Identifying Native American Populations at Risk of Exposure to Heavy Metals in Utah, Arizona and New Mexico

by

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Abstract

Previous literature has established the connection between drinking water contaminated by arsenic (As) and uranium (U) from uranium mines to serious health complications in Native Americans (Hoover 2018; Lin et al. 2020; McGraw, Fox 2018). Despite lack of public data directly measuring heavy metal levels in drinking water on tribal lands, there is some success using proxy variables in a GIS- MCDA model to assess the potential risk of exposure to harmful contaminants on tribal land (Lin et al. 2020). This project uses a Multi-Criteria Decision Analysis approach to combine unconventional pathways of potential exposure to As and U in drinking water for Native Americans living in Utah, Arizona and New Mexico. In addition to GIS-based research, this project uses institutionalist theory to analyze political foundations and cultural factors potentially increasing the exposure to contaminated drinking water for Native Americans. Institutions are important channels for political power and sovereignty, there is a long history of institutions in the U.S. being used against Native American sovereignty to profit off of the extraction of U and hard rock in the Southwest (Diver 2018). This project offers evidence there are political, social and cultural factors directly impacting the level of exposure to contaminated drinking water Native Americans in the Southwest experience by using advance GIS methods. The results from the Multi-Criteria Decision Analysis indicate county subdivisions with a high population of Native Americans are also in areas with a high potential exposure to arsenic and uranium.

Introduction

Throughout the Southwest, Native Americans are disproportionately affected by health issues (Hoover 2017: Lin et al 2020), lack of access to running water (US Water Alliance, 2018), and are more exposed to heavy metals from uranium mines (Hoover 2017). There are many co-occurring factors contributing to these issues, from intricate institutional procedures in environmental regulations, historically discriminatory public policies, high rates of poverty among tribal residents, and a lack of adequate water treatment infrastructure—all affect the water quality and health of Native Americans in the U.S. There is a history of injustices and discrimination Native Americans have experienced in the U.S. this history has impacted the health of Native Americans and contributed to environmental injustices on tribal land (Lewis 2017).

Native Americans rely heavily on natural water sources, locally grown foods and medicine (Lewis 2017), posing a significant point of potential exposure to them on their lands. In order to determine where contamination is more concentrated on native lands, how to effectively reduce pollution from U mines and the main pathways of exposure to contamination. It is important to understand the multiple factors having led to the devastating effects of environmental racism. There are environmental, political, social and cultural factors all contributing to a higher rate of exposure to heavy metal contaminants and the associated health risks (Lewis 2017). The intersection of multiple factors outside of the proximity to U mines and contaminated drinking water complicates research studies discerning water quality and Native American health issues associated with As and U.

Water pollution caused by U mining in the West has been associated with a myriad of health complications in Native Americans including hypertension (Hund et al. 2015), cardiovascular disease (Harmon et al. 2017) to many different cancers (National Cancer Institute) and immune changes (Erdei et al. 2019; Hund et al 2015). In literature, the negative effects of As and U are well documented in humans, animals and environment (Hoover, 2018) mostly due to the solubility of As and U. The legacy of mining in the Southwest has historically released U, As and other heavy metals into the natural environment through multiple pathways, most common are dust and drinking water (Lin et al. 2020), though both As and U are documented as naturally occurring in Southwest landforms (Longworth 1994).

The main research question of this project is how research can use GIS tools to identify Native American populations most at risk of exposure to As and U in Arizona, Utah and New Mexico. To answer the first part of the research question, we use Exploratory Spatial Data Analysis (ESDA) to locate county subdivisions with high populations of Native Americans. To answer the second part of the research question, we use three criteria to identify sites at risk of exposure. The three criteria are proxy variables used in previous research, the first criteria is identifying locations close to uranium mines, the second is identifying locations close to primary and secondary roads, lastly we want to identify locations close to surface water.

According to previous literature, a notable source of exposure to As and U is unregulated water sources (Hoover et al. 2017; Lin et al 2020; Lewis 2017) and the proximity to U mines because of the concentration of heavy metals within 6-10km (Hoover et al 2018). There is some inconsistency in the literature as to how many people rely on unregulated water sources (McGraw, Fox 2018: Lin et al 2020) but it is well established Native Americans and rural residents have more restricted access to regulated sources compared to most Americans (Lewis et al. 2017; US Census Bureau).

An unregulated water source is defined as "a water supply that does not meet the criteria for classification as a public water system: a set of pipes or other conveyance system with 15 or more service connections or provides water to 25 or more people at least 60 days a year." (Hoover 2018). Unregulated sources are difficult to manage and monitor by regulatory agencies in the U.S. mostly due to their remoteness. The general purpose of this creative component is to fill in the gaps in research on why Native Americans are more likely to use unregulated water sources and have a higher rate of exposure to heavy metals.

The following document begins with a literature review on the issues in political science that contribute to poor water quality and exposure to As and U on tribal land. This literature review uses a historical institutionalist approach to understanding policies and practices in the U.S. federal government relating to water quality and Native Americans. The literature review also covers a background on health issues related to As and U or poor water quality observed in Native Americans. A review on GIS methods for risk assessments on tribal lands and methods to identify patterns in the distribution of populations are also included. Emerging technological developments in water quality and summary of organizations working to improve water quality on tribal lands are included at the end of the literature review. All methods, data and processes for the Exploratory Spatial Data Analysis (ESDA) and Multi-Criteria Decision Analysis (MCDA) are outlined under the Research Design section. Results and discussion for the fuzzy analysis and weighted overlay are under the Fuzzy membership and Euclidean distance sections. Finally, limitations and further research are the last sections of the document. All terms related to Native American are referred to in this paper as being both formal and informal native lands in the U.S. and generally mean the designated lands belonging to federally recognized tribes. This paper also uses terms such as Indigenous, Native Peoples, Native Americans, First Nations to refer to those living on tribal lands and belong to a Native Tribe whereas individuals who do not belong to a tribe are referred to as non-native people/s.

Literature

Water contamination and unequal access to public water systems (PWS) are important issues for the U.S. for First Nations (McGraw, Fox 2018) and policymakers. "Closing the Water Gap in the U.S.", a report funded by Dig Deep and the U.S. Water Alliance, uses quantitative and qualitative studies across different states, races and household types to document the gap in access to safe and reliable water. According to the report there are several states having seen population increases without increasing access to water resources between 2000 and 2014 (McGraw, Fox 2018) which has the potential to pose issues in drinking water quality in PWS. The Navajo Nation is one of the most extreme examples of the gap in access to public water systems in the U.S. (McGraw, Fox 2018), this nation is the most populated tribal area as well as the largest in America.

The Uinta and Ouray Reservation covers 4.5 million acres in Utah in the northwest Colorado Basin. Majority of the Native American population in all three states are concentrated on or near tribal land. All terms related to Native American are referred to in this paper as being both formal and informal native lands in the U.S. and generally mean the designated lands belonging to federally recognized tribes. As of 2017, there are 67 designated water hauling stations in the Navajo Nation (Hoover et al. 2017) but for an area of 70,000 km^2 and a population of over 173,000 it is not an adequate number to serve Native residents of the Navajo Nation (Hoover et al. 2017). Residents in the Navajo Nation use 2-3 gallons of water per day compared to an average consumption of 88 gallons of water per day by most Americans (McGraw, Fox 2018). A lack of PWS in the Navajo Nation, combined with high rates of poverty, unemployment, remoteness and decreasing surface or groundwater water are all factors contributing to poor public health on tribal lands.

Though drinking water insecurity is widely documented, there is some inconsistency in the literature as to what percentage of Native Americans lack access to regulated water sources; the most recent report using data from the U.S. Census Bureau estimated 5% of Native households do not have indoor plumbing or running water compared to 0.3% of white households in the U.S. (McGraw, Fox 2018). Navajo residents without access to PWS must haul water for bathing, cooking and drinking or otherwise rely on unregulated sources; the authors explicitly state they expect the percentage without access to PWS to be much higher than the reported figure (McGraw, Fox 2018). In some literature, up to 30% of Native Americans do not have access to PWS and rely on unregulated water sources (Lin et al. 2020), other literature cites somewhere between 7.5%-12% lacking access (Hoover et al. 2017). Despite a concrete statistic, the negative health, cultural and political impacts are widely documented throughout the literature.

