences can also be seen in the correlation matrix, where the correlation coefficients with all the other factors and indicators differ between the block and tract scales. Of particular interest is the higher correlation coefficients for the block level with the historic industrial sites (0.11 higher than tract level) and the historic potential contaminated sites (0.135 higher than tract level). As the resolution of the historic data is roughly 80 feet, the block scale would allow for more of the smaller scale patterns to be identified. This of course presents its own issues, as even the smallest block size still covers thousands of square feet, far off from the resolution of the historic data. This disparity between scales was cautiously accepted for the purposes of this research as it is focused on citywide trends, but any more precise similar research would need to give significant consideration to the possible misrepresentation of the data due to the scaling issue. However, for smaller scale and more targeted research, data at the census tract level would likely not be sufficient to begin with and sources of higher resolution demographic and socioeconomic data should be identified.

Although only minor, if not negligible, correlations between the environmental indicators (historic or current) and the five current demographic and socioeconomic factors were found in this study, this does not imply that environmental injustice is not a significant problem in the city of Grand Rapids. In fact, a much more focused and in-depth study by Grier *et al.* (2019) found that five census tracks in Grand Rapids accounted for half of the top ten census tracks in Michigan with the highest environmental justice score, which indicates communities that have both a high risk of exposure to environmental hazards and high vulnerability due to demographic and social factors. Therefore, the current presence of environmental injustice in Grand Rapids is not debated or disproved in this thesis research. Rather, it has shown that environmental data retrieved from historical maps can add knowledge and understanding to the historical processes and temporal trends of environmental justice. Furthermore, this thesis research reaffirms that using GIS to visualize and share this type of information with local communities, including developers and policy makers, makes the data more accessible, user-friendly, and impactful.

6. CONCLUSIONS AND APPLICATIONS TOWARD FUTURE RESEARCH

Historical maps have been shown to be a relatively untapped source of big data. While there is little, if any, debate over the importance of the historic data they hold, relatively few researchers have invested the time to collect this data in a format that can be readily accessed and exploited using modern research methods and technologies. The Sanborn fire insurance maps are an example of these data-rich historical maps that hold information on site/land use, environmental indicators, and cultural and economic factors. For the case study of the city of Grand Rapids, extracting this information from the maps has allowed for the production of a city-wide database of land/site use in 1912 to 1913 along with tens of thousands of attribute data. This data can be used by environmental specialists to locate, target, and prioritize testing, mitigation, and remediation efforts depending on contaminant type, especially as new and emerging contaminants are identified. Industrial and social trends were mapped from the historic data to show evidence of environmental injustice in Grand Rapids over a century ago. Current geographic patterns of environmental indicators are similar to these historic patterns, although this thesis research did not find strong correlations between these indicators and current demographic and socioeconomic factors. Still, Grand Rapids is unfortunately well established as a city with imbalances in environmental justice, especially as it applies to marginalized groups. GIS is an appropriate and effective tool for not only gathering and analyzing these data, but also for dissemination of the data to educate and empower the residents, developers, and policy makers of Grand Rapids to understand the historic and current trends of environmental concerns in their city.

Despite the vast benefits this type of data has towards building a deep and robust historical understanding of lost landscapes and cultures, there are some issues and lessons learned that should be taken into account when considering similar research:

1. The data collection portion or this thesis was a significant time commitment. Map preparation, and data collection and extraction accounted for approximately 150 workhours, which included only a minor amount of georeferencing. The process can also be repetitive and monotonous. Generally, however, work for research like this is very front-loaded as the use of GIS allows for quick analysis and data visualization once the data collection portion is complete.

2. For this thesis, only the Sanborn map collection from 1912 to 1913 was used due to time limits and accessibility, but extensive collections exist for many cities across the United States and the globe. For Grand Rapids, similar scale maps are available through the David Rumsey Map Collection and thousands of historic photos are available through the Grand Rapids Public Library.

3. Several maps, including the Sanborn fire insurance maps, are color coded depending on the preferred categorization scheme of the publisher. While small written details would not be collected, imagery analysis and automated classification through GIS could be used to quickly pull this categorical information based on cell color values.

4. A significant portion of the industry fell along or near railroad tracks. These tracks were not digitized as they did not directly apply to the research questions, however this type of data could help to understand the processes behind the geographic patterns of industry in the city. Similar research would benefit by including data on transportation networks, or similar features, of the time.