Current literature identifies inhalation via windblown dust and exposure in drinking water (Hoover et al. 2017) as the two main pathways of exposure to heavy metals (Beamer et al. 2014; deLemos et al. 2009; Hoover et al. 2019). As and U are water soluble compounds, making them extremely difficult and costly to remove from a contaminated environment, their solubility allows them to impact human health through multiple different pathways (Lin et al. 2020). Abandoned U mines have contaminated groundwater and wells making untreated water very unsafe—though for some residents this is the only water they have access to in their area (McGraw, Fox 2018).

There are limited studies connecting U mining to widespread water contamination, one study in particular observed a higher frequency of Maximum Contaminant Level (MCLs) exceedance in unregulated water sources closer to U mines (Hoover et al. 2017) providing some evidence of a relationship between proximity to U mine and higher levels of As and U in drinking water. As and U are identified as contaminants of concern and are observed in water quality samples of groundwater on Native American Reservations throughout the Southwest (Hoover et al. 2017; EPA 2006;). Water quality sampling on Native Land has identified other harmful contaminants in surface water associated with increased risk of diabetes, gastric cancer, thyroid disruption, and lower birth rates (EPA 2020; McGraw, Fox 2018; U.S. Cancer Institute 2020; Hoover et al. 2018).

Institutionalism and Native American Powers

Federally recognized tribal reservations were created after treaty negotiations where tribes relinquished traditional land to the U.S. in exchange for sovereignty within their borders and preservation of their culture, traditions and land (Lewis 2017). The original treaties recognized Native Americans as independent nations within the U.S., as such they were exempt from paying taxes and state laws. The Indian Appropriation Act of 1871 drastically changed the tribal-federal relationship, and made Native American nations wards of the federal government ending their sovereignty. This act granted congress the institutional power to control tribal land throughout the U.S. During the 20th century, the 66th congress made sweeping changes to tribal sovereignty and treaty rights previously granted to Native American tribes. Legislation was passed to shrink reservation land and allow for mining and prohibited the creation of reservations on public lands via executive orders (Lewis 2017). Compensation for mining on tribal land was built into the legislation, and provided tribes with 5% of the net value of mined resources (Lewis 2017). Rather than the provisions going directly to the tribes with the tribal rights, the funds were sent to the U.S. Treasury (Lewis 2017). Recently there has been some reparations paid back to the tribes for this gross mismanagement of funds, from 2009-2016 a settlement of $3.3 billion was reached with over 100 tribes (Lewis 2017). The compensation awarded to tribes does not address the regional issue of the more than 4000 abandoned U mines and requires more direct policy to adequately address.

In public policy, the judicial branch has been vital to the interpretation of blame in environmental disasters and has helped establish the institutional powers tribes possess over their lands. Court cases are the foundation of institutional procedures in the U.S. as judicial ruling and civil cases brought by and against tribes relating to water quality standards (WQS). Judicial rulings could be considered as a mode of change in institutional procedures, as they have the ability to shrink or expand the decisions and policy of tribal leaders regarding environmental regulations both on and off their land (Hoffman, 1990). The institutional procedure within the Clean Water Act (CWA), as well as state policy both dictate the powers and authority tribal leaders hold—both depend on the interpretation of institutional proceedings in the form of laws or precedents. There are several court cases signaling changes to the institution of environmental regulation upholding tribal sovereignty and self-determination for the purposes of WQS under the CWA.

The Montana test is the result of *Montana v. United States* 1981, the results of which limit the civil jurisdiction tribal leaders have over non-Native Americans on non-Native fee lands within tribal boundaries with two important exceptions: first is agreement through consent via contract or lease, and the health and welfare exception (450 U.S. 544), the second effectively gives tribes the ability to exercise their civil authority over non-native lands if there are activities which threaten the health and wellness of Indigenous peoples or their land. Despite these exceptions, the U.S. has retained the ultimate authority over tribal lands barring "Congressional delegation of authority to states under applicable statutes and have also upheld EPA policies treating reservations as 'single administrative units'" (Sibyl Diver, 2018).

In the *1989* case, *Brendale v. Confederated Tribes and Bands of the Yakima Indian Nation* the court upheld tribal self-determination according to the United Nations definition as well as citing the *Montana Test* for its decision. The court reaffirmed tribal sovereignty and upheld the tribe's authority to zone closed fee land within its borders (492 U.S. 408). In the 1996 *City of Albuquerque v. Browner* it is documented as the first time a state filed a suit challenging the EPA approval of WQSs set by a tribe under TAS provisions and confirms the ability of tribes to set more stringent standards than federal minimums (97 F.3d 415). Montana was the next state to file a similar suit in *Montana v. EPA* 1998, the state challenged the EPA's grant of TAS status to the Confederated Salish and Kootenai Tribes. The court again upheld the EPA's approval of the confederated tribes' TAS status based on substantial threats to tribal health and welfare from non-member activities.

When the Penobscot and Passamaquoddy Tribes requested stricter permits for pulp mills impacting tribal waters against state opponents Georgia-Pacific Corp, Great Northern Paper, Inc. and Champion International Corporation. Under section 1331 of Main state law, Maine tribes are subject to all state laws and regulations, this law decreases tribal sovereignty and is common among states. Ultimately the Maine Supreme Court ruled the tribe did not have to comply with the lower court ruling and the tribe was protected under the internal affairs limitation (770 A.2d 574). This example is just one of many cases documenting the conflict within the institution of environmental regulations.

As is documented throughout these rulings, tribal sovereignty and self-determination have been repeatedly upheld against infringement from states, corporations and individuals. There is a strong foundation for the federal protection of tribal sovereignty, and it is the inconsistency of state institutions threatening the ability of tribes to protect their environmental resources both within their borders and outside of their borders (Diver 2018). This poses a great challenge for tribes; they must work within the state and federal institutional framework in order to gain more freedom and choices to regulate their land. According to judicial rulings and previous literature, there is a strong foundation for Tribal sovereignty.

Water Quality Standards

There is a complicated relationship between the U.S. and tribes predating the constitution and the formal U.S. government, it is the result of an institution with policies controlling tribal sovereignty. Most of the conflicts over tribal land ownership today began after the drastic changes to the property system on Reservations by the 1887 Dawes Act. The relationship between the U.S. and Native Americans is paternal, the U.S. government holds the title to tribal lands in lieu of the Tribe in trust (Sibyl Diver, 2018). The Dawes Act allows the U.S. government to hold power over "surplus" tribal lands and infringes upon tribal sovereignty by selling land to non-natives. Before the Dawes Act, Native Americans held 138,000,000 acres of land but after the Dawes Act, they held 48,000,000 acres. About 90,000,000 acres were sold to non-native people by the end of the policy in the mid-20th century (Corn tassel, Witmer 2008).

This institutional policy of parceling land has created a checkerboard of land ownership on reservations, which negatively affected the ability of tribes to enforce environmental regulations but was remedied by the 2016 CWA revision. Discriminatory practices in water infrastructure development and policies have also greatly impaired the choices tribal leaders can make today regarding infrastructure, monitoring and treatment of their waters (Lewis 2017). Funding behind water infrastructure development has declined from 63% in 1977 to 9% in 2018, leaving communities unable to develop proper infrastructure, and still not able to do so due to lack of federal support (McGraw, Fox 2018). Reservations do not have funds required to build or expand water infrastructure on their own, without public water systems it creates public health issues threatening the safety of residents on the reservation, effectively impairing the tribe's ability to gain TAS under section 518 of the CWA (Diver 2018).