5. Historical documents are results of the culture of the time at which they are published and may include terms that are obsolete, derogatory, or politically incorrect. These data are helpful to understand the social dynamics of the time but should be considered for appropriateness prior to dissemination.

Digital Products

In addition to the written thesis, two digital products were created to disseminate the research, an AGOL web map application and an ArcGIS StoryMap. Links to these products are below but are possible to change upon confirmation and approval of all associated parties, although unlikely. The current link will be available through Western Michigan University's Geography, Environment, and Tourism Department. They are property of the author and Western Michigan University, but are for public use and will be free and accessible to the public.

AGOL Web Map Application: *http://wmugeography.maps.arcgis.com/apps/webappviewer/index.html?id=8c07b76ce5294a8d9f5e119f5e9bd37d*

StoryMap: *https://storymaps.arcgis.com/stories/35277cb59dc5436291d16804f73ed2e9*

Impacts on Research

Research for this thesis was impacted by the stay-at-home directive in response to the COVID-19 pandemic in the state of Michigan. Original plans were to include historical photo research and analysis to corroborate the data from the historical maps and to add any additional visual information available only in these historical photos, as well as conducting research into other historic documents and sources as available. Due to the stay-at-home directive, it was not possible to visit archive locations or to gain access to any data that was not available in digital format. Additionally, several specialists and historians were furloughed during this time and were not able to support the research. For similar research and applications, it is highly suggested to exploit these other resources as they contain a wealth of knowledge, as well as meaningful and impactful data that is not available from any other source.

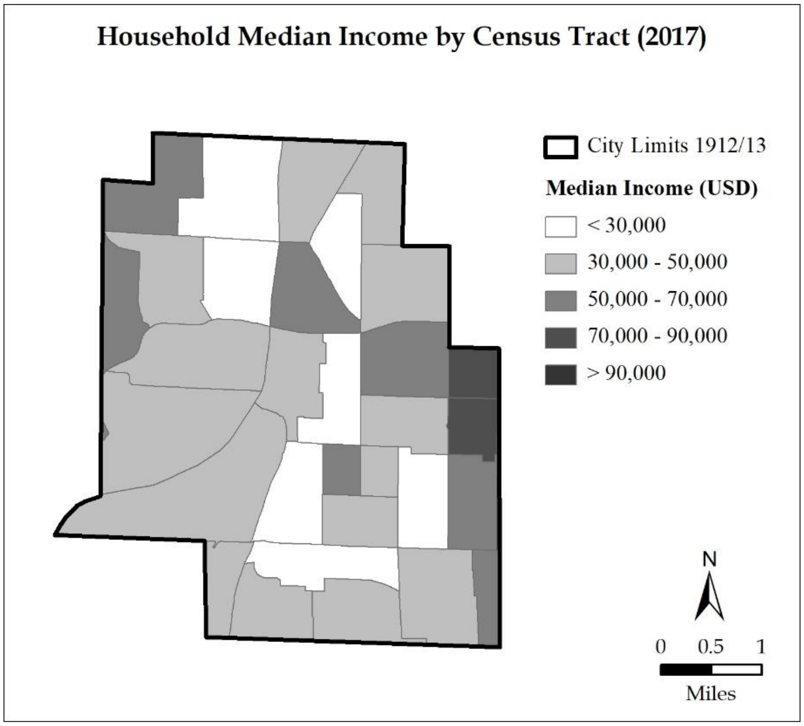


Figure A1. Household median income by census tract (2017)