Within the U.S. federal institution, it is important for tribes to be able to implement their own environmental regulations in addition to having the resources to enforce them within their borders in order to protect the environment as well as the health of tribal members. The United Nations defines self-determination as the right of indigenous people to determine their political status, freely pursue economic, social and cultural development and is an important part of environmental regulations. This definition could include the free establishment of traditional indigenous governance and other traditional practices (Diver 2018).

What does self-determination look like within institutionalism? What was originally the Federal Water Pollution Control Act of 1948 is now the CWA and is recognized as the foundation of water quality regulation. The CWA provides federal support for monitoring and treatment of drinking water sources or public water systems in the United States. Treatment as a state provision in section 518 of the CWA, provides tribes the authority to establish their own WQS under the CWA. Once eligible, WQSs established by tribes must be approved by the Environmental Protection Agency (EPA) before they can be enforced on tribal lands (Sibyl Diver 2018). The criteria to qualify for TAS under section 518 of the CWA excludes many tribes because they must be federally recognized, have a governing body to carry out "substantial governmental duties and powers" (Diver 2018), appropriate jurisdictional authority over the regulatory area, capable of carrying out program functions (Diver 2018). Despite needing to qualify for authority under section 518, tribes are able to apply for TAS under the potential for future environmental pollution (941 F. Supp. 945).

One of the main issues with the Treatment as a State provision in the CWA is a tribe must be federally recognized to draft WQS to be reviewed by the EPA. In the U.S., there are 574 federally recognized tribes, only fifty-four of these meet the requirements to be included in the treatment as a state provision and forty-four tribes have approved WQS. This means only 10% of all federally recognized tribes in the U.S. have been able to adopt their own WQS (Diver, 2018). It is still possible to instate some environmental protections using a different section of the CWA, criteria in section 106 allows 75% of federally recognized tribes in the U.S. to gain TAS in order to receive funding for water pollution control efforts (EPA, 2020). Section 106 does not provide federal support for building water treatment infrastructure nor support for tribes to legislate or enforce WQS.

The Safe Drinking Water Act (SDWA) is the second foundational policy regulating water pollution and delegates authority to the EPA to create contaminant standards for each identified contaminant (Conroy-Ben, Crowder 2020). This regulation defines primary and secondary drinking water standards by setting max concentration levels according to human health concerns for each contaminant. Primary regulations require monitoring and reporting of drinking water systems along with public notification in the case of a maximum contaminant level or treatment technology violation as soon as it occurs (Conroy-Ben, Crowder 2020).

Developments in water quality issues

The lack of regulated water sources and public water systems on tribal land is as much a political issue as it is an environmental one, without federal funds to expand public water systems on tribal land it is unlikely these nations will be able to expand public water systems to improve public health for Native Americans. Previous research has established a link between a lack of access to PWS and higher mortality, poverty, and unemployment rates could be solved through political action to expand public water systems for Native Americans living on reservations (McGraw, Fox 2018; Hoover 2017). In 2005, the Natural resource Protection Act was passed by the Navajo Nation council effectively banning U mining within tribal borders. There have been very few new policy developments in drinking water improvement on tribal lands but there is a growing number of non-profits and non-governmental organizations working to increase access to safe drinking water for Native Americans. In 2017 the first Mni Ki Wakan (Water is Sacred): World Indigenous Peoples Decade of Water Summit was held and is a promising first step towards water quality improvements for indigenous people worldwide (McGraw, Fox 2018).

The International Association of Plumbers and Mechanical Officials started a plumbing certificate program in the Navajo Nation (McGraw, Fox 2018) to fill the gap in infrastructure repair for Navajo residents. Dig Deep started a Water, Sanitation and Hygiene program in the Navajo Nation in 2016 to help provide clean running water to residents (McGraw, Fox 2018). Grants and low-interest loans are available for tribal regions in the USDA Rural Development program to construct or upgrade private wells (McGraw, Fox 2018). Another important project is working specifically with Native Americans in Utah, New Mexico and Arizona. The Navajo Water Project has been providing safe running water within the Navajo Nation through a variety of different ways to residents who have historically hauled their water. As of 2018, the Navajo Water Project has provided safe running water for affordable costs to 220 households (McGraw, Fox 2018).

Empirical Studies Using GIS

Despite the challenges in conducting water quality research on tribal lands, it is vital to improving health and decreasing exposure to high risk contaminants of Native Americans in the Southwest (Lin et al. 2020). Geospatial analysis is difficult due to the lack of consistent water quality sampling on tribal lands, or easily accessible data sources (Lin et al. 2020). Current popular or preferred methods for environmental risk assessment require detailed data with specific parameters. These challenges make risk assessment difficult as well as tedious (Lin et al. 2020), one solution for these challenges in literature is to create proxy variables for the GIS models. In literature, researchers used up to eight proxy variables in their GIS model to represent all possible points of exposure to heavy metals.

There are many GIS tools with the capability to assess areas at risk of potential drinking water contamination, in this case using an accurate and reliable model is important for accuracy of the risk assessment. GIS multi-criteria decision analysis (GIS-MCDA) is used in current literature for risk mapping and vulnerability assessments when key geospatial data is missing (Lin et al. 2020). In a recent study, authors used a GIS-MCDA approach with fuzzy theory to determine areas at high risk of exposure to As and U in the Navajo Nation (Lin et al. 2020). The result of this approach is one map with aggregated proxy variables showing the area's most vulnerable to potential heavy metal contamination based on the proximity to U mines, roads, and proximity from drainage areas along with five other proxies (Lin et al. 2020). There are many examples of this approach being used for a range of different GIS focused studies in the literature, popular uses are for site suitability analysis, risk mapping and vulnerability assessment (Lin et al. 2020).

There are few studies having measured the occurrence of As and U in unregulated water sources in the United States (McGraw and Fox, 2018), let alone in the Southwest. Previous literature (Hoover et al. 2017) determined the frequency of As and U in unregulated water sources used by residents in the Navajo Nation according to the maximum contaminant level defined in the national primary drinking water regulations (NPDWR). This study found 55.1% of unregulated water sources in the NN were contaminated with As and 15.1% contained a frequency which exceeded the MCL (Hoover et al. 2017). The frequency for U was much higher in the Navajo Nation and found in 75% of unregulated sources and 12.5% of tested sources exceeding the MCL according to the NPDWR (Hoover et al. 2017). Because As and U are associated with the same contaminant pathways, the frequency of both occurring in the same location was found in 49% of unregulated water sources; 3.9% exceeded both MCL's (Hoover et al. 2017).

Literature mentions a concentration of homes without access to PWS near abandoned mine sites in the Navajo nation (McGraw, Fox 2018) this increases the risk of exposure through unregulated water sources. A risk assessment of As exposure conducted on Hopi lands within the Navajo Nation had similar findings (Blohm et al. 2021) and observed higher rates of cancer in individuals with exposure to As and U. Preliminary results of tap water and urine samples indicate there is an increased risk of lung and bladder cancers for both men and women due to consumption of tap water (Blohm et al. 2021). There are indirect opportunities for exposure to heavy metals specific to Native American culture; political discrimination and environmental racism affect the level of exposure Native Americans experience in drinking water (Lewis 2017).

Research Design

This project will focus on the population of Native Americans by county subdivisions in Arizona New Mexico and Utah to assess the populations at risk of potential exposure to heavy metals. Together these three states have a total Native American population of 513,956 in the 2017 ACS. There are 13,387 U mines in the area, 1,695 are within tribal boundaries. There are two primary tribal nations within the study area: the Uinta and Ouray Tribe and the Navajo Nation. The Navajo Nation is 16 million acres (Indian Health Service 2017) and is divided into five administrative agencies covering parts of New Mexico, Arizona and Utah. Elevation in the

Navajo Nation ranges from 940 to 3153 m, it is a sparsely populated arid desert, and many residents live in geographically remote areas (McGraw, Fox 2018: Lin et al 2020).

It is important to calculate a sensitive and statistically significant rate of Native Americans in the study area, to determine the appropriate unit of analysis, we compare population rate by county and county subdivision. County subdivisions with census county divisions (CCDs) represent community areas focused on trading centers or major land use areas and are the unit of subdivision in Utah, Arizona and New Mexico. These areas conform to groupings of census tracts or block numbering areas and are focused on grouping local institutions and economies. An important feature of CCD's is they center around an incorporated place, making them ideal for identifying Native American populations. CCD's delineate boundaries according to important areas of land ownership, such as Native American reservations. Population rate by county is compared to county subdivision because county subdivisions are an atypical unit of measurement for population density, but could increase statistical significance for population density of Native Americans.

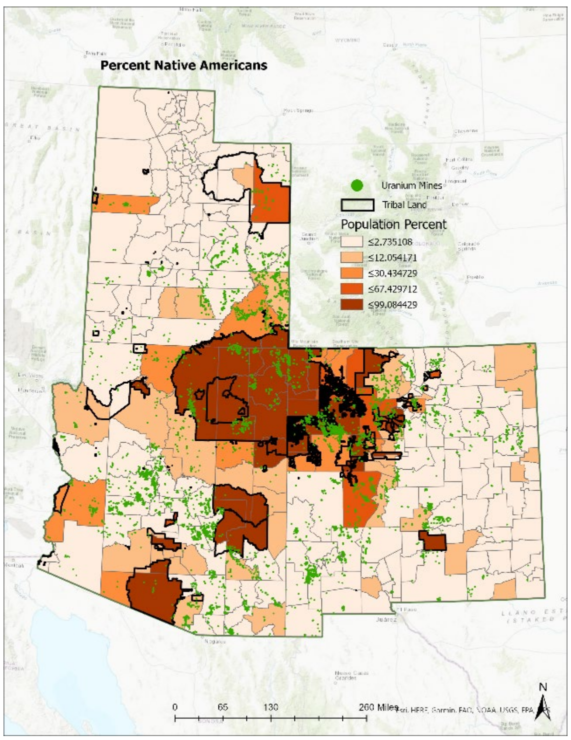


Figure i: *Population percent of Native Americans, location of tribal lands and uranium mines*

Native Americans are facing public health and environmental crises, and there is a lack of research investigating the cultural, social and political variables affecting the exposure of Native Americans in this region. Without these factors, research misses distinct exposure patterns to heavy metals from traditional practices on tribal lands (Lewis 2017). Another gap in drinking water quality research is a lack of resources within tribal communities to consistently collect water quality data. To date, there are no water monitoring stations able to cover large areas of land making monitoring on the Navajo Nation difficult (Lin et al. 2020).

It is important for researchers and the general public to have a wider understanding of what factors negatively affect the health of Native Americans, their lands and how to remedy these issues. There is a small but growing body of literature studying the relationship between water quality on tribal lands and health risks in the U.S., most are focused on the quantitative or geographic factors affecting water quality (Lin et al 2020). Determining which GIS-based models are useful and relevant to water quality research and conducting small sampling studies are important in the absence of official data. Historically, there is a lack of improvements in drinking water quality or increased access to public water systems for Native Americans, current emerging developments in water security for Native Americans is discussed later in the paper. Determining environmental injustices are not a new trend in research, the negative health effects of heavy metal contamination is well established along with its presence in tribal water supplies (Hoover 2018; Hoover 2017; Blohm 2020; McGraw, Fox 2018).

The structure of the state and federal institutions, as well as judicial rulings determine what tribal leaders can and cannot do in terms of WQS and regulations on their land. This project helps close the gap in current research by including the institutional and political processes in tribal WQS along with cultural factors contributing to potential exposure. A contribution to GIS-based research is made by including population density in previously established risk assessment methodology.

Research Questions

This project covers a broad issue in drinking water quality and incorporates many factors leading to poor drinking water quality in tribal communities. To explore the relationship between population density and U mines this project asks two questions: 1. What is the structure of institutional power of environmental regulation in the U.S.? 2. What clusters of Native American populations are most at risk for potential exposure to As and U in the study area? The objectives of this project are to identify areas at high risk for heavy metal contamination and outline the institutional process of tribal WQS for a better understanding of the what factors contribute to the high heavy metal exposure rate in drinking water among Native Americans.

This research could be used to improve public policy based on an evaluation of institutional barriers tribal leaders face instating environmental regulations on tribal lands. The hypothesis tested of this project is looking a difference in statistical significance of spatial autocorrelation in global and local indicators in population rate of Native Americans per county subdivision compared to population rate per county. We predict there will be a positive spatial autocorrelation in the distribution of Native American populations in the study area, and county subdivisions will be more statistically significant compared to population rate per county. A positive spatial autocorrelation in the population distribution of Native Americans means there will be groups or clustering among the population of Native Americans throughout Arizona, Utah and New Mexico. Ultimately, we expect there will be a pattern in the population distribution.

Methodology

An important facet of drinking water quality is the population exposed to contaminated sources. There is no official documentation of how many people use unregulated water sources in the study area according to previous literature (Hoover 2017: Hoover 2018). We cannot directly measure the Native Americans use of potentially contaminated water sources, instead, we used the total Native American population density per county subdivision combined with proximity to uranium mines, proximity to roads, and proximity to streams as a way to assess where potential sites of contamination in relation to population clusters. Clusters are identified in the study area by performing a test of local indicator of spatial association (LISA) with the population rate of Native Americans.

Due to the lack of spatial data measuring groundwater contamination for all locations of tribal boundaries, there is a major problem for determining water quality analysis on tribal land. In order to conduct analysis without direct variables measuring presence of As and U in drinking water, we used proxy variables in a Geographic Information Systems multi-criteria decision analysis (GIS-MCDA) model to determine the highest risk sites in the study area. The research design is based on methodology used in previous literature, where the risk was assessed using a GIS MCDA, with fuzzy logic (Lin et al. 2020). The methodology for this project uses an overlay with fuzzy membership for layers representing potential contamination identified in results from previous literature, while including population density in the model as novel considerations in risk exposure.

Model Approach Using GIS-MCDA

This project uses a novel approach from previous literature to better understand the risk of exposure to As and U contamination of Native Americans living in Arizona, New Mexico and Utah. The methods used are somewhat complex and utilize fuzzy logic, the variables in the model are proxy variables due to the lack of observable water quality data Native American lands. The methodology used in Lin et al 2020 identified the three "primary risk" factors as the proximity to U mine, proximity to roads, and proximity to downslope drainage. Another key risk factor is landform and topography where valleys and lower slopes are expected to accumulate more pollutants (Lin et al 2020).

Three factors are used to represent primary risk for this project; proximity to major streams, U mines, primary and secondary roads, with the addition of the population clusters determined in the LISA analysis. Primary and secondary roads database were obtained from the US Census Bureau, major streams in the U.S. collected from ArcGIS Hub, location of U mines in the U.S. were obtained from the EPA and the population by race data is provided by the US Census Bureau American Community Survey (2017) 5-year estimates. The main objective for site selection analysis in this project is to identify areas with a high potential risk of exposure to As and U. To accomplish this, we use important pathways of contamination transportation from literature. These criteria for analysis include roads (EPA 2008), surface water (Lin et al. 2020), and U mines (Hoover 2017; Harmon et al. 2017). There are some initial steps to prepare the datasets before they can be aggregated in a weighted overlay and fuzzy overlay.

To identify sites with a high potential to be exposed to As and U in the study area, the Euclidean distance from uranium mines, primary and secondary roads, and surface water is calculated. Once these layers are aggregated using weighted overlay, the output will show areas that are closest to each exposure pathway. Euclidean distance describes each cell's relationship to a set of sources based on the straight-line distance, in this case we calculate the distance from each potential contamination pathway. The sources used for calculating the Euclidean distance are uranium mines, primary and secondary roads, and surface water. The Euclidean distance tool derives the true Euclidean distance as the shortest distance to each cell center from each cell center by calculating the hypotenuse and the x and y axes of a triangle (ArcGIS: Understanding Euclidean distance analysis). If the Euclidean distance is less than the maximum distance from a cell, the value of that cell is assigned to the cell location in the output layer (ArcGIS: Understanding Euclidean distance analysis).