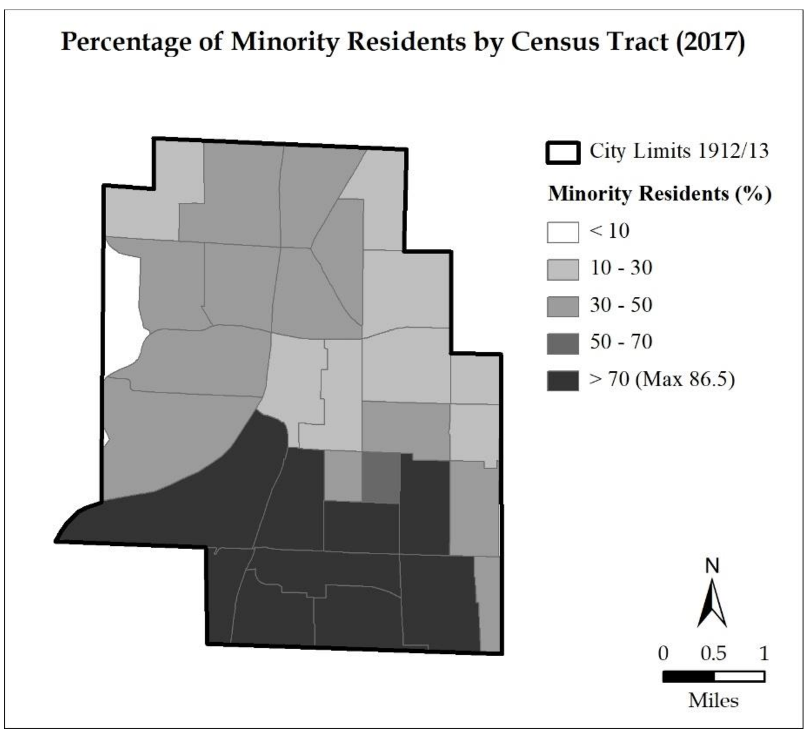


Figure A2. Percentage of minority residents by census tract (2017)

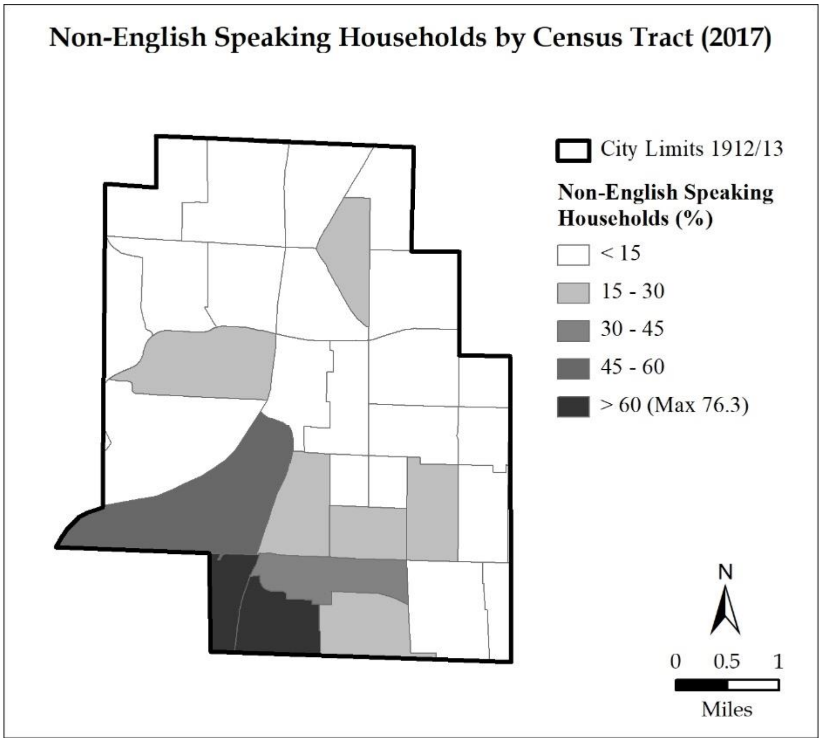


Figure A3. Non-English speaking households by census tract (2017)