Weighted overlay tool aggregates each reclassed Euclidean distance layer into a final raster map, this tool has the ability to give one layer more influence on the final result, the total weight must add up to 100%. Weighted overlay uses Boolean logic limiting the inclusion of uncertainty into the model and combines feature layers with crisp classes. Using previous research (Lin et al. 2020), proximity to U mines is the most important factor in determining level of exposure to As and U; this layer is weighted at 50%. The layers for roads and streams are each weighted at 25%. There are some issues with weighted overlay mentioned in literature, mainly this method assumes the input data layers correctly represent reality which is not always the case. The result of the aggregated criteria layers and the relationship to locations at risk and LISA clusters is further explored further in a later section of this paper.

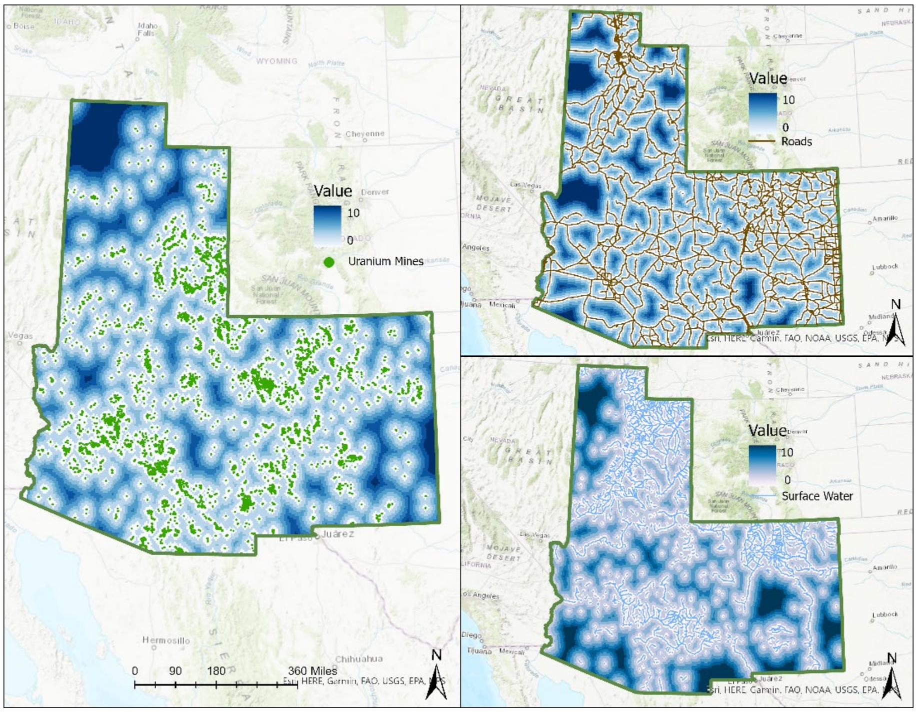


Figure 1: *Euclidean Distance layer*

The other option for a GIS-MCDA approach is using fuzzy logic and aggregates the fuzzy membership layers together, this is another way to aggregate criteria layers for site selection. Fuzzy logic is distinct from Boolean logic, it is based on degrees of truth whereas Boolean logic is based on yes or no, true or false, 0 and 1. For problems including uncertainty, fuzzy logic is appropriate because it accounts for uncertainty and the possibility input layers will not represent reality. This is helpful for this project, because there is a good deal of uncertainty using proxy variables. Classes in Fuzzy logic are inexactly defined classes known as fuzzy sets, these sets do not have sharp boundaries but assign all cells with a degree of membership from 0 to 1, this range is known as the fuzziness.

There are various memberships researchers can use to derive the fuzziness of locations, MS small and small, MS large and large, linear, and near. Each membership type returns a different output and are appropriate for different types of data, near membership shows suitable sets in the middle range of the data, as values decrease or increase from the mid-range there is less likelihood they will be part of the suitable set. Linear membership decreases or increases at a constant rate for large and small values. MS large and MS small return values greater than the mean or less than the mean respectively. Small and large membership types show either smaller numbers or large numbers as being most likely to belong to a fuzzy set.

Small membership type is most appropriate for situations where none of the values are less than zero and smaller numbers are the fuzzy set. In this case the reclassified Euclidean distance layers are on a scale of 1-10, 1 is closest to the source and 10 is locations farthest away from the source so small fuzzy membership is the most appropriate membership type based on data classification, previous literature also uses small membership type (Lin et al 2020). Once the fuzzy membership using small membership is derived from performing fuzzy membership function in ArcGIS Pro, we can use Fuzzy overlay with and function to return the value of the sets the cell location belongs to and identifies least common denominator for membership according to the input criteria. For this project we selected locations with at least 0.5 or greater possibility of being suitable for all criteria outlined in the project objectives. The fuzzy overlay returns smoothed classes and shows less surface is at risk of exposure to U and As based on the likelihood of the location being a member.

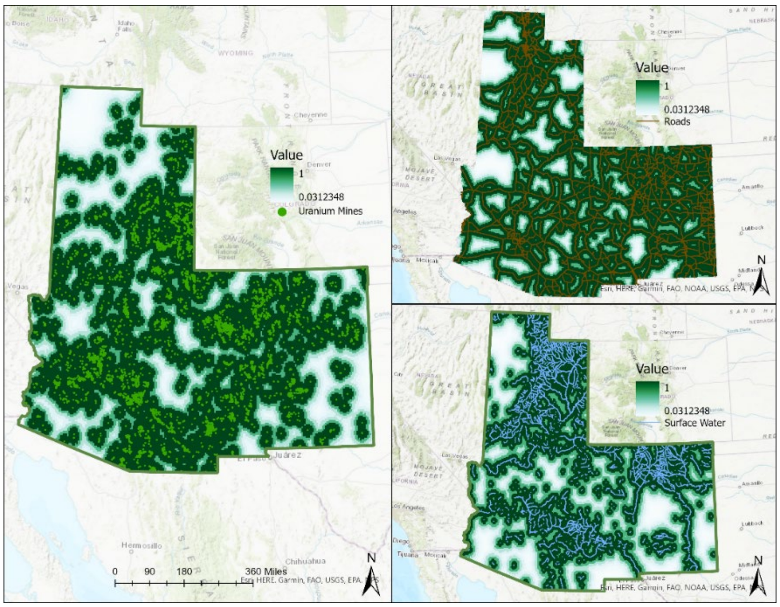


Figure 2: *Fuzzy membership of each Euclidean distance layer before aggregation*

Spatial Autocorrelation in Native American Population with ESDA

Determining spatial autocorrelation is important to determine if there is a pattern in the distribution of Native American population in the three states. To perform spatial autocorrelation and test for population clusters, the 2017 population by state American Community Survey (ACS) was used because it is the most recent ACS with all county subdivisions in Arizona, Utah and New Mexico. To visualize the data in GeoDa and ArcGIS Pro, the ACS table is joined to the county and subcounty TIGER/line files. We expect there will be a pattern in the population distribution, and county subdivisions will have a higher statistical significance compared to population per county. To test this hypothesis, we first calculate the raw and Empirical Bayes (smoothed) population for county and county division to estimate the population using a K-nearest neighbor and Queen matrix (Anselin 2020).

The Empirical Bayes method is used to correct spurious outliers, effectively improving the precision of the risk estimation (Anselin 2020). Spatial weights determine neighbor relation in a matrix (Anselin 2020), a first order queen weighted matrix and a k-nearest neighbors weighted matrix were used to calculate the population rates and establish a neighbor matrix; it is important to compare both weights to ensure robust results. For the final weight, a queen contiguity-based weights matrix is recommended in literature, this weight yields more neighbors for irregular polygons and can deal with potential inaccuracies (Anselin 2020). The results of the queen weighted matrix are six neighbors; raw and Empirical Bayes rate of Native

American population are calculated with queen and nearest neighbor weight in order to compare, and ensure robustness of results (Anselin 2020).