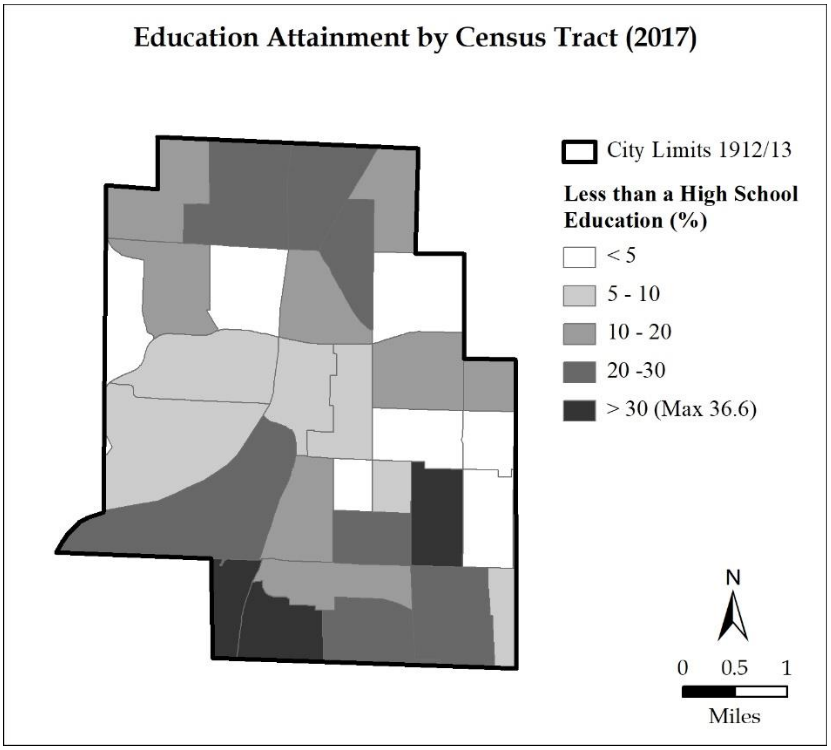


Figure A4. Education Attainment by census tract (2017)

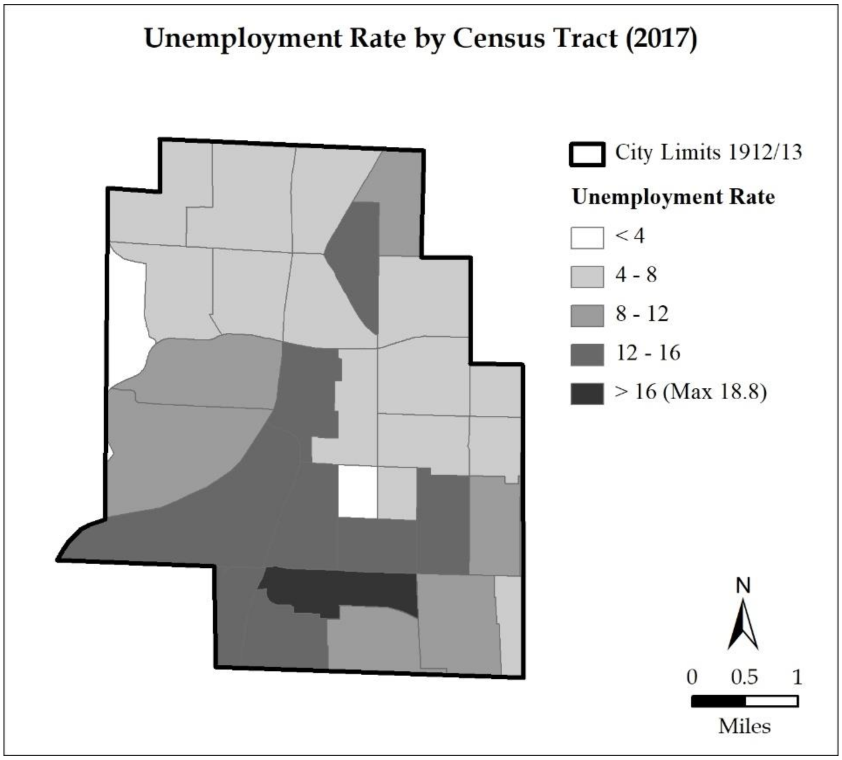


Figure A5. Unemployment rate by census tract (2017)