Conducting analysis of spatial autocorrelation provides a "statistic for each location with an assessment of significance as well as establishes a proportional relationship between the sum of the local statistics and a corresponding global statistic" (Anselin 2020). Table 1 shows the results of the p-value and z-value from the global Moran's I for population by county and county subdivision. Using a significance level of 5% (0.05) to assess the significance of the p-value for both variables, it is clear there is a pattern in the population distribution of Native Americans at both spatial units of analysis. The pseudo p-value was calculated using 999 permutations, confirming a pattern in the spatial distribution of Native American population in the three states, the population distribution is not random.

The p-value for both County and county subdivision have the most extreme pseudo p-values possible, indicating none of the permuted data yielded a statistic higher than the p-value in the actual data (Anselin 2020). Since we are interested in determining the best unit of analysis for population distribution, we can look at the z-value to determine which variable is more significant based on the highest z-value. In this case, population per subdivision has more significance compared to population per county, indicated by a higher z-value.

Table 1: *Global Moran's I Hypothesis Test*

Unit of Analysis	**P-value**	**z-value**
County	0.001	10.06
County subdivision	0.001	17.79

To determine clusters of Native Americans, two maps are generated: LISA cluster map and LISA significance map. These maps show the clusters identified in the Local Moran's I scatterplot (Figure A), which plots the smoothed population rate with a queen weight on the x axis, and the weighted average of the neighboring values to the smoothed population rate on the y-axis. The scatterplot separates outliers into four categories based on their position in the distribution; High-High (HH) clusters are points in the distribution with high values surrounded by other high values in the top right quadrant of the scatterplot. High-Low (HL) are high values surrounded by lower values in the lower right quadrant. Low-Low (LL) clusters are low values surrounded by other low values in the bottom left quadrant, and Low-High (LH) are low values surrounded by high values in the top left quadrant.

Rates not in one of these four groups are not significant. The plot shows the linear fit in the distribution, the red line in the scatterplot corresponds to the Moran's I value which is 0.599 noted at the top of the graph, and is influenced by the outliers in the HH quadrant. There are several outliers about three deviational units above the mean, in the LL quadrant, the points are bunched together and there is less of a spread in the population rate on the low end of the distribution. In order to determine clusters in population rate we calculate the Local Indicators of Spatial Autocorrelation (LISA), similar to the global Moran's I statistic LISA returns a pseudo p-value but this time there is a value for each location rather than the entire distribution. The LISA statistic is constructed from the average of an observation's neighbors, this statistic is sensitive to the effect of outliers (Anselin 2020). References to high and low are relative to the mean of the population rate and do not represent absolute significance (Anselin 2020). Before we can fully assess geographic significance, 999 permutations for each observation using a random seed to allow replication were calculated, this step assesses the sensitivity of the significant locations to the number of permutations. No changes in the significant locations were observed.

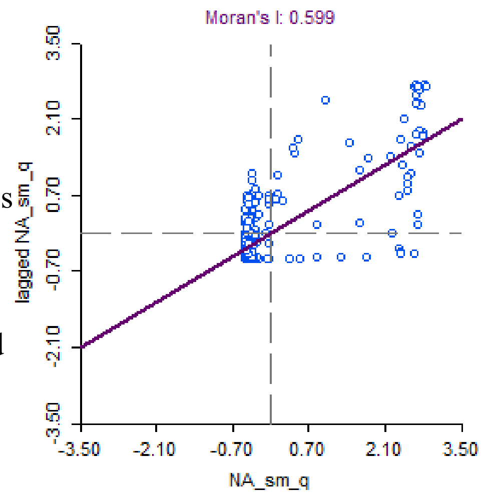
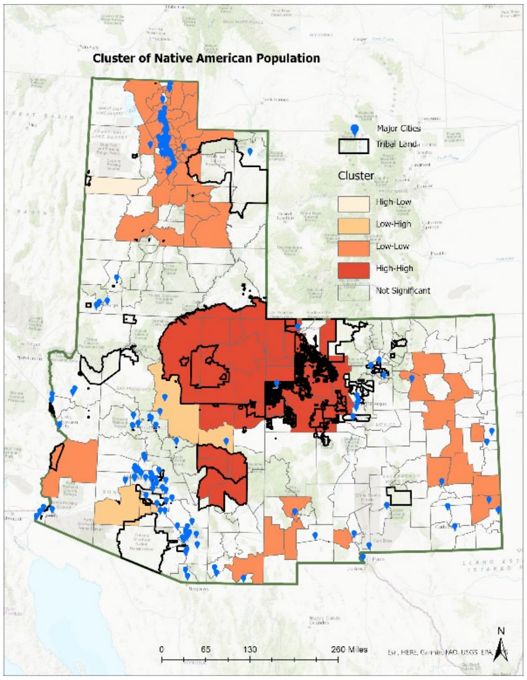


Figure A: *Global Moran's I scatterplot show HH, HL, LL, LH population outliers*

To further assess sensitivity of clusters and solve the issue of multiple comparisons or false positives (Anselin 2020) by comparing significance levels smaller than the typical 5%. At significance level 0.05, there are fifty-five significant clusters; for 1% there are twenty-one significant clusters; at p 0.01 there are 26 significant clusters. An important note about cluster analysis is significant clusters shown on the map are the core of clusters including surrounding neighbors, the cores and neighbors are illustrated in Figure B. Figure C shows the geographic locations of LISA clusters; the HH population rates of Native Americans, symbolized with dark orange, are located mostly in the center of the map. These county subdivisions are located within Navajo Nation borders, San Carlos and Fort Apache Reservation in Arizona. The HL population cluster is located in the county subdivision containing the Goshute Reservation in Northwest Utah.



The LISA results confirm our assumption, higher population rates of Native Americans per county subdivision will be on or near reservations in the study. This observation could be attributed to the original treaties between the U.S. and Native American tribes which forced indigenous people onto designated lands throughout the United States. An interesting observation from this map is there are several tribal lands that do not overlap with significant LISA clusters but have high population rates in the smooth population rate map. There is no explanation in literature explaining why we would see this, but this region has a relatively low population density so some areas may simply have a low population density of Native Americans.

Figure C: *LISA Cluster map with major cities and tribal land symbolized to show the spatial relationship between population clusters, tribal land and cities in the study area.*

Euclidean Distance

There are three main pathways of exposure mentioned in literature, the most important is proximity U mines. The closer in proximity to U mines, the higher the risk of exposure to As and U (Hoover 2017; Hoover 2017; Lin et al. 2020; McGraw, Fox 2018). The other two main pathways of exposure mentioned in literature is proximity to roads, and exposure via drinking water from unregulated sources. Heavy metals can be concentrated in dust moved around through traffic on paved and unpaved roads (Lin et al. 2020). Proximity to an unregulated source of water is mentioned in literature (Hoover 2017; Lin et al. 2020), since there is no current national database of private wells it is difficult to accurately represent this pathway in analysis. Previous literature has used proxy variables like landforms and proximity to downslope drainage (Lin et al. 2020) but deriving these variables form Digital Elevation Models (DEM) are difficult to accomplish at this scale. Instead, the Euclidean distance from headwaters and streams is calculated for the entire study area and the fuzzy membership function was used to assign membership for each potential pathway of exposure. The inclusion of primary and secondary roads is based on the primary contamination pathways used by Lin et al. (2020), who establish dust containing heavy metals can be disturbed by traffic on paved and non-paved roads.