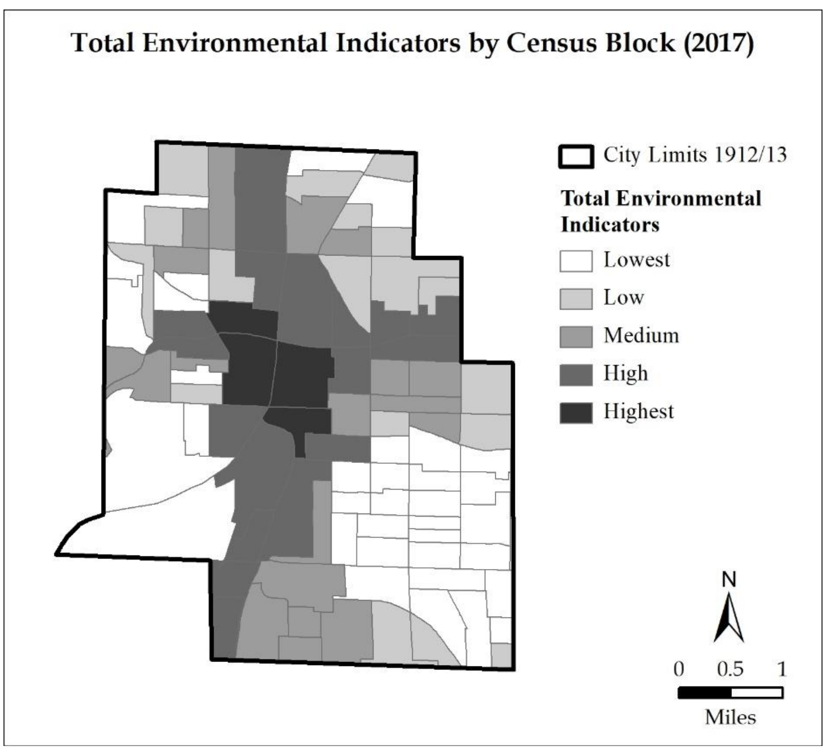


Figure A6. Concentration of total environmental indicators by census block (2017)

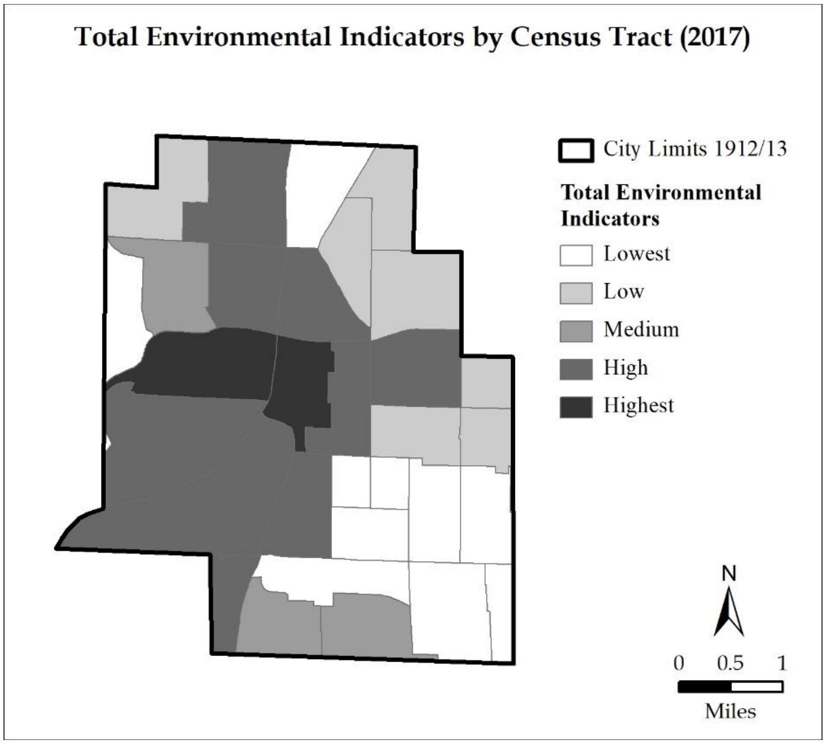
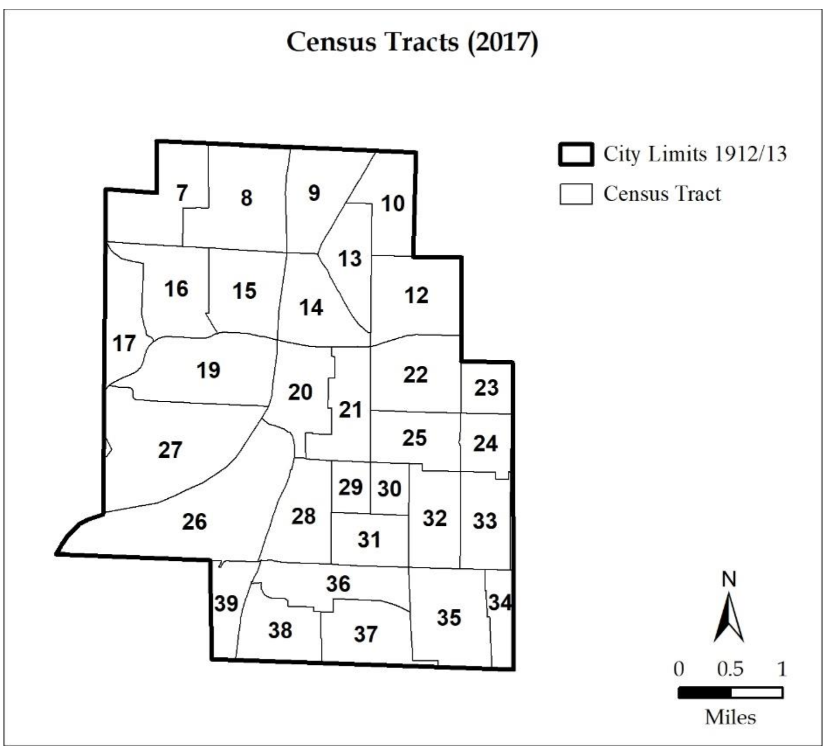


Figure A7. Concentration of total environmental indicators by census tract (2017)



A8. Census Tract Boundaries (2017)

Table A1. Demographic and socioeconomic data and total environmental indicators by census tract (2017)

Census Tract ID	Minority Residents (%)	Median Income (USD)	Non-English Speaking Households (%)	Less than a High School Education	Unemployment Rate	Total Environmental Indicators
7	29.2	51,129	8.1	11.1	5	484
8	50.0	29,741	4.5	21.8	5.7	2,325
9	43.0	35,655	7.5	25.1	6.8	733
10	27.7	45,931	11.6	15.0	8.5	624
12	29.3	42,838	5.5	1.5	4.8	1,906
13	45.5	28,982	15.4	21.6	13.7	1,138
14	37.3	60,000	5.4	14.7	5	4,142
15	44.2	25,804	9.6	4.0	5.6	6,338
16	45.0	39,318	13.7	12.2	4.3	1,142
17	9.1	54,778	2.0	3.6	1.1	1,126
19	43.4	47,216	20.0	6.5	9.8	3,336
20	25.1	31,031	9.4	8.8	13	7,687
21	18.6	29,209	4.7	7.4	4.6	2,930
22	29.9	50,679	2.9	14.4	5	2,725
23	13.4	72,783	7.0	16.3	4.1	1,074
24	11.5	72,733	3.7	0.6	5.1	468
25	32.5	45,871	13.5	1.2	6.6	732
26	70.7	32,827	59.0	27.9	13.5	2,092
27	39.3	38,327	13.4	7.0	11.6	1,437
28	83.0	18,276	21.5	12.1	15	2,569
29	30.9	50,750	5.1	2.0	3.2	252
30	53.6	43,125	10.5	5.1	6.1	111
31	86.5	32,632	15.1	23.5	12.9	223
32	79.4	28,139	16.5	30.4	15.4	106
33	41.3	57,344	6.5	3.0	10.2	106
34	30.1	57,000	9.0	8.1	6.1	425
35	70.3	32,222	7.2	29.2	11.8	387
36	83.9	26,563	35.7	19.3	18.8	874
37	78.7	30,856	29.1	28.0	11	1,205
38	82.0	30,378	71.2	30.1	14.5	1,840
39	75.5	31,179	76.3	36.6	15.9	2,742

Table A2. Total environmental indicators by census block (2017)

Census Block ID	Total Environmental Indicators
7001	562
7002	434
7003	855
8001	5,450
8002	1,563
8003	1,439
9001	528
9002	564
9003	1,334
10001	569
10002	674
10003	1,159
10004	150
11013	2,140
12001	1,050
12002	864
12003	3,053
12004	3,655
13001	982
13002	1,615
13003	818
14001	4,913
14002	3,371
15001	6,550
15002	11,225
15003	1,238
16001	1,334
16002	233
16003	158
16004	3,035
16005	948
17001	484
17002	473
17003	2,421
19001	10,667
19002	660
19003	2,429
19004	4,263
19005	1,673
19006	325
20001	7,677
20002	7,696
21001	3,295
21002	1,489
21003	4,006
22001	5,335
22002	1,609
22003	1,641
22004	2,315
23002	1,074
24001	1,101
24002	121
25001	892
25002	1,684
25003	220
25004	131
26001	3,779
26002	141
26003	4,778
27001	3,556
27002	371
27003	383
28001	3,232
28002	1,906
29001	223
29002	281
30001	111
30002	111
31001	114
31002	117
31003	439
32001	108
32002	105
32003	105
32004	106
32005	106
33001	111
33002	107
33003	103
34001	106
34002	128
34003	1,042
35001	107
35002	493
35003	247
35004	700
36001	125
36002	1,622
37001	1,523
37002	886
38001	1,484
38002	1,971
38003	2,064
39001	4,843
39002	3,951

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