Previous studies have determined the dust in homes in the Navajo Nation have similar levels of heavy metal contamination compared to dust on U mine sites (Hoover 2017). The proximity from mines is the most important contaminant pathway (Lin et al. 2020) and represents areas with the highest potential for exposure to As and U in drinking water or dust. The Euclidean distance tool calculates the distance from the source (U mines) to the nearest raster cell. This map shows the concentration of U mines in the study area, majority of U mines are located near population clusters of Native Americans or tribal lands. This is consistent with findings from previous literature which found the most at vulnerable areas to heavy metal contamination in the Navajo Nation are in the north, southwest and southeast (Lin et al. 2020). Euclidean distance from each source was classified on a scale of 1 – 10, one is areas very close to a source and symbolized by white, ten is as far away from the source according to the Euclidean calculation and is symbolized by dark blue. In the study area there are many major streams supplying water to indigenous communities in the absence of public water systems.

Figure 1 shows the layers before aggregation into the weighted and fuzzy overlays, the first three are contamination pathways according to previous literature. Euclidean distance calculated the straight-line distance from each source; streams, roads or mines, to the closest cell. Figure 1 shows the distance from each stream in the area to represent the risk of exposure from using water from an unregulated source, literature has established the cultural significance of local streams for agriculture and drinking water (Lewis 2017), we assume streams on or near tribal lands could be used as drinking water sources or for agriculture.

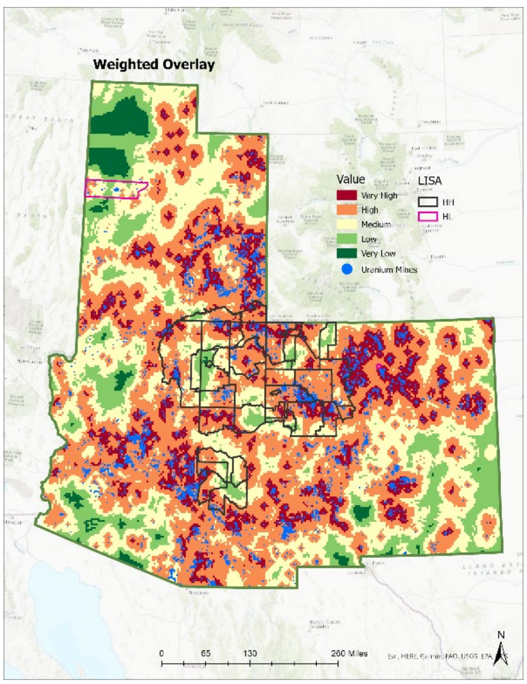


Figure 2: *Weighted overlay map showing areas at risk of exposure to As and U and HH/HL county subdivision clusters*

Figure 2 shows all reclassed layers aggregated using the weighted overlay tool with HH and HL county subdivisions and uranium mines on top of the GIS-MCDA output to show the relationship between LISA population clusters and areas most at risk of exposure to heavy metals. The weighted overlay is consistent with previous literature (Lin et al 2020) and indicates there is potential risk of exposure to As and U on tribal land. The next step will be to perform fuzzy membership tests for each Euclidean distance layer and aggregate these layers using a fuzzy overlay, the output for the fuzzy overlay is smoother compared to the weighted overlay output.

Fuzzy Membership

Each fuzzy membership layer indicates to what degree each cell belongs to the fuzzy set. The higher likelihood the cell belongs to the fuzzy set areas are symbolized by dark green; locations closer to zero are not likely to be at risk of As and U exposure from drinking water, these areas are symbolized by light green or white. Figure 3 shows the fuzzy overlay; the output of this tool is a layer showing the likelihood of each location in the study area belonging to the fuzzy set. There are some issues with precision and sensitivity because the study area is so large, but some careful assessments can be made.

Throughout the study area, there are many areas at risk for potential contamination from U mines in Utah, New Mexico and Arizona. All tribal lands are within areas that have a very high likelihood of belonging to the fuzzy set, the clusters with HH are located in the Navajo Nation, Fort Apache and San Carlos tribal areas are located in areas with a very high likelihood of membership. The zonal statistics indicate locations in the 0.07 - 0.11 fuzzy set have a very low likelihood of being a member to the fuzzy set, whereas areas in the 0.53 – 1 fuzzy set have a very high likelihood of being a member to the fuzzy set.

Category	HH Clusters	Mean	Population (%)
Very High (1 – 0.537)	19	12.2	1.61
High (0.536 – 0.294)	12	5.8	1.23
Medium (0.293 – 0.172)	3	0.7	0.03
Low (0.171 – 0)	0	0	0
Very Low	0	0	0

Table 2: *Zonal statistics for fuzzy overlay and LISA clusters*

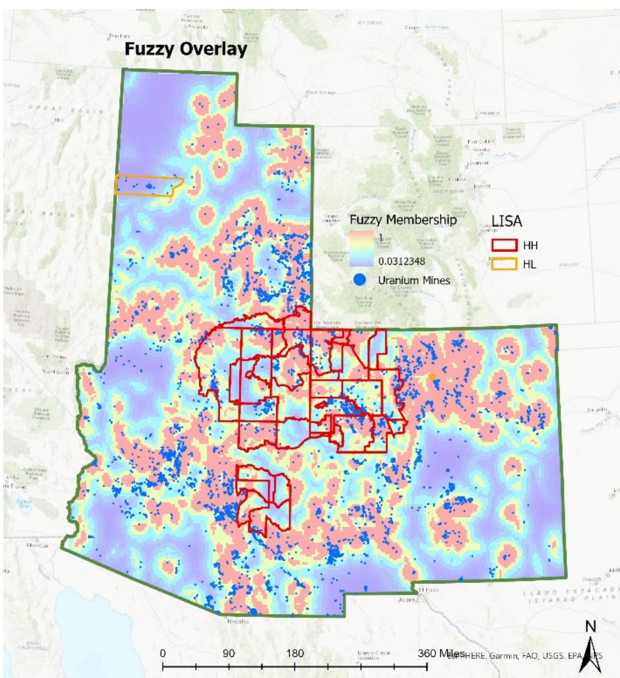


Figure 3: *Fuzzy membership layers aggregated using the fuzzy overlay tool with HH Native American population clusters over the fuzzy overlay.*

It is important to note the fuzzy overlay map in Figure 3 is showing the area's most to least likely to be a membership of the specified fuzzy set. The fuzzy overlay output has smoother classes compared to the weighted overlay, and despite the weighted overlay output assigned more influence to uranium mines, the area's most likely to be a fuzzy set member are somewhat similar to areas most at risk of exposure. This indicates there is some reliability and sensitivity to the fuzzy overlay model. Figure 3 shows the LISA clusters with HH county subdivision populations in red, these subdivisions are within the San Carlos, Fort Apache, Hopi and Navajo Nation. The one HL LISA cluster is a Utah county subdivision with the Goshute reservation, this area is not in a location with a high likelihood of membership to the fuzzy set.

Limitations

There is limited, readily-available data on groundwater quality on Native American land (Lin et al 2020). There are a few important spatial variables left out of this model because they are not readily available, because the GIS-MCDA model is missing these key variables there is some uncertainty in the final results. The location of private wells in the U.S. would provide more information on exposure by population if added to the model. There is no current shapefile or geodatabase showing private well use in the United States, the most recent national database on private well use is from 1990 (Johnson, Belitz 2019).

There is a large burden on researchers to maneuver around the lack of data in this field, this creates an opportunity for novel research but does not help populations without access to clean drinking water. Population rates are likely higher than reported in the 2017 US Census community survey, literature suggests Native Americans are undercounted from 5-20% (Lewis 2017). Because this project looks at a large study area, there is some sensitivity and precision lost in the model despite efforts to negate this. Due to the nature of this project, it lacks the ability, time and funds to conduct an in-depth analysis of As and U exposure among Native American populations in the SW.

Further research

There is a lot of room for further research on this topic, though further research should focus on identifying how many people are using unregulated drinking water sources in the U.S. and creating a current national database of private wells in the U.S., and conduct field sampling to identify frequency of contaminants according to the MCL. Further research should focus on treating contaminated sources on tribal lands, and uses literature to establish public water systems for tribal residents. In addition to treating contaminated sources of drinking water, research should establish water quality monitoring on tribal lands for further studies. Further research should focus on conducting sensitive and reliable GIS-Based risk assessments within tribal borders and county subdivisions with high population rates of Native Americans to coordinate efforts to decrease reliance on unregulated water sources and improve the public health of Native Americans

Conclusion

To better understand why Native Americans, suffer from health issues associated with exposure to heavy metals or lack of access to PWS it is vital to consider the political, cultural and institutional factors. There are many factors contributing to poor public health and water quality on tribal lands, the amount of uranium mines in the study area is the main contributor but there are multiple points of exposure to As and U affecting the health of Native Americans including cultural and political factors. Only 10% of federally recognized tribes have water quality standards under the CWA and approved by the EPA, this combined with other historic policies enacted to extract natural resources from tribal lands limits the powers Tribes have to protect their land and has led to checkerboarding on tribal land.

The effects of political, economic and environmental factors on the level of contaminants in unregulated sources of drinking water is well established in literature. The results from the MCDA indicate Native Americans are more likely to face water insecurity, and are in close proximity to U mines as well as other pathways of exposure. At the same time, there are specific cultural factors presenting unique opportunities for exposure to contaminated water; Native Americans have been growing plants for food and medicine, as well as collecting water from unregulated sources as cultural practices. These cultural practices are often overlooked in previous literature but are nonetheless important to understanding potential points of exposure to As and U contamination (Lewis 2017).

The GIS-MCDA approach is helpful to identifying areas that are at high risk of potential As and U contamination based on the proximity to roads, surface water and mines. The zonal statistics table indicates that the HH LISA clusters are all located in areas that have a high or very high likelihood of membership in the fuzzy overlay. The county subdivisions with HH LISA clusters were county subdivisions with the Fort Apache, San Carlos, Navajo Nation and Hopi reservation indicating there is some spatial relationship between areas at risk of potential exposure to heavy metals and tribal land. Including population clusters in the MCDA provides an important contribution to GIS literature through the analysis of the spatial relationship between LISA clusters of and areas with a high likelihood of membership in the fuzzy overlay. The addition of LISA and spatial autocorrelation to the GIS-MCDA approach is novel and unique to this project

References

Angel, B. (1991). The Toxic Threat to Indian Lands. *Greenpeace Report, Indigenous Environmental Network*. https://www.ejnet.org/ej/toxicthreattoindianlands.pdf

Conroy-ben, O., & Crowder, E. (2020, June 1). Unregulated and Emerging Contaminants in Tribal Water. *Journal of Contemporary Water Research & Education*, *169*(1) https://onlinelibrary.wiley.com/doi/full/10.1111/j.1936- 704X.2020.03334.x

deLemos JL, Brugge D, Cajero M, Downs M, Durant JL, George CM, Henio-Adeky S, Nez T, Manning T, Rock T, Seschillie B, Shuey C, Lewis J (2009) Development of risk maps to minimize U exposures in the Navajo Churchrock mining district. Environ Health 8(1):29. https://doi.org/10.1186/1476-069X-8-29

Diver, S. (2018, May 15). Native Water Protection Flows Through Self-Determination: Understanding Tribal Water Quality Standards and "Treatment as a State". *Contemporary Water Research & Education*, *163*(1) https://onlinelibrary.wiley.com/doi/full/10.1111/j.1936- 704X.2018.03267.x

Duong TTT, Lee B-K (2011) Determining contamination level of heavy metals in road dust from busy traffic areas with different characteristics. J Environ Manag 92(3):554–562.

Harmon ME, Lewis J, Miller C, Hoover J, Ali A-MS, Shuey C, Cajero M, Lucas S, Zychowski K, Pacheco B, Erdei E, Ramone S, Nez T, Gonzales M, Campen MJ (2017) Residential proximity to abandoned U mines and serum inflammatory potential in chronically exposed Navajo communities. J Exposure Sci

Hoffman, A. (1999). Institutional Evolution and Change: Environmentalism and the U.S. Chemical Industry. *Academy of Management*, *42*(4), 351-371. JSTOR. Retrieved March 2021, from https://www.jstor.org/stable/257008?seq=6#metadata_info_tab_contents

Hoover J, Gonzales M, Shuey C, Barney Y, Lewis J (2017) Elevated As and U Concentrations in Unregulated Water Sources on the Navajo Nation, USA. Exposure Health 9(2):113 –124.

Hoover J, Coker E, Barney Y, Shuey C, Lewis J (2018) Spatial clustering of metal and metalloid mixtures in unregulated water sources on the Navajo Nation – Arizona, New Mexico, and Utah, USA. Sci Total Environ 633:1667–1678.

Harmon ME, Lewis J, Miller C, Hoover J, Ali A-MS, Shuey C, Cajero M, Hund, L., Bedrick, E.J., Miller, C., Huerta, G., Nez, T., Ramone, S., et al., 2015. A Bayesian framework for estimating disease risk due to exposure to U mine and millet on the Navajo Nation. J. R. Stat. Soc. A. Stat. Soc. 178, 1069 –1091 https://agupubs.onlinelibrary.wiley.com/doi/full/10.1002/2016WR01

Johnson T.D., and Belitz, K., 2019, Domestic well locations and populations served in the contiguous U.S.: datasets for decadal years 2000 and 2010: U.S. Geological Survey data release,

Jones DS (2006) The persistence of American Indian health disparities. Am J Pub Health 96:2122–2134

Lewis J, Hoover J, MacKenzie D (2017) Mining and Environmental Health Disparities in Native American Communities. Curr Environ Health Rep 4(2):130–141. https://doi.org/10.1007/s40572-017-0140-5

Lucas S, Zychowski K, Pacheco B, Erdei E, Ramone S, Nez T, Gonzales M, Campen MJ (2017) Residential proximity to abandoned U mines and serum inflammatory potential in chronically exposed Navajo communities. J Exposure Sci

Lutz, E. (2005, December). Indigenous Peoples and Water Rights. *Cultural Survival Quarterly Magazine*. https://www.culturalsurvival.org/publications/cultural- survival-quarterly/indigenous-peoples-and-water-rights

McGraw, G., & Fox, R. (2018). Closing the Water Access Gap in the United States: A national action plan http://closethewatergap.org/wp- content/uploads/2020/03/Dig-Deep_Closing-the-Water- Access-Gap-in-the-United DIGITAL compressed.pdf

Morales, L. (2019, November 18). Many Native Americans Can't Get Clean Water, Report Finds. *NPR*. Retrieved March, 2021 from: https://www.npr.org/2019/11/18/779821510/many-native- americans-cant-get-clean-water-report-finds

Multi-criteria Decision Analysis Approach to Site Suitability of U.S. Department of Defense Humanitarian Assistance Projects, Procedia Engineering, Volume 78,2014, Pages 59-63, ISSN 1877-7058, https://doi.org/10.1016/j.proeng.2014.07.039

Oram, B. (n.d.). *National Secondary Drinking Water Standards*. Water Research Center. Retrieved November2020, from https://waterresearch.net/index.php/standards/secondary- standards

Read, E., & et al. (2017, February). Water Quality Data for National Scale Aquatic Research: The Water Quality Environmental Health Literacy--A Focus on Water Quality and Tribal Lands. *Health Communication*, *24*(3). https://www.tandfonline.com/doi/full/10.1080/10810730.2019.159799993

U.S. Environmental Protection Agency (2007) Abandoned U mines and The Navajo Nation: Navajo Nation AUM screening assessment report and Atlas with regulations; Radionuclides; Final Rule. National Archines and Records Administration, Washington D.C.

Judicial Cases

492 U.S. 408 Brendale v. Confederated Tribes & Bands of Yakima Indian Nation. June 29, 1989.

770 A.2d 574, 592 (Me.2001) Great N. Paper, Inc. v. Penobscot Nation, . June 20, 2001

450 U.S. 544 Montana v. the U.S. March 24, 19

97 F.3d 415. *City of Albuquerque v. Browner* (10th Cir. 1996). October 7